

Society and Technological Change

Eighth
Edition

Rudi Volti

Society and Technological Change

Eighth Edition

Rudi Volti
Pitzer College

 | **worth publishers**
Macmillan Learning
New York

Vice President, Editorial, Social Sciences: Charles Linsmeier
Senior Associate Editor: Sarah Berger
Development Editor: Thomas Finn
Editorial Assistants: Kimberly Morgan-Smith, Un Kim
Executive Marketing Manager: Katherine Nurre
Marketing Assistant: Morgan Ratner
Director, Content Management Enhancement: Tracey Kuehn
Managing Editor, Sciences and Social Sciences: Lisa Kinne
Project Manager: Jouve
Senior Production Supervisor: Stacey B. Alexander
Photo Editor: Richard Fox
Director of Design, Content Management: Diana Blume
Senior Design Manager: Blake Logan
Art Manager: Matthew McAdams
Composition: Jouve
Printing and Binding: LSC Communications
Cover: Maximilien Brice, CERN/Science Source

Library of Congress Control Number: 2016955866

ISBN 978-1-319-12972-9

© 2017, 2014, 2009, 2001 by Worth Publishers

All rights reserved

Printed in the United States of America

First Printing

Worth Publishers
One New York Plaza
Suite 4500
New York, NY 10004-1562
www.macmillanlearning.com

CONTENTS

About the Author xi

Preface xiii

PART ONE Defining Technology 1

Chapter 1 The Nature of Technology 3

Defining Technology 4

Technological Advance and the Image of Progress 8

Technology as a Metaphor 11

Technology and Rationality 13

Technological Determinism 16

Living in a Technological Society 18

Questions for Discussion 19

Chapter 2 Winners and Losers: The Differential Effects of Technological Change 21

Technology as a Subversive Force 22

The Luddites 26

Neo-Luddism 27

Whose Technology? 28

What Technology Can Do—And What It Cannot Do 29

Questions for Discussion 36

PART TWO

The Process of Technological Change 39

Chapter 3

The Sources of Technological Change 41

Technological Change as a Social Process 41

The Great Breakthrough 42

The “D” in R&D 44

Putting It All Together 45

Clearing Bottlenecks through Technology Transfer 47

Supply and Demand: The “Push” and the “Pull” 48

Belated Demand: The Question of Market Timing 51

How Market Economies Drive Technological Innovation 52

Obstacles to Innovation in Centrally Planned Economies 53

Noneconomic Sources of Technological Advance 54

Questions for Discussion 58

Chapter 4

Scientific Knowledge and Technological Advance 61

The Historical Separation of Science and Technology 61

Studies of Contemporary Science–Technology Relationships 63

How Technology Differs from Science 64

How Technology Facilitates Scientific

Discovery	67
Legitimizing Science through Technology	70
The Translation of Science into Technology	72
The Commonalities of Science and Technology	74
Questions for Discussion	77

Chapter 5	The Diffusion of Technology	81
	Technology on the Move	81
	Clever Copyists	86
	Adaptation and Adoption	87
	Learning to Make Steel in Old Japan	88
	Appropriate Technology	89
	Organizations and Technological Diffusion	92
	A Risky Business	93
	The NIH Syndrome	94
	Efforts to Restrict the Diffusion of Technology	95
	Patents and the Diffusion of Technology	96
	Questions for Discussion	98

PART THREE How Technology Affects the Health of Earth and Its Inhabitants 103

Chapter 6	Technology, Energy, and the Environment	105
	Fossil Fuels, Air Pollution, and Climate Change	106
	A Planet under Stress	109
	Is Technology the Problem or the Solution?	110
	Some Technological Fixes of the Past	111
	Alternatives to Fossil Fuels	113

Doing More with Less	117
More Miles to the Gallon	118
Economic Systems, Government Policies, and the Environment	120
Questions for Discussion	122

Chapter 7

Medical Technologies 127

New Medical Technologies: Choices and Trade- offs	129
The Case of Kidney Dialysis	130
Replacing Broken Hearts	133
Diagnostic Technologies	137
Medical Technologies and Medical Ethics	140
New Ways of Making and Sustaining Babies	140
When Does Life End? When Should It?	142
Halfway Technologies	143
Questions for Discussion	143

Chapter 8

Genetic Technologies 147

The Genetic Fix	147
Discovering Genes and Patenting Them	148
Bioengineering on the Farm	150
Genetic Mapping and Screening	153
Cloning, Present and Future	155
Stem Cells and Future Therapies	157
The Perils of Genetic Intervention	158
Questions for Discussion	161

PART FOUR

Technology and the Transformation of Work 165

Chapter 9

Work in Nonindustrial Societies 167

Working with the Earliest Tools	167
Work and Leisure in Technologically Primitive Societies	169
Work and the Development of Agriculture	171
Farming Techniques and Patterns of Work	172
The Ironies of Progress	174
Urbanization, Specialization, and Economic Relationships	174
Guild Organization and Technological Change	177
Slavery and the Inhibition of Technological Development	179
The Measurement of Time and Changed Working Patterns	180
The Clock	181
Questions for Discussion	183

Chapter 10

Technology and Jobs: More of One and Less of the Other? 187

The Technological Threat in Historical Perspective	187
A Case for Optimism	189
How Technology Creates Jobs	191
The Indirect Effects of New Technologies on Employment	192
The Machines Aren't Ready to Take Over	193
Technology, Jobs, and the Changing Structure of the Economy	195
Technology and the Distribution of Income	198
Technology, Globalization, and Jobs	201
Rebounding from Job Losses	202
Benefits, but Disruption Too	204
Questions for Discussion	205

Chapter 11 Technological Change and Life on the Job 209

- Industrial Production 209
- Machine-Paced Labor 211
- Is Technology to Blame? 213
- Industrial Technology and the Division of Labor 215
- Scientific Management Once Again 217
- Industrial Work and Recent Technological Developments 219
- Technological Change and White-Collar Work 220
- Telework 222
- The “Gig Economy” 224
- Smart Technologies and Dumb Jobs? 225
- Questions for Discussion 227

PART FIVE Communication 231

Chapter 12 Printing 233

- The Printing Revolution 234
- Printing and the Expansion of Knowledge 236
- Printing and the Rise of Protestantism 237
- Printing, Literacy, and Social Change 238
- Psychological Effects of Printing 240
- Newspapers 241
- Digitizing the News 245
- Reading Digitally 247
- Questions for Discussion 249

Chapter 13 The Electronic Media: From the Telegraph to Television 253

- The Invention of Radio 253

The Origins of Commercial Radio	255
The Rise of Television	257
The Federal Government Steps In	259
The Television-Viewing Public	261
Violence on Television and Its Consequences	262
Delivering the News	265
Television and Politics	267
Television and Thought	268
Questions for Discussion	270

Chapter 14

The Internet Age 275

The Birth and Growth of the Internet	275
Social Media and the Network Effect	277
Mobile Communications	279
Social Media and Social Movements	281
The Digital Divide	284
Video Games	285
Intellectual Property	287
Privacy in the Digital Age	290
The Electronic Media in Modern Society	291
Questions for Discussion	292

PART SIX

The Tools of Destruction 297

Chapter 15

Weapons and Their Consequences 299

Military Technology in the Ancient World	299
Military Technology and the Feudal Order	301
New Weapons and the Decline of Feudalism	302
The Gunpowder Revolution	305

War and the Centralized State 308
Technological Change and Naval Culture in the
Era of the Battleship 309
Weapons and the Making of the Modern
World 310
Questions for Discussion 315

Chapter 16 The Era of Smart Weapons 319

Cruise Missiles 319
Smart Bombs 321
High-Tech Surveillance 322
Drones 323
The Cost of Technological Sophistication 325
Asymmetrical Warfare 326
Cyberterrorism and Cyberattacks 330
Military Technologies in a Changing World 332
Questions for Discussion 334

**Chapter 17 How New Weapons Emerge—And
How They May Be Contained 337**

Action and Reaction 337
Social Structure and the Development of Military
Technologies 338
Expanding the Scale and Scope of War 345
Industrial Technology in the Service of War 347
Controlling Military Technologies 350
The Perils of Proliferation 357
Questions for Discussion 358

**PART SEVEN The Shaping and Control of
Technology 361**

Chapter 18 Technology and Its Creators: Who's in

Charge of Whom? 363

Technological Advance and Cultural Lag 363

Technology, Globalization, and Cultural
Convergence 365

Experts, Expertise, and the Shaping of
Technology 369

Engineers and the Control of Technology 373

Questions for Discussion 378

Chapter 19

Organizations and Technological Change 381

Technology as a Cause of Organizational
Structure 381

Technology as a Consequence of Organizational
Structure 386

Organizational Size and Technological
Innovation 390

Organizations and New Information
Technologies 392

Interorganizational Relations and Technological
Development 395

Entrepreneurs and Organizations 396

Questions for Discussion 398

Chapter 20

Governing Technology 401

Government Actions and the Shaping of
Technology 401

Paying for Science and Technology 404

But Is It Really Necessary? 405

Government Institutions for the Guidance of
Technology 407

How Government Policies Shape Technological
Change 409

The Democratic Control of Technology	413
The Challenges of the Future	417
Questions for Discussion	418

Notes

Index	421
--------------	------------

ABOUT THE AUTHOR

Rudi Volti is Emeritus Professor of Sociology at Pitzer College, where he was a founding member of the program in Science, Technology, and Society of the Claremont Colleges. His books and articles have covered a variety of topics on the interaction of technology and society, including technology transfer to East Asia, the history of the engineering profession, the origin of frozen foods, commercial air travel, and the history of automobile engines. His personal encounters with modern technology center on cars, motorcycles, and model railroading.

PREFACE

When the first edition of *Society and Technological Change* came out in 1988, Microsoft's initial public offering had occurred only two years earlier, tweets were something birds did, and Mark Zuckerberg had not yet entered kindergarten. Since that time, ongoing technological changes and new ways of interpreting the interaction of technology and society have provided new opportunities to revise and expand succeeding editions. Even so, the animating spirit of the book remains the same. This eighth edition of *Society and Technological Change* continues to explore the many ways in which various technologies have influenced our lives. At the same time, it shows how these technologies have themselves been shaped by social, economic, cultural, and political forces, and that the study of technology is important not just for its own sake, but also for what it tells us about the kinds of societies we make for ourselves.

This book is oriented to the growing number of courses on technology and society. It will also be useful in other courses that explore technology's role in human affairs. It presents perspectives, theories, and facts that should help the reader to understand the consequences of technological changes, as well as the forces that have produced these changes. Many specific examples of the interaction between technological change and other changes will be introduced, for general processes are often best understood through references to particular instances.

The rapid pace of technological change during the opening years of the twenty-first century may have led to an overuse of the word "revolutionary," but it also provides the basis for significant new discussions of the reciprocal interactions of technology and society. In particular, this book now devotes a

considerable amount of space to issues that scarcely existed when the book was first published: the internet, social media, genetic engineering, and challenges to intellectual property and personal privacy. In similar fashion, the book covers instruments of warfare that have emerged in recent years such as cruise missiles, smart bombs, drones, and cyberattacks.

One of modern technology's strongest influences has been on the development of the cluster of political, cultural, social, and economic changes that are subsumed in the term "globalization." New material in this edition covers offshoring and technology transfer, appropriate technologies in poor countries, new media and social movements in authoritarian societies, and the extent to which the world's cultures are converging toward a common pattern.

Economic globalization has been blamed for growing inequalities in the distribution of wealth and income. No less culpable has been technological change. This book looks into the connection between technological advance and rising social and economic inequality. Considered here are technological unemployment, the changing rewards for particular skills, and the ongoing evolution of twenty-first-century economies.

Some of the most important issues involving technology and society center on health, both the health of humans and the health of Earth. In regard to the latter, the broad issue of sustainability is addressed by expanded coverage of climate change and the use of sources of energy other than fossil fuels. As far as human health is concerned, advances in genetics research are giving rise to new healing technologies. At the same time, however, technologies that alter an organism's genetic makeup also pose many practical and ethical problems discussed in a chapter devoted to these matters.

The preparation of this edition has also provided an opportunity to update and extend many pertinent facts and statistics. These include new data on climate change, the costs of medical care, unemployment, the distribution of income, sales of recorded music, fracking, alternative energy sources, the use of various media (including email, mobile phones, and social media), future employment prospects, and government support of research and development.

Although this edition has quite a lot of new material, no pretense is made that it presents an all-encompassing view of technology and society. Much has been left out because of space limitations, and my own limitations of

time, energy, and expertise. At the same time, the systematic study of the interactions between technology and society is a relatively recent endeavor, and many gaps remain to be filled. It can only be hoped that this book will provide a foundation for thought and future study. If annoyance at the inadequacy of coverage leads the reader to undertake more extensive explorations of some of the topics presented, then this book will have served its purpose.

Acknowledgments

Writing can be a lonely activity. While I was putting this book together, some of my loneliness was alleviated by being able to call on a number of colleagues for assistance. I would like to thank the following people for reading portions of the manuscript and making invaluable suggestions: Hugh G. J. Aitken, Newton Copp, David Cressy, Stephen Cutcliffe, Paul Faulstich, Barbara Gutek, Margaret Hamilton, Lamont Hempel, Christine Ilgen, Sue Mansfield, Meg Mathies, Richard Olsen, Robert Post, Leonard Reich, Kathryn Rogers, Mark Rose, John Truxal, James C. Williams, and Andrew W. Zanella.

I would also like to thank those who have reviewed this and previous editions: Janet Abbate, University of Maryland; Patience Akpan, Arizona State University; Elazar Barnette, North Carolina A&T University; Wenda K. Bauchspies, Pennsylvania State University; Donald Beaver, Williams College; Paul Cesarini, Bowling Green State University; Dave Conz, Arizona State University; Jennifer Croissant, University of Arizona; Adam Driscoll, North Carolina State University; Kerry Dugan, Northeastern University; R. Valentine Dusek, University of New Hampshire; David Eastwood, University of North Dakota; Anna Erwin, Appalachian University; Nora Foust, Alamance Community College; Martin Friedman, SUNY Binghamton; Ted Gaiser, Boston College; Gary Gappert, The University of Akron; James Gerhardt, Southern Methodist University; Kenneth Gould, Northwestern University; James P. Hamilton, Pennsylvania State University; Kurt Helgeson, St. Cloud State University; Robert Hoffman, North Carolina State University; Charles Jaret, Georgia State University; Richard Kahoe, University of Central Missouri; Felix Kaufmann, Eastern Michigan University; Robert Keel, University of Missouri–St. Louis; Mark Kelso, Embry-Riddle Aeronautical University; David Klein, Metro State University of Denver; Diane N. Long, California Polytechnic University; Carol MacLennan, Michigan Technological University; Toy McEvoy, Wayne State College; Marilyn Mertens, Midwestern State University; Todd Morgan, DePaul University; Karen Oslund, University of Maryland, College Park; Robert S. Paradowski, Rochester Institute of Technology; Karin E. Peterson,

University of North Carolina–Asheville; Dretha M. Phillips, Roanoke College; John Renzelman, Wayne State College; Terry Richardson, Northern State College; Laurel Smith-Doerr, Boston University; Donald Sorsa, DePaul University; James Steele, James Madison University; David Swift, University of Hawaii; L. E. Trachtman, Purdue University; Yung-Mei Tsai, Texas Tech University; Della M. Vanhuss, Tri-County Technical College; Steve Vergara, Wayne State College; Rollin Williams III, East Tennessee State University; and Thomas Zeller, University of Maryland, College Park. Their knowledge and expertise exceed my ability to make complete use of the help they have given me, and they are not responsible for any errors of fact or interpretation that may be found in these pages.

I would also like to thank the editorial and production staffs of Worth Publishers. Sarah Berger has been a terrific source of guidance and encouragement. I also appreciate the very able assistance of Andrea Stefanowicz, Blake Logan, Richard Fox, Thomas Finn, Kimberly Morgan-Smith, Lisa Kinne, and Stacey Alexander. Finally, special thanks go to my wife, Ann Stromberg, and our daughter, Kate, for their unfailing support.

Rudi Volti

PART ONE

Defining Technology

The ability to create and use a great variety of technologies is one of the distinguishing characteristics of humans, but what exactly is meant by “technology”? The term is a familiar one, but like many words in current circulation it carries with it a multitude of meanings. For a start, it encompasses much more than the array of digital devices that have been integral parts of our lives for only a few decades. It also goes well beyond the ‘wave of gadgets’ famously recounted by a student to historian T.S. Ashton as a major impetus for the Industrial Revolution. So then what is it? Chapter 1 offers a definition of technology that is meant to be precise yet elastic enough to cover the many connotations of the word. Although technology is often associated with particular items of hardware, the ultimate basis of technology is knowledge, and this chapter delineates the ways of thinking that are associated with technological advance. This chapter also includes an effort to disentangle technological advance from an even more slippery concept: “progress.”

In Chapter 2, the discussion is continued by noting that many technological changes do not necessarily make things better for everyone, as is implied in the word “progress.” To the contrary, they may affect individuals and groups in different ways, leaving some better off while others are left in a worse position. This aspect of technological change is often ignored, making it hard to resist the temptation to seek “technological fixes” for problems that require more than the introduction of new devices and

processes. This chapter describes the kinds of situations where technological fixes are likely to be successful and others where they are doomed to failure.

CHAPTER ONE

| The Nature of Technology

Today's technology leaves us both exhilarated and terrified. Recent technological developments have presented us with such marvels as spacecraft leaving the solar system, instant access to billions of internet Web pages, and diseases cured through gene therapy. At the same time, however, the seemingly inexorable march of technology has produced global pollution, overpopulation, and the threat of nuclear annihilation. On many occasions, technological change has also produced social disruptions, as when automation destroys jobs in a particular industry or a new weapon upsets the balance of power between nations. And when technologies fail, some of them do so in a big way, as exemplified by the loss of the *Challenger* and *Columbia* space shuttles, the massive oil spill in the Gulf of Mexico, the catastrophic failure of the Fukushima nuclear plant in Japan, and the disastrous breaching of the levees in New Orleans in the wake of Hurricane Katrina.

Despite all the crises, disruptions, and disasters that have accompanied it, modern technology is still viewed in a favorable light, according to public opinion surveys. Although significant minorities of respondents express their disapproval of certain technologies like nuclear power and genetically modified foods, the positive achievements of technology as a whole are seen to substantially outweigh the negative ones.¹ But this support of technology is based more on faith than on understanding. When confronting technology, most of us are poorly informed spectators, seemingly incapable of understanding an esoteric realm of lasers, microprocessors, gene splicing, and

nanomaterials.

This inability to understand technology and perceive its effects on our society and on ourselves is one of the greatest, if most subtle, problems of an age that has been so heavily influenced by technological change. But ignorance need not be a permanent condition. Although no one can hope to comprehend the inner workings of even a small number of the most significant technologies, it is still possible to come to a better understanding of the major causes and consequences of technological change. All technologies, be they high-definition televisions or reinforced concrete bridges, have some basic features in common. It will be the task of this chapter to show what they are.

Defining Technology

Gaining an understanding of the meaning of words is often the beginning of knowledge. Before plunging into a discussion of the nature of technology, it is necessary to provide a more precise definition of what is meant when we use the term. The linguistic roots of the word “technology” can be traced to the Indo-European stem *tekhn-*, which seems to have referred to woodworking. It is the source of the Greek word *tekne*, which can be variously translated as “art,” “craft,” or “skill.” It is also the root of the Latin word *texere*, “to weave,” which eventually took on the larger meaning of fabrication or construction. By the early eighteenth century, the word had come close to its present meaning when an English dictionary defined it as “a Description of Arts, especially the Mechanical.” In 1831, Jacob Bigelow published *Elements of Technology*, the first book in English with the word “technology” in its title. As he defined it, technology consisted of “the principles, processes, and nomenclatures of the more conspicuous arts, particularly those which involve applications of science.”²

Tools and Techniques

Technologies are developed and applied so that we can do things not otherwise possible, or so that we can do them cheaper, faster, and more easily. The capacity of human beings to employ technologies sets us apart from other creatures. To be sure, beavers build dams, otters crack open shellfish with rocks, and chimpanzees use sticks to extract termites from their nests. But no other animal comes close to humans in the ability to create tools and techniques—the first two elements in our definition of technology—and no other creature is so dependent on them. The development of technology is in large measure responsible for the survival and expansion of a species that lacks many of the innate abilities of other animals. Left with only our innate physical capabilities, we humans cannot match the speed of a cheetah, the strength of an elephant, or the leaping ability of a kangaroo. We do not possess the eyesight of an eagle or the defensive armament of a porcupine, and we are among the 25 percent of all species that are incapable of flying. All in all, humankind is a physically puny bunch. But compensating for this physical weakness is an intelligence that is the ultimate source of technology. Humans stand apart from all other animals in their ability to gain and transmit knowledge, and to use this knowledge to develop tools and techniques. Without this capacity to invent and use a great variety of technologies, the human species would have never been able to establish itself on virtually every part of the globe.

Reliance on technology is as old as humanity itself. Whatever evils have accompanied the use of particular technologies, it is pointless to indict technology as being somehow “unnatural.” Our past as well as our future as a species is inextricably linked to our capacity to shape our existence through the invention and application of implements and techniques that allow us to transcend our meager physical endowments. It is certainly true, as Jacob Bronowski observed, that “to quarrel with technology is to quarrel with the nature of man—just as if we were to quarrel with his upright gait, his symbolic imagination, his faculty for speech, or his unusual sexual posture and appetite.”³

Organizing Humanity

Tools and techniques have been of unquestioned importance in allowing the physical survival of the human species. Still, they are not the whole story. It is necessary to add some elements to our definition of technology that go beyond the usual identification of technology with pieces of hardware and ways of manipulating them. The first of these is *organization*. This follows from the fact that the development, production, and employment of particular technologies require a group effort. Even a relatively simple technology, such as one centering on the use of earthenware pots, requires a complex network of material suppliers, potters, toolmakers, marketing agents, and consumers capable of making good use of the pots. Of course, one person can learn all these skills adequately if not expertly, but the day is not long enough for him or her to do them all on a scale that produces a reasonable degree of efficiency. In the case of a complex technology like a computerized manufacturing system, there is no possibility of a single individual developing even a tiny fraction of the requisite skills.

For a technology to be developed and used, the energies and skills of many individuals have to be combined and coordinated through some organizational structure. Organization may be likened to the software that controls and guides a computer; without an operating system and application programs, a computer is a useless arrangement of capacitors, transistors, resistors, and other bits of hardware. In similar fashion, an organizational structure allows the integration of diffuse human and material inputs for the attainment of particular tasks. From this standpoint, there is considerable merit in Lewis Mumford's assertion that the first "machine" was not a physical object, but the organizational structures that the Egyptian pharaohs employed to build the pyramids.⁴



Construction of the Pyramids, 1862 (coloured engraving)/Leutemann, Heinrich (1842–1905)/INDEX Fototeca/Index, Barcelona, Spain/Bridgeman Images

According to one perspective, the workers who labored to build the pyramids were components of a kind of machine.

When technology is seen as a combination of devices, skills, and organizational structures, it becomes natural to think of it as a *system*, the next element in our definition. For an individual technology to operate effectively, more is required than the invention of a particular piece of hardware; it has to be supported by other elements that are systematically interconnected. When Thomas Edison began to work on electrical illumination, he realized that this technology would require the development of such a system. The invention of a practical, long-lasting lightbulb rested on the development of a serviceable filament and the use of an improved vacuum pump that evacuated the interior of the bulb, thereby preventing the combustion of the filament. But by itself, a lightbulb was useless. An effective electrical generator was needed to supply the current that produced the incandescence of the filament. A network of electrical lines had to be strung up between the generator and individual homes, shops, and factories. And metering devices were necessary so that users could be accurately billed for the electricity they used. Edison and his associates worked out all of these problems, and in so doing brought large-scale electrical illumination to the world.⁵

The development of all the elements of a technological system can be an uneven process, for technological advance often entails the resolution of tensions that are generated when one part of the technological system

changes. This process is exemplified by the development of the modern airplane. Early biplanes with their drag-inducing wires and struts could not make effective use of more powerful engines. The availability of these engines became a strong inducement to the design of aerodynamically cleaner aircraft. The faster aircraft that resulted from the marriage of streamlined airframes and powerful engines produced a new problem: dangerously high landing speeds. This, in turn, stimulated the invention of wing flaps and slots. By the 1940s, it had become apparent that improved airframes could achieve still higher speeds if provided with more powerful engines; this possibility gave a strong stimulus to the development of the turbojet.⁶

For an example of the interplay of devices, skills, and organizational patterns, we can take note of Lewis Mumford's analysis of the technology of handwriting.⁷ Two hundred years ago, the standard writing instrument was a goose-quill pen. Based on an organic product and sharpened by the user, it represented the handicraft technologies typical of its time. Cheap and crude, it called for a fair degree of skill if it was to be used effectively. In contrast, the steel-nib pen of the nineteenth century was a typical artifact of the industrial age, the product of a complex manufacturing process. Less adaptable than the quill, it was mass-produced in many different forms in order to meet specialized needs. Although Mumford's ideas were formulated before the invention of the ballpoint pen in the 1940s, his analysis fits this implement perfectly. Made from a variety of artificial materials and manufactured to close tolerances, the ballpoint pen could only be produced through sophisticated industrial processes. It is completely divorced from the organic world and requires very little skill from its user. Indeed, the technological artistry embodied in the pen itself stands in sharp contrast to the poor quality of the writing that so often comes from the hand that wields it.

A technological system does not emerge all at once with every one of its components neatly fitting together. In addition to changes in tools, techniques, and organizational structures, many social, psychological, economic, and political adjustments may be required for the support of a technological system. Technological change is not always a smooth process, and many of the necessary changes may entail considerable pain and disruption. Seeing technology as a system should help us to understand that

technological change is closely connected with a variety of associated changes, and that the creation of a technological system may be fraught with tension and discomfort.

Much of what has just been said can be incorporated into a schematic definition of technology: **a system created by humans that uses knowledge and organization to produce objects and techniques for the attainment of specific goals.**

Useful as it may be, this definition of technology is incomplete and possibly misleading in one important respect. The last part of the definition implies that technological change comes about as a response to existing needs: its purpose is “the attainment of specific goals.” In the first place, one could legitimately ask *whose* goals are to be attained. This is an important issue, but it is best left for the next chapter. For now, we should note that although it is a human creation, technology does not always respond to existing needs; a new technology may in fact create its own needs. The development of technology on occasion exemplifies a phenomenon that has been dubbed “the law of the hammer”: give a six-year-old a hammer, and to the child everything starts looking like a nail.

The history of technology is replete with examples of inventions looking for problems to solve. One example that illustrates this point is found in almost every medicine chest: a bottle of aspirin. One of the most common uses of aspirin is to suppress fevers that accompany various illnesses. But medical research (as well as some ancient practices) has demonstrated that running a fever is a therapeutic process that aids in a patient’s recovery; it is the body’s way of naturally combating infection. Yet since the introduction of aspirin in the early 1900s fever has been seen as a problem requiring intervention. As one medical researcher has noted, “It’s no surprise that society’s deep worries about fever closely followed the synthesis of aspirin, the first drug that could safely reduce it.”⁸ In short, a new technology created its own need.

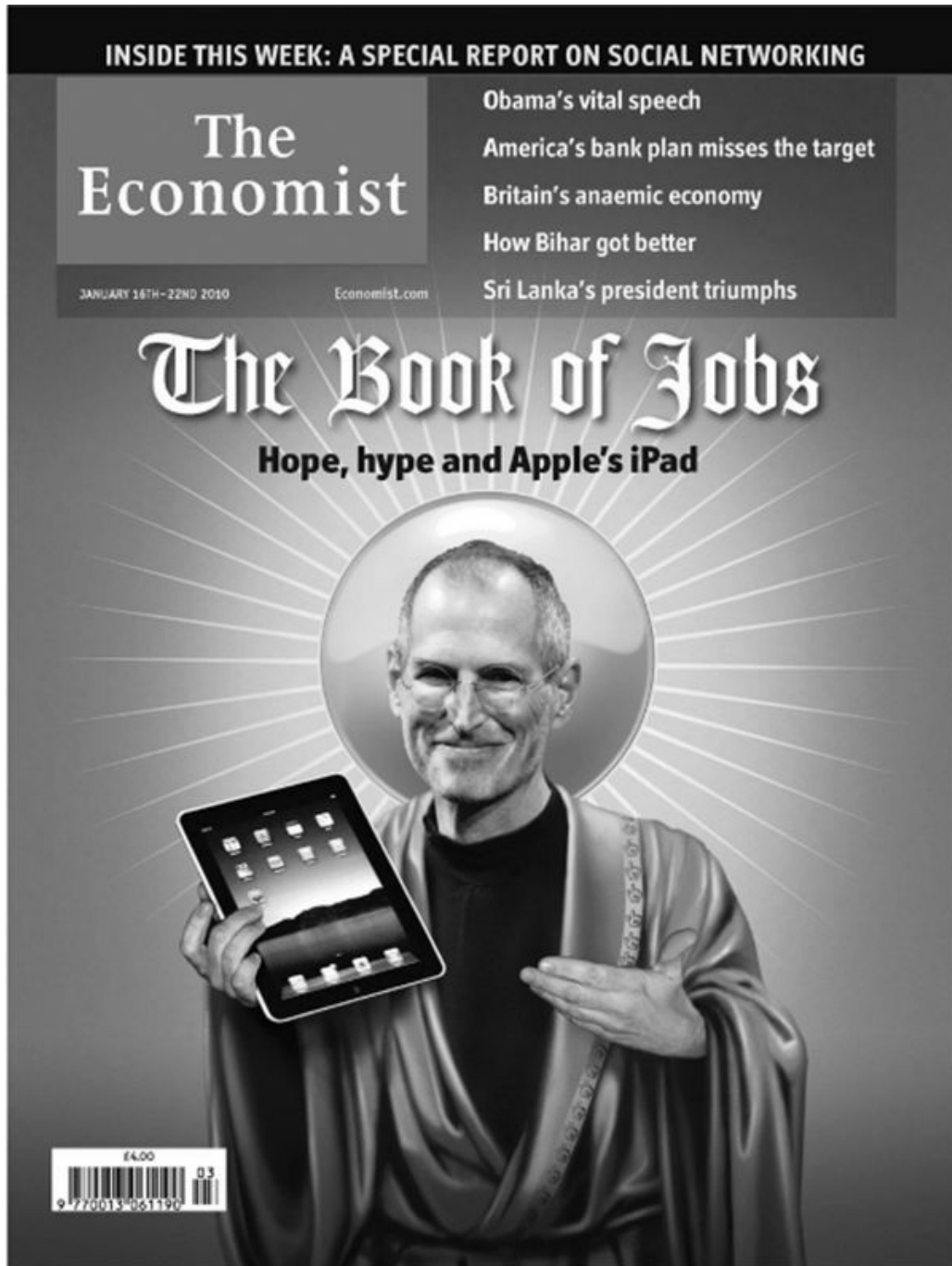
It is also important to note that the goals achieved through the use of a technology do not have to be “practical” ones. Some technologies have been developed so that we can grow more food or construct more comfortable buildings, but others have been developed simply for the challenge and enjoyment of solving technological problems, a proclivity that Robert Post

has described as “technological enthusiasm.”⁹ The prodigious efforts that went into the Daedalus project, a successful attempt to build a human-powered aircraft capable of flying 40 miles across the open sea, were certainly not motivated by an effort to produce a new form of transportation. A major reason for creating the aircraft was that its construction posed an intriguing technological challenge to those who designed, built, and flew it.

Flight seems to be a particularly attractive object for this kind of spirit. Immensely expensive technological endeavors such as the supersonic Concorde airliner and manned space exploration programs are hard to justify on practical grounds, although their supporters have made valiant efforts to do so. Their primary purpose seems to be the elevation of national prestige by demonstrating a nation’s collective ability to solve daunting technological problems. At the same time, many other technologies have a dual nature; they serve a practical purpose, but they are not valued only for this reason. An outstanding example is the automobile. It would be hard to justify the enormous resources employed for the building and operation of cars if transportation were the only goal. For many people (the author included), cars are objects of inherent fascination. Technological features like variable valve timing and active suspension systems have little to do with utilitarian transportation. The appeal is at least as much in the sophisticated technologies themselves as in the purposes that they serve.

Technological Advance and the Image of Progress

The development of technology is an inherently dynamic and cumulative process. It is dynamic because a technology is never perfect; there is always room for improvement. As Henry Ford said of his firm, “If we have a tradition it is this: Everything can always be done faster and better.”¹⁰ It is cumulative, for one advance paves the way for another. The lessons learned in working with an existing technology very often provide materials, tools, and, most importantly, a knowledge base for the next stage of development.



© The Economist Newspaper Limited, London (1/30/10). Illustration by Jon Berkeley/
Debut Art.

Sometimes we are inclined to look to technology for our salvation, as personified in this tongue-in-cheek rendition of a sanctified Steve Jobs.

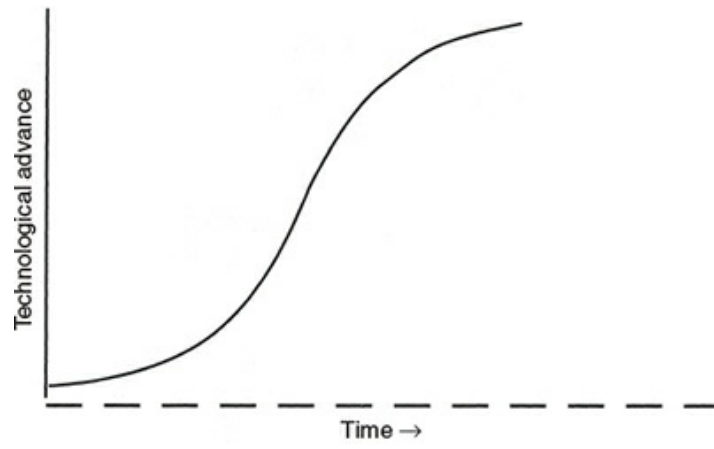
The dynamic and cumulative nature of technological change sets it apart from many other human endeavors. Ignoring for the moment the social consequences of technology, the process of technological change is usually

one of continuous improvement in the internal workings of a particular technology: as they evolve, engines develop more power and are more efficient, integrated electronic circuits pack more components on a single chip, aircraft fly higher and faster.

The process of technological advance can be graphically portrayed according to the following diagram, in which the horizontal axis represents time and the vertical axis represents just about any aspect of technological advance: the speed of commercial airliners, the production of synthetic materials, or the number of articles in engineering journals. Although there are inevitable fits and starts over time, the general trend can be depicted as a sigmoid, or S-shaped curve (see figure below).

Note that at first the curve rises rather slowly, inclines steeply in the middle, and then begins to slow down. That is, after an initial period of slow growth, the rate of advance accelerates, reaches a maximum, and then begins to proceed at a slower pace but never completely levels off. Although the rate of increase is smaller as the curve moves toward the right, this rate is applied to an increasingly larger base, so the actual addition is still substantial.

Not all human endeavors can be fitted to this sort of curve. While technology tends to be dynamic and cumulative, the same cannot always be said of other manifestations of human creativity. Although there is ample room for debate, a good case can be made that succeeding generations of writers, composers, and painters have not produced works superior to the ones created by Shakespeare, Beethoven, and Vermeer. And while we continue to take great pleasure in the artistic creations of eras long past, few of us would be satisfied with the technologies that were prevalent in those times. We also see few indications that people are more humane than they were centuries ago. The present era certainly provides a multitude of horrifying examples of human cruelty, many of them augmented by enlisting technology in the service of slaughter and destruction.



Volti, *Society and Technological Change*, 8e, © 2017
Worth Publishers



Hulton Archive/Getty Images

Built with slave labor, the V-2 rocket exemplified the technological progress of Nazi Germany.

Still, when judged solely according to internal criteria, technology is one

of the best examples of humankind's largely unrealized dream of continual progress. Technological progress, however, is not the same thing as progress in general. The fact that a society is able to develop and make use of advanced technologies does not guarantee that it will be equally advanced in other areas.¹¹ Nazi Germany produced many technological triumphs, such as the all-conquering Mercedes and Auto Union grand prix racing cars of the late 1930s and the V-2 rocket used during World War II, but in its ideology and treatment of people it can only be described as barbaric. Conversely, many technologically primitive peoples have exhibited a high level of sophistication in their artistic creations, religious beliefs, and social relationships. The term "progress" can be used with some precision when applied to the development of technology per se, although even here problems can crop up because different standards of evaluation may lead to conflicting conclusions. Is it really "progress" when a new medical technology maintains an individual's life, but does so only at enormous expense while preserving nothing but the maintenance of organic functions? Does maintaining a "life" of this sort justify expenditures that otherwise might be used for expanded prenatal care or other preventative measures? Given all of the value judgments, ambiguities, and complexities surrounding the word "progress," its use is avoided here unless its meaning is clearly defined.

Technology as a Metaphor

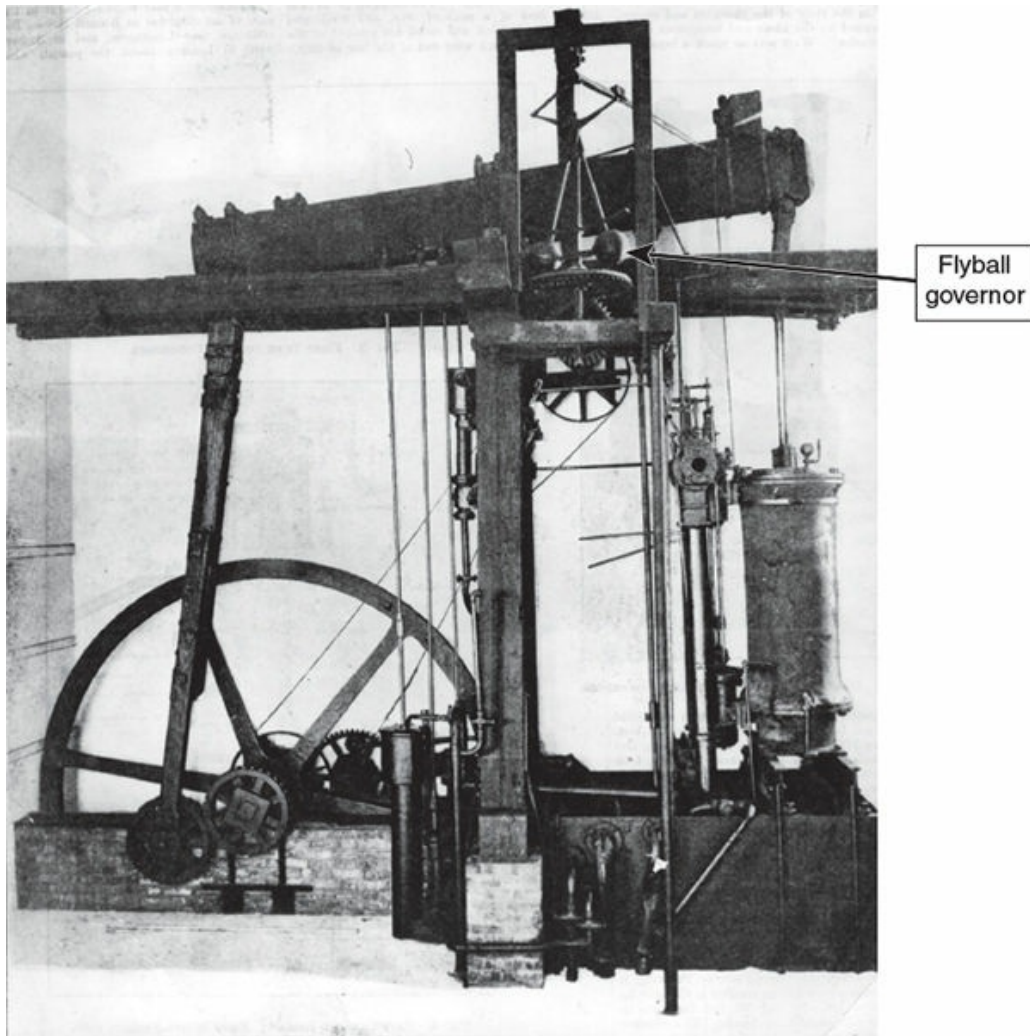
Despite these qualifications, it is evident that beginning in the late eighteenth century and continuing today, technology's stunning advances have fueled a belief in generalized human progress. In this way, technology has operated as a metaphor—the transference of an idea from one area to another.

Technology has provided many other metaphors that have affected our way of looking at ourselves and the world, as when human thought is made analogous to the operation of a digital computer.

A further example of the power of a technology to shape our way of thinking comes from the late eighteenth century. At that time, the designers of windmills and steam engines discovered the important principle of *feedback*, which the great twentieth-century mathematician Norbert Wiener defined as “a method of controlling a system by reinserting in it the results of its past performance.”¹² When a steam engine begins to rotate too rapidly, a feedback device such as a flyball governor closes the valve that admits the steam, thereby bringing the engine back into its proper operating range. When it slows down, the reverse happens, and the governor opens the valve to admit more steam.

During the late eighteenth century, the feedback principle offered a suggestive metaphor for the workings of the economic system: instead of being guided by a centralized authority, an economy might best be organized through the operation of a self-regulating market, with the actions of independent buyers and sellers providing the feedback. Thus, when buyers wanted a particular commodity, its price would be high, motivating sellers to produce more of it. If the price were low, less would be produced. In similar fashion, an increase in production would cause the price of a commodity to fall, so more of it would be purchased, while a drop in production would cause the price to rise, leading to a reduction of purchases. In this way, the actions of buyers and sellers in the market provide a feedback mechanism through which supply and demand are supposedly brought into equilibrium. It is probably no coincidence that the Scottish economist Adam Smith developed this basic concept at the same time that the steam engine was

being put into service.¹³ Today, the widespread use of the feedback principle makes its apparent applicability to the economic system even more appealing, even though the real-world economy is hardly a neat closed system like a steam engine. Laws and regulations, as well as a host of other extraneous elements, may strongly affect individual feedback loops, thereby preventing a complex economy from operating solely on the basis of supply-and-demand signals. Technological development has supplied a useful metaphor in the feedback principle, but like all metaphors it cannot be taken as a literal depiction of reality.



Hulton Archive/Getty Images

A steam engine with a flyball governor. Changes in the rotational speed

of the vertical shaft at the top of the engine causes the two balls to move up or down, thereby controlling the linkage that opens and closes the throttle.

Technology and Rationality

The development of technology has stimulated a belief that progress is a natural part of human life. At the same time, the progressive development of technology has itself been the product of a distinctive set of cultural values and mental processes that are characterized by a rational approach to the world and how it is to be controlled. Technological development is more than the random accumulation of tools, techniques, and organizational forms. Underlying the process is a set of attitudes and orientations that are collectively described as “rational.”

What makes a technologically progressive society different from others is that its methods of problem solving are oriented toward an objective scrutiny of the problem at hand, coupled with a systematic, empirically based examination of possible solutions and a logical selection of the most appropriate ones. Beyond this approach to the solution of problems lies another cultural attribute: the belief that solutions are *possible* and that constant changes are necessary in order to realize them. A society imbued with a rational ethos is dynamic and essentially optimistic, and it exhibits the confidence necessary to alter existing ways of doing things in order to gain particular benefits.

These abstract concepts may be illustrated through a simple example. All societies are faced with the problem of coping with the capriciousness of the weather. A great deal of human suffering has been the result of the vagaries of rainfall, and history provides many examples of the tragic consequences of drought. A number of responses are possible when people are confronted with this problem. The simplest is to succumb to despair, and perhaps try to find meaning in it by attributing the drought to fate or God’s will. A more active approach might be to offer prayers, perform a special ceremony, or sacrifice a member of the community. These latter activities are not likely to meet with success. There is no logical or empirically verifiable connection between them and the circumstances that produced the drought, a fact that could be demonstrated by a systematic inquiry into the long-term connection between prayers, ceremonies, or human sacrifices and the incidence of

rainfall.

Attitudes and behaviors of this sort stand in sharp contrast with rational ones. Through the use of logic and empirical observation it is possible to develop ways of dealing with problems like drought that are both more effective and more closely connected to the way the world actually works. A systematic and empirical observation of weather patterns might allow the prediction of a drought so that necessary steps can be taken to alter farming practices and conserve water. Other solutions could be the development of drought-resistant crops, improved methods of conserving water, and the distillation of seawater. It might also be possible to artificially stimulate rainfall through cloud seeding. In short, a rational approach to problem solving is continuously concerned with identifying and developing appropriate means for achieving particular ends.

The Limits of Rationality

These remarks are not meant to convey the ethnocentric belief that modern Western culture is superior to all others. The intention here is not to ridicule the beliefs and practices of people and societies that use nonrational approaches to problem solving. There is no reason to believe that rationality has been and always will be the special attribute of a particular group of people. Moreover, modern societies often manifest behaviors and patterns of thought that are anything but rational, as when large numbers of people continue to find value in astrology, numerology, and the predictions of supposed psychics.



PA Images/Alamy

Science cannot prevent natural disasters, such as tornados, but it can and has helped develop better ways of predicting when they will occur to reduce injuries and fatalities.

It is also important to recognize that rational ways of thinking do not confer moral superiority. To the contrary, the rigorous development and use of rational procedures can be accompanied by major moral and ethical

transgressions. The rational method of problem solving, with its overarching concern for devising appropriate means for attaining particular ends, makes no distinction concerning the ends being pursued. There is nothing in the rational approach to the world that prevents the use of logically and empirically derived means in the service of goals that are neither rational nor ethically justifiable. We can take note of the words of Captain Ahab, the main figure in Herman Melville's novel *Moby Dick*: "All my means are sane, my motive and subject mad." Nazi Germany provides many ghastly historical examples of human destruction ensuing from rational thinking and its resultant technologies. As Albert Speer, Hitler's Minister of Armaments, ruefully noted, "The criminal events of these years were not only an outgrowth of Hitler's personality. The extent of the crimes was also due to the fact that Hitler was the first to be able to employ the implements of technology to multiply crime."¹⁴

Even when rationality is not used for manifestly immoral purposes, it can still leave a dubious spiritual legacy. The very strength of rationality and the scientific and technological accomplishments that flow from it lie in their matter-of-fact approach to the world. A rational approach to things is often accompanied by a reluctance to admit there are any forces incapable of withstanding logical and empirical scrutiny. As the great German sociologist Max Weber put it, the world defined by rational thought processes had become "disenchanted," for it was bereft of the gods, genies, and spiritual forces that people not imbued with the spirit of rationality used to explain their world.¹⁵ But "disenchantment" is a two-edged sword, as the everyday meaning of the word makes clear. To be disenchanted is to lose the sense of awe, commitment, and loyalty that is a necessary part of a meaningful existence. Weber's melancholy analysis of a world that has lost its enchantment is summarized by the French sociologist Julian Freund:¹⁶

With the progress of science and technology, man has stopped believing in magic powers, in spirits and demons; he has lost his sense of prophecy and, above all, his sense of the sacred. Reality has become dreary, flat and utilitarian, leaving a great void in the souls of men which they seek to fill by furious activity and through various devices and substitutes.

Similar misgivings were voiced by the eighteenth-century political philosopher Edmund Burke. Burke's primary concern was the destruction of

traditional authority by modern mass movements, as exemplified by the French Revolution. Burke attributed much of the demonic energy of that movement to the spread of rational modes of thought that left no room for the traditional attitudes, values, and political structures that had long sustained European civilization. Burke's comment on the downfall of the queen of France, Marie Antoinette, thus contains a sharp indictment of the bearers of rational values who, in his estimation, were leading Europe to its doom:¹⁷

Little did I dream that I should have lived to see such disasters fallen upon her in a nation of gallant men, in a nation of men of honor and of cavaliers. I thought ten thousand swords must have leaped from their scabbards to avenge even a look that threatened her with insult. But the age of chivalry is gone. That of sophisters, economists, and calculators, has succeeded; and the glory of Europe is extinguished forever.

Rationality also implies objectivity; coolness and detachment are part of the rational approach to understanding and changing the world. Guided by a rational outlook, scientific inquiry and technological application are usually based on the abstraction or isolation of the part of the natural world that is being studied or manipulated. This is not always a good thing, for it can produce a sharp separation between the individual and the rest of the world. The scientist or technologist stands apart from the system that is being studied and manipulated, resulting in a kind of tunnel vision that may ignore the larger consequences of gaining and applying knowledge.¹⁸ For example, in discovering a genetic marker for a serious disease, a researcher might not consider potential abuses of that discovery, such as insurance companies refusing coverage of people with that marker.

It also may be argued that a logical, detached, and dispassionate approach to the world is suffused with a "masculine" approach to understanding and interacting with the world. Some technologies have largely been a male domain, but throughout history women have also made significant contributions to technological advance.¹⁹ The complex relationship of gender and technology is illustrated by the history of the technological artifact most strongly associated with the present era, the digital computer. Its development has generally been viewed as the product of hyper-rational male engineers, mathematicians, scientists, and technicians. In reality, many of the programmers of first-generation computers were women whose

accomplishments have often been passed over in standard histories.²⁰ More recently, the development of computer technology has depended on thought processes that are relentlessly rational, objective, and logical, but at the same time has required an intuitive, interactive, and generally less structured approach.²¹ This is not to say that either style is the exclusive province of men or women, only that technological advance often requires both approaches. Equally important, although these modes of thinking may be described in gender terms, they need not reflect the cognitive approaches of individual men and women.

Technological Determinism

Nothing worthwhile in life comes without some costs attached. So it is with technology; while it has expanded human power and made our lives materially richer, the advance of technology has created many problems—environmental degradation, alienation, and the threat of nuclear annihilation, to name only the most obvious ones. And, most bothersome of all, there looms the possibility that technology is out of control. If this is so, what began more than a million years ago as a human creation has taken on a life of its own, with technology advancing according to its own inner dynamic, unrestrained by social arrangements, systems of governance, culture, and thought.²² The belief that technology acts as an independent force in our life, unaffected by social forces, is known as “technological determinism,” and if it is true, we have become the servant of technology instead of its master.

There can be little question that technology exerts a great influence on social, political, and economic relationships. Everything from antibiotics to zippers has affected our lives to some degree; many of these influences will be explored in subsequent portions of this book. But that is not the end of the story. As will be explored at greater length in Chapter 3, students of technology have given extensive consideration to the opposite possibility, that instead of operating as an independent force, technology is shaped by social arrangements. According to social constructivists (adherents of the Social Construction of Technology approach), the emergence of particular technologies, choices between competing technologies, and the way these technologies are actually used owe a great deal to socially grounded forces such as political power, social class, gender, and organizational dynamics.

Asserting the supremacy of either technological determinism or social constructivism is not a very useful activity. Such straightforward cause-and-effect relationships can be found in some realms—Newtonian physics, for example—but technological and social change is better understood in terms of probabilities, reciprocal interactions, and feedback loops. Even William F. Ogburn, a sociologist who is often characterized as a technological determinist, on occasion took a more nuanced view of the subject: “The more

that one studies the relationships between mechanical and social invention, the more interrelated they seem.... The whole interconnected mass [i.e., social institutions, customs, technology, and science] is in motion. When each part is in motion and banging up against some other part, the question of origins seems artificial and unrealistic. If one pushes the question to the extreme, origins are lost in a maze of causative factors.”²³

The wondrously complicated interactions of technology and society often result in unimagined consequences when new technologies emerge. To take one example, when the first digital computers appeared in the mid-1940s, they elicited modest expectations about their future applications. Today, the world as we know it is almost unimaginable without computers, as everything from air travel to the mapping of genomes is totally dependent on the storage, retrieval, and manipulation of information performed by computers. Accordingly, the history of the computer would seem to lend credence to technological determinism. Nobody saw it coming in the 1940s, but within a few decades the computer had become a universal and essential part of contemporary life.

This is the story from a technological determinist standpoint, but social constructivists would challenge it by noting that the technical development of the computer in the 1950s and 1960s was heavily supported by military expenditures, just as one of today’s major computer applications, the internet, was initially a creation of the U.S. Department of Defense. Someone taking a social constructivist approach might also point out that the expansion of the market for computers was also powerfully stimulated by commercial enterprises like banks and insurance companies, and that this huge market supported the research and development that rapidly advanced computer technology.

A similar story could be repeated for most successful technologies. New technologies bring changes to many aspects of society, while at the same time social forces do much to stimulate and shape these technologies. To try to assign primacy to one or the other is to ignore a crucial feature of technological and social change. Both are dynamic processes characterized by the reciprocal interaction of a host of factors, some of them narrowly technical in nature, others not. No reasonable person could deny that technology has been a major force in making the world we live in, but it is

important to always keep in mind that technology has not operated as an agent independent of the society in which it is imbedded.

Social constructivism therefore offers the possibility for more human agency than technological determinism, but it is not likely that the ability to influence the course of technological change will be evenly distributed among the population as a whole. To the contrary, social constructivist analyses have often shown how differences in power and access to resources have shaped technological change. Particular technologies may be devised, selected, and disseminated because they serve the interests of a particular group, possibly in opposition to the interests of other groups. Technology confers power, but this power is not wielded over only the nonhuman universe. As C. S. Lewis has reminded us, “Man’s power over nature is really the power of some men over others with nature as their instrument.”²⁴

Living in a Technological Society

The development and application of technologies that are suited to our needs requires the informed participation of a wide range of people. Unfortunately, the very nature of modern technology places severe limits on popular understanding. The sophistication and complexity of contemporary technologies preclude direct involvement by all but those immediately concerned with them. The rest of us are passive consumers, content to reap the benefits of rationally derived knowledge but woefully ignorant of it. This creates the fundamental paradox of modern society: technology has generated massive powers available to human society, while as individuals we exert very little of that power. We have access to a wide range of powerful technologies, yet our inability to understand them often leaves us with feelings of impotence and frustration, as anyone who has experienced a computer crash will attest.

As has been noted, the application of rationality for the solution of human problems is both the consequence and the cause of optimism and a willingness to accept constant change. Yet one cannot help but wonder if these characteristics can be sustained in an environment that sharply limits participation and inculcates widespread feelings of having little or no power over the process of technological change.

Strange notions can emerge when feelings of powerlessness are coupled with an extravagant faith in technology. The consequences of this combination are sometimes exhibited by fervent believers in alien spacecraft or UFOs (unidentified flying objects). Although convincing evidence of UFOs is lacking, a belief in their existence does not necessarily make one a crackpot. In some cases, however, a strident belief in the existence of UFOs takes on the characteristics of membership in a religious cult where the deities are superior beings who have produced an advanced technology. Alien spaceships represent a level of technical sophistication not attained on Earth, and some UFO enthusiasts entertain the hope that the aliens that created them will take over this planet and solve its problems. Faith in a higher technology may be combined with a mistrust of the “establishment,” as a fair number of

UFO adherents claim that their government is engaged in a massive conspiracy to prevent the general public from being aware of the existence of UFOs. There is no denying that on occasion governments lie to their citizens, but a cover-up of the required magnitude would be impossible for even the most well-organized government to pull off. Still, conspiracy theories strike a resonant chord with people who feel that they have been excluded from decision making, both political and technological. A quasi-religious belief in UFOs may therefore combine an excessive confidence in technology in general with a distrust of the people and organizations that control it in actual practice.

Distrust flourishes when people have no ability to participate in decisions that shape their lives, and the inability to affect the course of technological change can produce a mixture of naive hope and paranoid reaction. A realistic sense of control, including a sense of having some control over technology, is essential for an individual's mental health. No less important, widespread participation in the shaping of technology is essential for democracy. Technology's benefits cannot be separated from its costs, and thus it becomes necessary to determine if the former justify the latter. If a society is truly democratic, such decisions will be made with as much citizen participation as possible. Moreover, the benefits and costs of technology are not shared equally, and once again the apportioning of costs and benefits should be done in as participatory a manner as possible. We will return to these themes in Chapter 17, but first, we will take a closer look at how technology can affect people and groups in different ways.

QUESTIONS FOR DISCUSSION

1. In your opinion, which recent technology has produced the greatest benefit? Which has produced the most harm? Are there any harmful elements to the beneficial technology, and has anything good come from the harmful one?
2. You have probably heard the old saying that “necessity is the mother of invention.” Are new technologies usually a response to an existing need of some sort? Can you think of any technologies that created a need before most people were aware of it?
3. Are technologies “gendered”? Are some technologies identified with women and others with men? On what bases do we make these distinctions? Will this situation necessarily continue in the years to come?
4. Can you think of any technologies that were developed simply because of the technical challenges involved? How can these “impractical” technologies be justified?
5. How do you feel when a technological device upon which you depend malfunctions? What do these feelings tell you about your attitude toward technology in general?
6. It is sometimes asserted that the development and use of birth control pills were responsible for the sexual revolution that began in the 1960s. Is there a simple cause-and-effect relationship of the two? Have there been any other forces that contributed to changing sexual mores?

CHAPTER TWO

Winners and Losers: The Differential Effects of Technological Change

The last chapter may have seemed a bit negative in its assessment of technology and the culture that supports it. In one regard, however, there is no denying technology's positive consequences: technological advance has been the greatest single source of economic growth. If our material lives are better than those of our grandparents, it is largely because technological development has boosted the production of goods and services. Equally important, it has created entirely new products while at the same time improving the quality of existing ones.

Curiously, economists were slow to grasp this seemingly obvious fact. Conventional economic analysis identifies three basic "factors of production": land (which includes natural resources), labor, and capital. Any increase in production was therefore taken to be the result of an increase of these factors. This view began to change in the 1950s when the historical course of economic development in the United States was analyzed through the use of sophisticated statistical techniques. It then became apparent that increases in the traditional factors of production did not adequately explain the actual record of economic growth. The amount of land had remained constant, and capital accumulation and increases in the labor force accounted for only 10 to 20 percent of economic growth during the first half of the twentieth century.¹ Accordingly, the major source of economic growth was a "residual" factor of overwhelming importance. Most economists agree that

technological advance is the main element of this residual, although organizational development and improved worker skills, along with economies of scale, are also key components. Still, as we have already seen, organization and skill are integral parts of technology, so it is reasonable to view technological change as the major source of economic growth, a conclusion that is widely supported by economists today.²

While technological development has been the primary source of economic advance, it has not been cost-free. One of the most pleasant myths about technology is that it can work its wonders without altering existing social arrangements. Americans in particular have often seen technological progress as the surest basis for progress in general, and have tended to believe that technological solutions to problems are less painful than solutions that require political or social changes.³ These beliefs are not easily sustained after an examination of the actual pattern of technological advance.

It is a truism that a particular technology can be used for either good or evil purposes; a construction team employs explosives to build a road, while a terrorist uses them for roadside bombs. But there is less appreciation for a more subtle point: technological change is often a subversive process that results in the modification or destruction of established social roles, relationships, and values. Even a technology that is used exclusively for benign purposes will cause disruptions by altering existing social structures and relationships. There are many technological changes that are small in scope, the effects of which are felt by only a few. A few technological changes are massive and they lead to vast social restructuring. In either case, technology does not yield its benefits without exacting a cost.

Technology as a Subversive Force

The disruptive effects of technological change can readily be seen in the economic realm, where new technologies can lead to the destruction of obsolete firms, as when the fabled Pony Express rapidly lost its customers after telegraph wires had been strung across the West. Of course, sometimes the disruption is less apparent when technological innovation results in the creation of entirely new industries that are not in direct competition with existing ones. Many new industries and individual firms owe their existence to the emergence of a new technology. Witness, for example, the rapid growth of personal computer manufacturing, peripheral equipment production, software publishing, and app development that followed the invention of the integrated circuit. Even so, lurking behind these successes were a number of failures, most notably the manufacturers of vacuum tubes and individual transistors, who faced a diminished market for their products.

Concerns about the disruptive effects of technological change are not new, as can be seen in an English magazine editor's fulminations against the first railroads in 1835: "Railroads, if they succeed, will give an unnatural impetus to society, destroy all the relations that exist between man and man, overthrow all mercantile regulations, and create, at the peril of life, all sorts of confusion and distress."⁴

Anyone convinced of the virtues of technological change could easily criticize this reactionary view by noting how the railroad stimulated economic development and produced many social benefits. Even so, there is more than a grain of truth in the concerns expressed by the agitated magazine editor. Technological changes, both major and minor, often lead to a restructuring of power relations, the redistribution of wealth and income, and alterations to human relationships.

One recent and much-debated instance of a disruptive new technology is the rise of ride-sharing services like Uber and Lyft. The use of private automobiles for the paid transportation of individuals is nothing new; a century ago, privately owned cars known as "jitneys" regularly picked up and delivered paying passengers.⁵ Although it can be argued that they performed

a useful service, jitneys were quickly banned by municipal governments due to safety concerns, but also because they were deemed unfair competition for public trolley and bus lines. The resurgence of ride-sharing services today has come as a result of the ubiquity of smartphones. After downloading an appropriate app, individuals can easily request a car and driver to pick them up and take them to their destination.



Boston Globe/Getty Images

Technological change may contribute to the decline of many established products and organizations, as exemplified here by the closure of a Borders bookstore.

Ride-sharing services are convenient for their users, and they allow drivers to work as much or as little as they prefer with no immediate supervision. The convenience and generally lower fares offered by these services has led to their spectacular growth. Uber, the largest, began in San Francisco in 2010; a mere five years later, it was operating in 58 countries and was valued at \$50 billion.⁶

At the same time, however, ride-sharing services and especially Uber have generated a storm of protest. Drivers of established taxi firms and their supporters have mounted vociferous and sometimes violent protests against

Uber in New York, France, Brazil, Australia, and elsewhere.⁷ Critics of Uber and similar services point to the iniquities that result from treating drivers as contractors rather than employees. As such, they are not eligible for pension and health care benefits, and ride-sharing firms avoid making contributions to Social Security payroll taxes. Issues have also been raised concerning the screening of drivers, vehicle safety, and insurance coverage.

In addition to energizing a considerable amount of mass protest, ride-sharing firms have met with government opposition. In California, the birthplace of so many new technologies, government agencies have challenged some of the practices of ride-sharing firms. In 2015, the California Labor Commission ruled that Uber drivers were employees, and not contractors, which would make them eligible for the benefits noted above. In the same year, New York taxi-enforcement officials seized nearly 500 cars over a six-week period, citing illegal street pickups by Uber drivers.⁸ But government agencies elsewhere have been less decisive. In 2015, the Florida state agency charged with resolving unemployment compensation issues overturned an earlier decision that had labeled Uber drivers employees and not contractors.⁹ In both California and Florida, the cases centered on single individuals and the overall applicability of either of these legal rulings is debatable. All that can be confidently said at this point is that it will likely take several years for the governments and the law to sort out the status of ride-sharing services and their drivers.



LUIS ROBAYO/Getty Images

Taxi drivers in Cali, Colombia protest the presence of Uber in their city.

On occasion, technological advance has fatally disrupted entire communities and the people living in them. One such place was Caliente, Nevada.¹⁰ Caliente was a small town with a variety of civic amenities—schools, churches, a hospital, a theater, a park, and many prosperous small retail businesses. Many of its inhabitants were proud members of civic organizations such as the Chamber of Commerce, Rotary, the Masons, and the American Legion. It was a typical American small town, with typical American small-town values.

The life of the town was supported by a single industry: the servicing of steam locomotives. Caliente was an important division point on a transcontinental railroad, and many of the town's people worked as machinists, boilermakers, and repairmen. Their incomes in turn supported Caliente's commercial and civic establishments. Then, in the late 1940s, the diesel-electric locomotive rapidly replaced the steam locomotive. Diesels had many advantages; they were more fuel-efficient, hauled longer trains, and did less damage to the rails and roadbed. They also required less frequent servicing. When servicing was required, it took place in large centralized shops. As a result, service facilities were eliminated at many division points, and Caliente was one of them. The town lost its economic base, and within a few years, it had become a shell of its former self. People moved out, homes

were abandoned, and shops were boarded up. The local newspaper sadly noted, “Employees who have given the best years of their lives to this railroad are cut off without anything to which they can turn, many of them with homes in which they have taken much pride; while others, similarly with nice homes, are told to move elsewhere.”¹¹



Jack Delano/Farm Security Administration-Office of War Information Photography Collection (Library of Congress)

By providing many jobs, the servicing of steam locomotives formed the economic base of towns like Caliente, Nevada.

The tragedy of this small town has been repeated in many other

communities affected by technological change. Many places of employment have closed down as new products and processes have replaced old ones, leaving communities and their inhabitants in desperate straits. The technological advances that produced these dislocations may have benefited society as a whole, but at great cost to the people who were immediately affected.

Technological changes do not always result in the disruption or modification of an existing social order; sometimes they may help to preserve it, as happened when pneumatic molding machines were adopted by the McCormick reaper manufacturing plant in the 1880s.¹² These machines were not installed, as conventional analysis would lead us to think, in order to reduce costs or to produce a better product; in fact, they were deficient on both counts. They were installed for the sole purpose of eliminating the skilled workers who formed the backbone of the National Union of Iron Molders, an organization that was challenging the entrenched authority of McCormick's management. The molding machines allowed the replacement of skilled workers by unskilled ones, and three years later, having served their purpose, they were discarded by McCormick's management.

Groups that are threatened by a technological innovation are not always as helpless as the iron molders apparently were. Many affected parties have been able to defend themselves against changes in the way of doing things. To take one example, prefabricated buildings were vigorously resisted by many local construction workers' unions because they threatened their members' jobs. One sad tale is narrated by Peter Blake:¹³

Shortly after the end of World War II, an enterprising manufacturer decided to mass-produce a so-called service core: a complete "package" containing kitchen, bathroom, and utility room, with all fixtures, pipes, ducts, and wires in place, ready to be plonked down in any typical suburban house.

The first twenty of these beautifully designed and beautifully made "packages" arrived on a site near Detroit; local union plumbers and electricians promptly refused to install them. Finally, after nine months of heated debate (during which the units, parked on a sidewalk, were exposed to weather and vandalism), the local unions agreed to handle the "packages"—by disassembling them on the sidewalk and then reassembling them, piece by piece, in each of the houses. The manufacturer, needless to say, thereupon went out of business.

The Luddites

In the cases previously described, the successful resistance to a new technology entailed some disruptive, even violent, acts. A resort to violence was also a feature of the case of the most famous example of resistance to technological change, the outbreaks of machine-smashing that occurred in early nineteenth-century England.¹⁴ These attacks were the work of different groups who were collectively known as Luddites, a name that was derived from one Ned Ludlum, an apprentice stocking maker who, as legend had it, answered his master's reprimand by smashing his stocking frames with a hammer. There was really nothing new about these attacks; the breaking of machines by disgruntled workers had a long history in England, the earliest recorded episode taking place in 1663. But the Luddite disturbances that began in 1811 did represent a substantial increase in the scale of these attacks; by the following year, the government had to deploy 12,000 troops to restore order to the parts of England affected by the movement.

Since these attacks coincided with an era of rapid technological change, it is easy to draw the conclusion that they were motivated by the fear of many workers that their jobs would be lost to new machinery. The actual story is a bit more complicated. Luddite attacks occurred in a number of separate branches of the textile industry, and each was characterized by a distinctive set of motivations and responses. The Luddite movement began in the hosiery trades, where there had long been opposition to the use of wider stocking frames, which allowed the employment of poorly paid unskilled labor for the manufacture of an inferior product. The situation might have been resolved in a peaceful manner had it not been for the dire conditions encountered by many of England's working people at the time. The Napoleonic wars had resulted in the closure of many export markets, leading to a general trade depression. To make matters worse, a series of bad harvests led to sharp increases in the cost of food, and many workers found that their wages were insufficient to meet their basic needs. These conditions produced a fertile ground for the spread of "collective bargaining by riot," and Luddite attacks were soon fomented by shearers in the textile industry. Another

occupational group, the handloom weavers, viewed the advance of steam-powered weaving machinery with understandable apprehension, and, following the example of workers in the hosiery trade, some of them attacked the factories housing mechanized looms, as well as the houses of their owners. Only in a few instances was the machinery itself directly attacked.

Luddite disturbances were expressly oriented toward blocking technological change in the cropping trade. Wool cloth was traditionally finished by raising the nap and then leveling the surface through the use of a heavy set of shears. The growing use of the gig mill, a device for raising the nap, along with the employment of a crude device for the mechanized cropping of cloth, threatened the livelihood of the traditional handworkers. They responded with some of the most severe attacks of the Luddite epoch. Although the machinery had been used for many years in many textile establishments, the severe economic conditions of the time brought matters to a head. More than the other instances of Luddite revolt, the attacks on cropping equipment were motivated by a deep fear of unemployment induced by technological change.

Within a few years, the Luddite assaults came to an end due to the deployment of government troops; the execution, imprisonment, and exile to Australia of a number of the participants; and the general improvement in living conditions after the defeat of Napoleon. The succeeding decades of the nineteenth century also saw the replacement of the small manufacturing establishment by the large factory. Machine-smashing by riotous crowds was a likely form of labor protest when workers were scattered and lacking in permanent organizational linkages. In contrast, the factory served as a fertile ground for the development of labor unions and other organizational vehicles for pressing the interests of workers. Industrial sabotage did not come to an end, but it was generally superseded by unionization and more effective forms of worker protest.

Neo-Luddism

These early episodes of machine-smashing have led to the application of the “Luddite” label to anyone opposed to modern technology. But it is perhaps unfair to impute to the original Luddites a hostility to technology per se. As we have seen, most instances of Luddism were not motivated by a fear and hatred of new machinery; their grievances were those of people suffering from the low wages and unemployment caused by a generally depressed economy. The machines were seen as convenient targets of their ire rather than the sources of it.

In recent times, technology itself has been attacked by individuals and groups who have been labeled as “neo-Luddites.” In 1995, the *New York Times* and the *Washington Post* published a lengthy critique of modern society and the pivotal role of technology in creating and maintaining it. According to its author, a society based on modern technology brings some material comforts, but “all these technical advances taken together have created a world in which the average man’s fate is no longer in his own hands or in the hands of his neighbors and friends, but in those of politicians, corporation executives and remote, anonymous technicians and bureaucrats whom he as an individual has no power to influence.”¹⁵ Regaining human freedom therefore required the total destruction of industrial society and the technologies that made it possible. This would not be a peaceful revolution, but one that required the destruction of factories, the burning of technical books, and the eradication of all of the components of an industrial civilization. This creed might have been dismissed as the agitated musings of a late twentieth-century Luddite, but its author was not just a misguided critic of the modern world. Shortly after the publication of the manifesto, it was discovered that its author was a brilliant mathematician named Theodore Kaczynski, dubbed by the media as “The Unabomber,” an elusive figure who from 1978 to 1995 had been responsible for 16 bombings that killed three people and wounded 23 others.

Kaczynski was an extreme example; most expressions of neo-Luddism are aimed at excessive involvement in particular kinds of technology,

especially those of the digital variety. A much milder criticism has come from a number of writers who have advocated “digital detox.” Few of them suggest jettisoning computers, tablets, and smartphones. Rather, they prescribe occasional respites from social media, Twitter feeds, email, and blogs. Occasional separation from digital devices, it is claimed, will lead to lower levels of stress, improved concentration, higher productivity, and more face-to-face human interaction.¹⁶

Whose Technology?

We have just seen how specific technologies have been used and resisted by particular groups in accordance with their own needs and concerns. These examples should help us to realize that technology does not proceed solely through its own momentum, as implied by technological determinism; its development is strongly influenced by existing social and political arrangements. Technological changes may take place because they advance the interests of a particular group. Conversely, some technologies may meet with stiff resistance because they threaten a group's interests. Technologies do not stand or fall solely on their intrinsic merits; the decision to develop and deploy a new technology is often shaped by the distribution of power in a society.

Social, economic, and political arrangements affect the course of technological change by influencing the kinds of investments that are made, the research projects that are funded, and the general priorities that are established. Large organizations, such as corporations and government agencies, often wield disproportionate influence over the process of technological change. As we will see in Chapter 17, the federal government is a major source of financial support for research and development, with the Department of Defense, the National Aeronautics and Space Administration (NASA), and the Department of Energy (primarily for nuclear research and development) accounting for a large share of these expenditures. Although we can only speculate about alternative outcomes, it seems likely that American technology would have diverged markedly from its historic path if financial resources had been distributed differently.

Perhaps with a different set of sponsors, technological development might have made greater contributions to the solution of a number of pressing social problems, such as poverty and crime. At the same time, however, it can be argued that certain kinds of problems are simply not amenable to technological solutions. Even with significant changes in the funding of research, technological solutions to many social problems will not be forthcoming. This is an important objection, and we will examine it in the

next section.

What Technology Can Do—And What It Cannot Do

The growth of technology has brought dazzling changes to our lives. At the same time, we seem to be mired in problems for which there seem to be no solution. The continued existence of these problems is all the more frustrating when contrasted with the rapid progress of technology. For example, we can use all kinds of sophisticated medical equipment and techniques to preserve the lives of sickly infants who have been born many weeks premature, but we cannot seem to conquer the poverty that often results in sick infants. Why, it is often asked, is there such a gulf between technological progress and social progress? Why can technology not be applied as a solution for more, if not all, of our problems? If we can put a man on the moon, why can we not ...?

The Technological Fix

These are troubling paradoxes, and in recent years we have searched for ways of finding technological solutions to a host of problems. The drug methadone has been widely used to eliminate addicts' cravings for heroin. As highway accidents continue to result in tens of thousands of deaths and hundreds of thousands of injuries each year, efforts have been mounted to develop and manufacture cars capable of protecting their occupants from the consequences of incompetent driving. Cities befouled by graffiti have turned to the use of new paints and cleaning solutions that resist the endeavors of spray-can artists. Overweight men and women spend billions of dollars annually on medications and exercise apparatus in the hope of shedding excess pounds. College professors worried about plagiarized papers use computer programs to detect possible cheating.

The list of technologies that have been or could be applied to the alleviation of social problems is an extensive one, and examples could be endlessly supplied. What they have in common is that they are "technological fixes," for they seek to use the power of technology in order to solve problems that are nontechnical in nature. In this section, we will briefly examine a few of these technologies and consider the extent to which technology can alleviate these pressing problems.

Many technological fixes have been employed over time, although not always with the conscious understanding that technology was being used in lieu of some other method of achieving a desired end. To take one example, at the beginning of the twentieth century the United States was undergoing severe growing pains; the urban population was expanding at a rapid rate, accompanied by congestion, pollution, and a host of other urban ills. In a nation steeped in the Jeffersonian belief that cities were inherently evil and that the countryside was the best location for virtuous living, the conversion of the American populace into a race of unhealthy and disaffected city dwellers was viewed with alarm. A number of technologies did make urban life more tolerable, most notably those concerned with public health and sanitation, but these only served to ameliorate living conditions without addressing the real issue: the desire of many Americans to escape the city and return to a vaguely perceived rural idyll.

The pursuit of this goal gave a great impetus to the development of transportation technologies that would allow the solution of urban problems by eliminating the need for cities, at least as places of residence. Instead of comprehensively addressing urban ills through planning and the development of social programs, Americans pinned their hopes on new transportation technologies. The first of these was the electric trolley. Through the construction of extensive networks of interurban electric lines, it was hoped, America's urban problems could be literally left behind as a new generation of workers could commute from their places of work to their rural or suburban homes.¹⁷

In many American cities, the trolley was displaced by the automobile, as a great deal of automobile ownership was motivated by similar sentiments. Widespread automobile ownership promised an escape from the harsh realities of America's cities through individual commuting. As Henry Ford neatly summed things up, "We shall solve the city problem by leaving the city."¹⁸ Ford's sentiments were taken to rhapsodical levels by one early twentieth-century journalist:¹⁹

Imagine a healthier race of workingmen, toiling in cheerful and sanitary factories, with mechanical skill and tradecraft developed to the highest, as the machinery grows more delicate and perfect, who, in late afternoon, glide away in their own comfortable vehicles to their little farms or houses in the country or by the sea twenty or thirty miles distant! They will be healthier, happier, more intelligent and self-respecting citizens because of the chance to live among the meadows and flowers of the country instead of in crowded city streets.

It is hardly necessary to note that these hopes were not realized. The mushrooming growth of suburbs spawned by trolleys and automobiles did not create a harmonious social order based on rural values. All too often the legacy has been suburban sprawl, the deterioration of city centers, visual blight, air pollution, traffic fatalities, and many other ills. This is not to say that the automobile has been an unmixed curse; the benefits of personal mobility, privacy, and a sense of power have been too eagerly accepted to allow such a judgment. But the automobile, just like its predecessor the trolley, was hardly the technological panacea that was envisioned. The examples of the trolley and the automobile remind us that while some specific problems may be amenable to technological solutions, larger issues

rarely admit of easy solutions through the application of technological fixes.



Archive Photos/Getty Images

The trolley held out the promise of an escape from the noise, dirt, and congestion of the early twentieth-century city.

Why Technology Cannot Always Fix It

The main difficulty underlying the use of technology to solve social problems is that these problems are fundamentally different from technical problems. In the first place, social and technical problems differ in their specificity. If you intend to design an air conditioner, you at least know what your goal is: to keep a space cool. In many ways, this problem is similar to the far more grandiose objective of landing a man on the moon; although there may be daunting technical problems to overcome, at least the goal is clear and unambiguous. But what if your goal is to reduce crime? Crime, unlike air temperature, is a very diffuse concept, encompassing everything from forgery to murder. Even when a particular crime is singled out for treatment, its causes are likely to be manifold and not easily addressed by a single technology.

To make matters even more difficult, social problems are directly concerned with human motivations and behaviors. It is one thing to change the temperature of the air by inventing and installing an air conditioning system; it is quite another to attempt to change human behavior through the same kind of technological intervention. Human beings are wondrously intricate creatures whose actions are governed by extremely complex motivations. Trying to understand, let alone change, human actions is an exceedingly difficult task. And humans are likely to resist when attempts are made to change their behavior. Consequently, successful technological fixes tend to be those that get the job done without challenging the existing values and interests of the population.²⁰

It is also apparent that technological solutions work best when they operate within closed systems—that is, when the issue to be addressed is sealed off from outside influences. Of course, no technology exists in isolation from the surrounding society. A transportation system based on private automobiles, for example, is the result of choices exercised within the economic and political realm, such as a government's decision to build a highway network. But within a given technology there are many specific matters that can be treated as purely technical problems. In these cases, it is possible to approach the problem directly and not worry about the influence of other factors. If your car fails to start one morning, you can be sure that the

problem lies only with its components; you need not concern yourself with sunspot activity or a recent presidential election in Peru.

When a problem is not so easily isolated, a technological solution is much less likely. Today, nearly one out of six boys under the age of 10 in the United States is diagnosed with attention deficit hyperactive disorder (ADHD).²¹ This behavioral problem undoubtedly has a neurological basis, at least for some children, and amphetamine-like stimulants such as Ritalin are routinely prescribed to alleviate the symptoms of ADHD. It is likely, however, that many children afflicted with the disorder have problems that go beyond the neurological. Dysfunctional relationships and actions within a family can create stresses that produce ADHD. Under these circumstances, the administration of a drug will be insufficient. As the ADHD website of the National Institute of Mental Health notes, “Sometimes, the whole family may need therapy.”²²

As a final point, it should be noted that no problem, technical or otherwise, is ever really “solved.” Not only are most solutions incomplete, they also generate new (and sometimes very different) problems. These unintended and often unforeseen problems may be even more difficult to solve than the original problem. This process has been dramatically illustrated by the rapid development of modern medical technologies, a topic that will be explored in greater depth in Chapter 7. Technical solutions such as the development of lifesaving drugs, organ transplants, and sophisticated diagnostic techniques have proliferated, but at the same time they have created a host of new dilemmas. Given the expense of many of these new technologies, it may be necessary either to spend more on medical care or to attempt to ration it. If these technologies are to be rationed, will this take place through the price mechanism, or will it be done according to some formalized procedure? In either case, serious ethical issues will have to be faced. Life-extending technologies have also raised vexing questions about the morality of prolonging a life under conditions that seem dismal indeed. Moreover, a longer individual life span leads to an aging population and the necessity for a wide range of adjustments to the society, the economy, and even the culture. Without belaboring the point, it should be apparent that no set of technologies will make our lives better without requiring the enactment of other changes, which may generate problems of their own.

The Appeal of Technocracy

These inherent limitations have not deterred a number of individuals and groups from trying to convert social problems into technical problems. There have been numerous flirtations with technocracy—the governance of society by engineers and other people with technical expertise, who attempt to develop policies based on technical and “scientific” principles. There is no denying that the technocratic vision is at first glance an appealing one. In a world too often governed by venal and incompetent politicians, there is something very attractive about a system of governance that supposedly bases itself on logic and the use of expertise. Moreover, where conventional political systems of all types seem endlessly involved with apportioning pieces of a small pie, adherents of some form of technocracy often promise a social and economic order that produces an ever-expanding pie through the application of the methods that have served technological development so well.

The promises and pitfalls of a technocratic approach to the solution of social problems are well illustrated by the theories of Scientific Management, as developed by Frederick W. Taylor (1856–1915) and his followers during the early decades of the twentieth century.²³ Scientific Management arose in an era marked by a profound paradox: industrial production was increasing at a rapid pace, but at the same time American society was racked by large-scale and potentially explosive conflicts between workers and management. Many cures for labor unrest had been proposed, but for Taylor, all of them missed the mark. Taylor had earned an international reputation as a metallurgical engineer, and his systematic studies on the cutting tools used for machining metal had resulted in major technological advances. If obdurate metals could be better controlled and shaped through the application of new technologies guided by scientific principles, why could the same thing not be done with workers?

To achieve this goal, Taylor and his colleagues developed a “scientific” regimen for studying work. The main technique used for this task was the time-and-motion study through which workers were systematically observed and their work motions precisely timed. Through an analysis of these observations and measurements Taylor came up with a supposedly optimum

set of motions for a given job, all of them subject to rigid time constraints. Equally important, the development and administration of these motions were the business of management exclusively, and any attempt by workers to go about their tasks independently would necessarily result in wasted motions and general inefficiency. A basic tenet of Scientific Management was that the planning and organization of work had to be separated from its actual execution. Only specially trained managers had the time and expertise necessary for the devising of optimal methods of production. The prime obligation of the workers was to do what they were told to do.

Although they had no power to plan and manage their own work, workers were supposed to benefit from the system. Because their work activities were now optimized, production would supposedly increase significantly. Workers would necessarily share in these higher returns, for Taylor also advocated that workers be paid according to piece rates rather than straight wages; the more they produced, the more they earned.

THE MIDVALE STEEL CO.

Form D—124.

Machine Shop.....18.....

ESTIMATES FOR WORK ON LATHES

OPERATIONS CONNECTED WITH PREPARING TO MACHINE WORK ON LATHES AND WITH REMOVING WORK TO FLOOR AFTER IT HAS BEEN MACHINED		NAME									
OPERATIONS	TIME IN MINUTES	Sketch	Number	Order	Weight	Metal	Heat No.	Tensile Strength....	Chem. Comp.	Per cent. of Stretch	HARDNESS, Class
Putting chain on, Work on Floor		OPERATIONS CONNECTED WITH MACHINING WORK ON LATHES									
Putting chain on, Work on Centers		OPERATIONS	Speed	Feed	Cut	Tool	Inches	Min-utes			
Taking off chain, Work on Floor		Turning Feed In									
Taking off chain, Work on Centers		" " Hand Feed									
Putting on Carrier		" " "									
Taking off "		Boring Feed In									
Lifting Work to Shears		" " "									
Getting Work on Centers		" " Hand Feed									
Lifting Work from Centers to Floor		" " "									
Turning Work, end for end		Starting Cut									
Adjusting Soda Water		" " "									
Stamping		Finishing Cut									
Center-punching		" " "									
Trying Trueness with Chalk		Fillet									
" " with Calipers		" " "									
" " with Gauge		Collar									
Putting in Mandrel		" " "									
Taking out "		Facing									
Putting in Plug Centers		Slicing									
Taking out "		" " "									
Putting in False Centers		Nicking									
Taking out "		" " "									
Putting on Spiders		Centering									
Taking off "		Filing									
Putting on Follow Rest		Using Emery Cloth									
Taking off "											
Putting on Face Plate		TOTAL									
Taking off "		Machining — Two Heads Used									
Putting on Chuck		" " — One Head Used									
Taking off "		Hand Work									
Laying out		Additional Allowance									
Changing Tools		TOTAL TIME									
Putting in Packing		HIGH RATE									
Cut to Cut		LOW RATE									
Learning what is to be done		Remarks									
Considering how to Clamp											
Oiling up											
Cleaning Machine											
Changing Time Notes											
Changing Tools at Tool Room											
Shifting Work											
Putting on Former											
Taking off "											
Adjusting Feed											
" " Speed											
" " Poppet Head											
" " Screw Cutting Gear											
SIGNED	TOTAL	Time actually taken									

INSTRUCTION CARD FOR LATHE WORK

© 1911 by Frederick Winslow Taylor in Shop Management

Frederick Taylor believed that all kinds of work could be reduced to rationally derived actions, much as machining operations could be precisely timed through the use of this worksheet.

The technocratic spirit of Scientific Management is thus evident: the tasks and prerogatives of management rested not upon the exercise of raw power but on management's technical superiority in guiding the production process. At the same time, Scientific Management promised relief from continual squabbling over relative shares of the fruits of production; an optimal system of organization would result in more of everything for everybody. Taylor was not content with using Scientific Management as a solution for the problems of the workplace; its principles, he claimed, "can be applied with equal force to all social activities: to the management of our homes; the management of our farms; the management of the business of our tradesmen large and small; of our churches, our philanthropic organizations, our universities; and our governmental departments."²⁴

The appeal of Scientific Management was not confined to the United States, or even to the capitalist world. Vladimir Lenin, the leader of the Bolshevik Revolution in Russia, expressed a deep admiration for American technology and American forms of industrial organization, and for Taylor's ideas in particular. Although he duly noted that Scientific Management embodied "the refined cruelty of bourgeois exploitation," Lenin made it clear that its basic principles and procedures could contribute to the realization of Soviet economic goals: "The possibility of building Socialism will be determined precisely by our success in combining Soviet government and the Soviet organization of administration with the modern achievements of capitalism. We must organize in Russia the study and teaching of the Taylor System and systematically try it out and adopt it to our ends."²⁵

The Technocrat's Delusion

Although some of its elements, such as the use of time-and-motion studies, can still be found in contemporary managerial practices, Scientific Management in its pure form never took hold in the United States, the Soviet Union, or anywhere else. A number of technical problems impeded its use. Considerable skill was required for the administration of time-and-motion studies, and they were especially difficult to conduct in work settings not characterized by repetitious actions. But of equal or greater importance, both management and labor realized that the implementation of Taylor's system posed fundamental threats to their own interests. Most managers were highly reluctant to delegate their authority to the dictates of "scientific" procedures.²⁶ Workers, on the other hand, resented the loss of what little autonomy they had, and they widely believed—with considerable justification—that higher levels of productivity would result in the downward adjustment of piece rates, leaving them no better off than before the program had been enacted.

Scientific Management, like all technocratically inspired systems, ignored the distinction between technical and sociopolitical problems. Even if Scientific Management had generated the productive increases it promised—which is unlikely—it would still have been strongly resisted by those who had to submit to it. Scientific Management promised a conflict-free method of administration where no such thing was possible. Workers and managers had their separate interests, and each group was unwilling to entrust its fate to Taylor and his disciples.

The basic fallacy of Scientific Management, one shared by all other variants of technocracy, is that *administration* can replace *politics*. Administration is based on the application of rules that allow the realization of given ends. It is thus a manifestation of the rational spirit of applying the best means for the achievement of a particular goal. It does not, however, determine these ends. The Internal Revenue Service (IRS) officials who administer the tax system are not the authors of the tax code. Around April 15, we may get angry about the perceived unfairness of the tax code, but it is pointless to blame the officials at the local IRS office, who are only executing a set of policies that they did not create.

Tax codes and other policies are formulated through choices made in the political arena. Neither technology nor administration can supply the values that form the basis of these choices. They cannot tell us what we should do with our lives, nor can they help us to resolve the fundamental issue that all societies confront: how to distribute fairly life's necessities and luxuries. The resolution of these issues will always be marked by sizable differences of opinion and a good deal of conflict. The technocrat's hope that society can be run on the basis of engineering principles will always remain an illusion.

To summarize, technological changes inevitably produce social changes. These changes, in turn, do not affect everyone equally. Although many technologies produce widespread benefits, not everyone benefits to the same degree, and there are instances where particular individuals and groups lose out completely. A choice of technology is often a determination of who wins and who loses; it is therefore proper that affected parties have the opportunity to participate in the process. This issue will be taken up in greater depth in the last three chapters. At this point, it can at least be hoped that without deflating the very real achievements of technology, some sense of its inherent limitations has been conveyed. Technology and the procedures underlying its development have been immensely powerful in their own realm; outside this realm, however, they are less likely to be effective. Equally important, the methods that have been so successful in developing and applying new technologies cannot be transferred to the governance of society. Technological development may make some aspects of our lives better, but it can never substitute for a just and effective political and social system.

QUESTIONS FOR DISCUSSION

1. Technological advance has often undermined established businesses. Most recently, the growth of internet-based e-commerce has posed a threat to conventional brick-and-mortar retail firms. Can you think of other business enterprises that the internet may damage or even destroy? Should anything be done to prevent this from happening?
2. Were the Luddites justified in mounting their attacks on machinery? How else might they have expressed their grievances? Would other kinds of actions have been more successful?
3. What examples of technological “fixes” can you think of? Have they been successful or not? What are your criteria for judging success and failure?
4. Political leaders at home and abroad are occasionally described as “technocrats.” What are the implications of this description? Would you be more or less likely to vote for somebody who was described in this way?

PART TWO

The Process of Technological Change

Much of the research, writing, and thinking about the relationship of technology and society centers on how particular technologies have affected some aspect of the latter. But how do new technologies come into being in the first place? Chapter 3 describes how social processes are at the core of technological innovation and examines two modes of technological change in that light—epochal transformations and less dramatic incremental ones. It describes how economics, politics, culture, and social arrangements have influenced the trajectory of technological change. A market-based economy is an important stimulus for technological innovation, but nonmarket forces—ranging from human curiosity to government institutions—are also stressed.

Scientific discoveries are often seen as the major source of technological advance, but Chapter 4 argues that this is at best a half-truth. Although science and technology have much in common, they do not interact in a straightforward manner. When they do interact, the commonly accepted relationship between scientific and technological advance may be inverted as technological advances propel advances in science.

Chapter 5 shifts the focus from the creation of technologies to the ways in which they spread, or diffuse. It pays particular attention to the pitfalls of transferring a technology from one social and cultural environment to another and from one business firm to another. Especially in the poor parts of the world, a technology may not be effective and may even be harmful for

reasons noted here. The chapter also takes a critical look at the patent system, which can be both a stimulus and an impediment to the diffusion of new technologies. Its influence on technological advance is examined in the final section.

CHAPTER THREE

| The Sources of Technological Change

What accounts for the emergence of particular technologies? Why do they appear when they do? What sort of forces generate them? How is the choice of technology exercised? To put it more concretely, why were digital computers developed only during the second half of the twentieth century even though their basic principles were understood more than a hundred years earlier? Why did photography undergo rapid development during the nineteenth century? What were the inventors of radio trying to accomplish, and how did their intentions differ from those of subsequent developers? These are some of the questions that this chapter will address as it considers some of the most basic issues in the study of technology.

Technological Change as a Social Process

As a starting point, it is important to keep in mind that technological change does not take place in a social vacuum. Technology is a human creation, and because humans are social creatures, technological change is necessarily a social process. In recent years, the study of technological change has been strongly influenced by a perspective known as “social constructivism,” which we looked at in Chapter 1. According to this approach, technological change does not occur because new devices and processes demonstrate their clear-cut superiority over other ways of doing things. For social constructivists, the analysis has to begin with the need to explain why certain technologies are assumed to work better than others.¹ As Wiebe E. Bijker has noted, social constructivism is predicated on a belief in “the malleability of technology, the possibility for choice, the basic insight that things could have been otherwise.”²

To explain why things turned out the way they did, social constructivists describe how social structures and processes have affected choices of technologies. Since the presence of interest groups and unequal distributions of power are fundamental aspects of every society, social constructivists are particularly interested in delineating the main actors involved in the development and selection of particular technologies, and in noting how their actions reflect their positions in society. Accordingly, for scholarly practitioners of social constructivism, technological change is an inherently political process. New technologies do not succeed or fail solely on the basis of narrow technical merits. Rather, the achievement of technological “closure” (the point at which a particular technology is recognized as the accepted way of doing things, while others disappear or are marginalized) is closely tied to the presence of specific interest groups and their ability to affect the selection process.

Some form of social constructivism informs most contemporary studies of technological change, but considerable variation can be found in the relative emphasis put on social versus technical factors. Moreover, some students of technological change, most notably Thomas P. Hughes, have

argued that the strength of the social constructivist approach may depend on the developmental stage of a particular technology. According to Hughes, social constructivism is most valid when a technology is at an early stage of development. Social, political, and economic forces are likely to exert the greatest influence when several alternative technologies emerge at about the same time.³ Conversely, once a technology has become well established, it becomes difficult to deviate from the path that has been laid out by technical requirements.

To take one example, at the end of the nineteenth and beginning of the twentieth centuries, motorists could choose between cars with electric, steam, or internal combustion power plants. The triumph of the latter was not simply a matter of technical superiority, but was a reflection of the needs and expectations of the individuals who were the prime purchasers of automobiles.⁴ Once automobiles powered by internal combustion engines became well entrenched, the adoption of another type of automobile engine became extraordinarily difficult because the basic elements of our personal transportation infrastructure were firmly in place, everything from the fuel used to the skills necessary for effective repair work. Under these circumstances, technical requirements will prevail.

The Great Breakthrough

One benefit of the social constructivist approach is that it challenges the belief that technological change largely stems from the insights and labors of a few supremely talented individuals. Popular histories of technology have often looked to individual genius as the chief source of technological advance; we have all heard or read stories of how the inspired labors of Thomas Edison or the Wright brothers produced epochal inventions that transformed the world. Histories written from this point of view are in essence biographies of great inventors whose brilliance is assumed to be the sole source of technological advance.

Other histories of technological advance have remained within this framework but have looked to a different kind of genius as the source of advance. The key players here are not the inventors of new technologies but rather the entrepreneurs who make inventions into commercial successes by taking risks, moving into uncharted territory, and in general doing what hadn't been done before. There have been some individuals who have been both inventor and successful entrepreneur—for example, Edwin Land, the inventor and moving force behind the Polaroid camera—but they have been rare. Entrepreneurs generally take other people's inventions and make them into commercial successes. From this perspective, the key figure in the development of the steel industry is not Henry Bessemer, the co-inventor of the iron-refining furnace that bears his name, but Andrew Carnegie, who laid the commercial and organizational foundations of the industry.

Arriving at a definitive determination of the relative importance of “great men and women” versus “social processes” in shaping the history of technology would require much more space than is available here. It can be noted, however, that an assessment of the relative contributions of the two has to take into account the fact that a great deal of technological change is the result of small, incremental changes. In contrast to the “heroic” approach to the history of technology, these involve the work of largely anonymous inventors, engineers, mechanics, and technicians. Although their individual contributions may seem modest, in aggregate they have been an extremely

important source of technological advance.

These incremental changes often are the result of a learning process that occurs as a technology is used. Problems are identified and overcome, bugs are worked out, and improvements are made. In many cases, the cumulative results of these efforts are technological advances at least as important as those that stem from fundamental breakthroughs. In industries as different as petroleum refining and building construction, the major source of productivity improvements has been a multitude of small technological improvements that have resulted in large cumulative gains.⁵

This process is nicely illustrated by Louis Hunter's narrative of how the impressive development of nineteenth-century steamboats was the result⁶

of plodding progress in which invention in the formal sense counted far less than a multitude of minor improvements, adjustments and adaptations. The story of the evolution of steamboat machinery in the end resolves itself in a large part into such seemingly small matters as, for instance, machining a shaft to hundredths instead of sixteenths of an inch, or devising a cylinder packing which would increase the effective pressure a few pounds, or altering the design of a boiler so that cleaning could be accomplished in three hours instead of six and would be necessary only every other instead of every trip. Matters such as these do not get into the historical record, yet they are the stuff of which mechanical progress is made.

One can also witness the far-reaching consequences of numerous small improvements in the development of railroad technology. According to one calculation, if the traffic loads borne in 1910 had been carried by railroads employing the technologies of 1870, the additional costs would have amounted to \$1.3 billion by the latter date. Fortunately, by 1910, American railroads had benefited from improvements in the size of cars and the power of locomotives, which in turn were the result of steady evolution.⁷

And so it goes today. Even though the railroad may be described as a "mature" industry, this pattern of incremental yet substantial technological development continues. American railroads have significantly lowered their costs through the implementation of a series of important but not epochal improvements to diesel-electric locomotives: turbochargers, computer-controlled fuel-injection systems, higher compression ratios, lower idling speeds, computerized controls to prevent wheelspin, and the substitution of alternators for direct-current generators. This cluster of advances has

culminated in locomotives capable of developing 4,000 h.p., along with a 44.7 percent reduction of energy costs (in Btus per ton-mile) that occurred between 1980 and 2006.⁸

In a world where the ability to produce successful technological innovations is increasingly a requirement for a firm's success, if not its survival, each firm needs to tap every source of technological advance, no matter how modest it may seem. This is a point stressed by Anthony Athos and Richard Pascale in their book about American and Japanese management: "Careful scrutiny reveals that despite the exalted status of 'strategy' in the lexicon of American management, few great successes stem from one bold-stroke strategic thrust. More often, they result from one half-good idea that is improved upon incrementally. These improvements are invariably the result of a lot of 'little people' paying attention to the product, the customer, and the marketplace."⁹

The “D” in R&D

The process of making a technology work is often summarized by the abbreviation R&D, which stands for research and development. “Research” calls to mind images of cutting-edge work in well-equipped laboratories, where great breakthroughs produce dramatically new technologies. Research can be an exciting, even glamorous activity, and we naturally look to it as the basis of technological progress. It is the source of fundamental change in technology, like the invention of integrated circuits, cloning, and composite materials. Still, this sort of research rarely results in usable products. The realization of the potentialities created by research breakthroughs usually requires a lengthy process of development. Numerous problems have to be resolved, and, equally important, the new material or device has to be put into a form that allows it to be produced at a reasonable cost.

Here, again, we can see the importance of the slow, unspectacular improvements that turn a good idea into a working product or process. And here, too, we can often see a substantial outpouring of money. If basic research is an expensive process, development is often even more so. The development work that goes into preparing a new technology for actual production can entail massive expenditures for equipment, material, manpower, pilot plants, and the like.

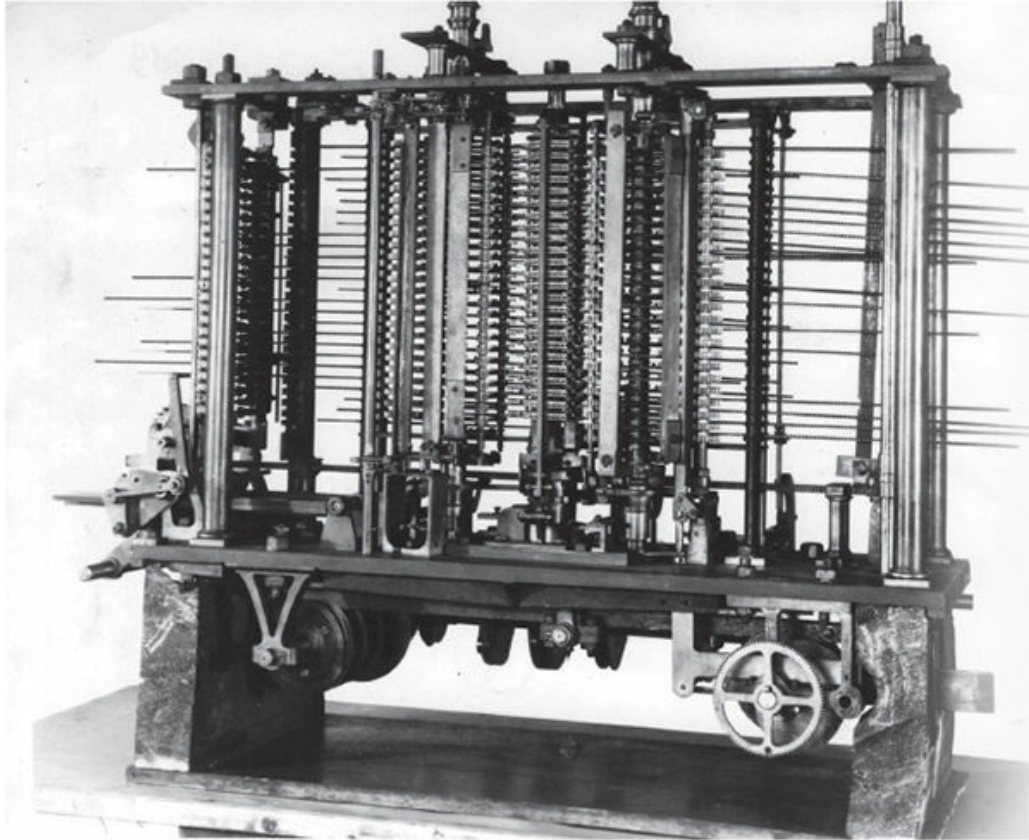
A great deal of development work is oriented toward “scaling up”—that is, making the transition from a successful research result to large-scale production. It is one thing to invent a device or process that works under laboratory conditions, and quite another to make a product in large quantity or extensively employ a process in an industrial setting where commercial success is the goal. The development of penicillin provides an excellent illustration of the many facets of the scaling-up process.¹⁰ Although the discovery of the bacteria-killing properties of penicillin initiated a major technological breakthrough, the development phase was certainly no less important.

Penicillin, a fermentation product of the mold *Penicillium notatum*, was discovered in 1928 by Alexander Fleming, who observed that bacteria were

destroyed in a culture that had been accidentally contaminated by the mold. Penicillium cultures grown in small quantities were the basis of laboratory and clinical research, but this process could not yield the large quantities of the drug needed for widespread therapeutic use. Large-scale production of penicillin was eventually done in huge fermentation vats, a process that required the solution of many technical problems. The key step was the development of a submerged fermentation process that allowed the mold to be grown directly in the nutrient medium. The success of this process in turn required a number of other improvements, such as new tank designs with special cooling systems and turbine mixers, which also had to be developed. The use of corn steep liquor (a by-product of corn starch production) as a culture medium increased yields tenfold, but it created a new problem. Penicillin requires air in order to grow, but severe foaming occurred when the culture was aerated. Antifoaming products therefore had to be developed to alleviate this problem. The extraction of penicillin from the moldy brew in the vats also created problems that were ultimately solved by the use of freeze-drying, which was itself scaled up from a process first used to preserve blood plasma. As a result of all of this development work, production of penicillin had reached 650 billion units by the end of World War II, and the cost of a dose was 55 cents instead of the \$20 it had been three years earlier.

Putting It All Together

The first chapter noted the importance of thinking of technologies as systems. This point is reinforced by a consideration of how particular technologies develop. Quite often, a technological leap forward takes place because of the availability of complementary technological developments that allow the resolution of fundamental problems. The history of the computer provides a good example of how complementary changes are essential for the translation of an idea into a workable technology. Beginning in the 1820s, Charles Babbage developed in England an “analytical engine” that contained a set of input devices, a processor, a control unit, a memory storage, and an output mechanism—the essential elements of today’s computers. But Babbage’s computer was operated by an exceedingly complex set of gears, cams, levers, and other mechanical linkages. Although he could draw on the talents of Ada Lovelace, who is often described as the world’s first computer programmer, Babbage’s ambitions were not fully realized for more than a century, when solid-state electronics, the cathode ray tube, and magnetic storage devices allowed the development of practical computers.¹¹



Photos 12/Alamy

A portion of Charles Babbage's computer.

Another illustration of the importance of complementary technological changes can be drawn from the history of one of the twentieth century's most important devices, the internal combustion engine. When these engines were first produced during the late nineteenth century, the spark that ignited the air-fuel mixture was timed to occur at the top of the compression stroke. This did not allow a sufficient time for the mixture to be completely ignited, and efficiency consequently suffered. When, after much experimentation, the spark was timed to occur before the piston reached the top of its stroke, the combustion process was greatly improved, and much more power was consequently delivered.

After all this work, early engines were deficient in power because compression ratios were kept low in order to prevent the sudden detonation of the air-fuel mixture and resultant damage to the engine. This problem was solved in part by conducting careful inquiries into the combustion process and by reshaping the combustion chamber and piston crown in ways

suggested by this research. But this was not enough. In order to employ higher compression ratios successfully, it was necessary to modify not just the engine but also the fuel it used. In particular, the research of Thomas Midgley and Charles Kettering demonstrated that the addition of tetraethyl lead to gasoline allowed higher compression ratios and a subsequent improvement in both power and economy. It was thus through a combination of cumulative improvements in both the engine and the fuel it burned that the internal combustion engine reached an acceptably high level of efficiency.

This is not the end of the story. As we saw in the previous chapter, technological solutions can give rise to new problems. So it was with the case of tetraethyl lead. In addition to the immediate environmental damage it caused, leaded gasoline destroyed the active elements in a major emissions-control device, the catalytic converter. Beginning in the 1970s, lead had to be removed from gasoline and replaced by less destructive additives.

It is important to note that these changes in engine technology were made well after the internal combustion engine was first invented, and was in widespread use. Lots of inventions require ongoing modifications over a lengthy period of time, and these in turn require ongoing sales revenues to pay for the needed improvements. Just as important, the experience of their customers may provide important guidance regarding where changes need to be made. Under these circumstances, customers may be unwitting participants in the beta testing of new products. A tragic example of this occurred in 2016 when a Tesla crashed into a truck, killing its driver. The car was in Auto Pilot mode, which automatically controls steering and braking. Unfortunately, the sensors that controlled these functions failed to detect a truck that had made a left turn in front of the Tesla because the white truck did not stand out against the bright background. Although Tesla had warned drivers to keep alert with their hands on the steering wheel, the temptation to yield control to a technology still being developed was too great.

Clearing Bottlenecks through Technology Transfer

The commercial viability of a new technology may thus stimulate the development of complementary technologies. A bottleneck that restricts the continued development of a particular technology creates strong economic incentives to find new technologies that clear the obstruction. Many obstacles are surmounted through the use of technologies that have been developed for use by a different industry or in a different sector. This can be seen today in the automobile industry, where emissions requirements have necessitated the use of microprocessors and computers for the regulation of spark advance and air–fuel ratios. Thus, a nineteenth-century technology, the four-stroke internal combustion engine, owes its survival to its marriage to a late twentieth-century technology.

The successful use of technologies from different realms can also be seen in the adoption of new ways of making things. This process is exemplified in the development of nineteenth-century metalworking industries. Although their products differed substantially, the processes employed by these industries were basically the same: turning, boring, drilling, milling, and planing. At the same time, they all confronted similar technical problems of transmitting power, reducing friction, and controlling the rate of feed. This meant that a technological solution arrived at by one industry was often directly applicable to the problems of another industry.¹²

This process of technology transfer can also be seen in the early automobile industry when it made abundant use of the products and manufacturing techniques that had been developed by the bicycle industry during the 1880s and 1890s. Ball bearings, spoke wheels, drive chains, and the use of electrical resistance welding had been extensively employed for the manufacture of bicycles in the decades immediately preceding large-scale automobile production. One of the most novel and significant technologies entailed the use of stamped components to take the place of forgings. Their use eliminated a great deal of machining, with a consequent lowering of production costs. The cheap, mass-produced automobile thus owed much to

technologies initially developed to make a product that it subsequently eclipsed.¹³

This is hardly the only example of technologies developed by an established industry paving the way for a radically new one. Although the turbojet engine was a novel method of propulsion when it first appeared in the 1940s, it drew heavily on designs, components, and processes that had already been developed for steam turbines. In Edward Constant's summary, "All the work done on blade design, gas flow, shaft and bearing loads, temperature distribution, lubrication systems, governors, blade-cutting machines, test procedures and instruments, and countless other facets of design and production could be applied to gas turbine development."¹⁴

Interindustry transfers of technology do not happen automatically. The effective transfer of hardware, information, or simply (but importantly) the belief that a problem is solvable requires individuals and organizations that are capable of functioning in both worlds and have the incentives to do so. It also requires that these individuals and organizations are acceptable to the other individuals and organizations with which they interact, and that they are capable of speaking the same technical language. Technological innovation is, in Christopher Freeman's phrase, a "coupling process" that occurs at the interfaces between science, technology, and the market. This does not take place solely through intuitive flashes: "It is a continuous creative dialogue over a long period of research, experimental design, and development."¹⁵

Supply and Demand: The “Push” and the “Pull”

The first chapter outlined the deficiencies of technological determinism. As we have seen, social constructivists have stressed the importance of social, economic, and political forces in shaping technological change. And as was noted a few pages ago, contemporary scholarship has moved away from the “great person” approach to the history of technology. To be sure, many technologies owe their existence to the inspiration and hard work of individuals, including the unsung heroes who were responsible for the myriad improvements necessary for the realization of a new technology. But surely more is involved than their efforts. After all, human ability is presumably spread evenly throughout cultures and historical epochs, yet significant technological changes are not equally distributed over time and place. Thomas Edison’s genius produced 1,093 patents, and some of his inventions transformed the world. Had he been born in ancient Rome or dynastic China, he might have helped to design aqueducts or sections of the Great Wall, but it is unlikely that his talents would have changed the course of Roman or Chinese history. Geniuses require appropriate social settings for the realization of their talents.

What kind of social system is required if inventive ability is to flourish? Why does technological innovation occur in some places and times and not in others? In beginning to answer these questions, it is helpful to apply to technological change the concepts that have been so useful to economists: supply and demand. Everything from fundamental scientific breakthroughs to minor refinements serves to “push” new technologies into the world. Still, simply having an available supply of new devices and techniques does not guarantee that they will be used. Many examples of technologies that languished because they were “ahead of their time” can be cited. The pneumatic tire was patented in 1845 and then forgotten until it was reinvented by John Dunlop in 1888. DDT was first synthesized in 1874, but it was not put to use as an insecticide until 1941. Several decades elapsed before the laser passed from being a laboratory curiosity to a practical device

used for everything from supermarket scanners to instruments for microsurgery.

For a technology to make the transition from the potential to the actual requires not just that it exist; there must also be a desire for it, coupled with the ability to pay for it. Economists call this “effective demand.” Seen in this light, technology is like any other good or service; it will not be produced unless some individual, group, or organization wants it and is willing to buy it. Technology is “pushed” by a variety of forces, but it also has to be “pulled” by effective demand. To understand why certain technologies have flourished while others have languished it is therefore necessary to consider the configuration of a society and the way in which it determines the effective demand for particular technologies.

The most influential research on the importance of effective demand inducing technological change was done by Jacob Schmookler.¹⁶ By examining a long series of patents in various industries, Schmookler found that their emergence was closely related to the level of demand for the products of these industries. To take one straightforward example, inventors’ interest in improving the horseshoe was strong when the horse was a primary means of transportation, but interest evaporated when the steam engine and the internal combustion engine began to displace it.¹⁷ Although Schmookler’s study was conducted more than fifty years ago, several studies have supported his thesis; for commercial enterprises, anticipated profits and the perceived size of a market are major drivers of technological innovation.¹⁸

An example of the importance of demand inducing technological development can be extracted from the history of photography in the nineteenth century.¹⁹ For centuries, painters and scientists had made use of the camera obscura, a darkened room into which light was admitted through a pinhole, resulting in the projection of an inverted image of an outdoor scene on the opposite wall. Later developments substituted optical lenses for the pinhole, which made for a sharper image. Photographs were first produced during the 1820s and 1830s when pioneers such as Niepce, Daguerre, and Fox Talbot devised chemical emulsions that preserved the image on paper or a metal plate. But the rapid growth of photography cannot be attributed simply to the supply of these inventions. At this time, social changes were sweeping across Europe, resulting in the ascendance of a new social elite, the

property-owning commercial and industrial bourgeoisie. The members of this group had a keen desire to flaunt their affluence by taking on characteristics of the old aristocracy. For the latter, a key artifact of their status was the painted portrait; we have all seen renditions of persons such as the Eighth Duke of Puddleswallop hanging in our local museums. But many of the rising bourgeoisie lacked the money or the time for such symbols of their importance, and, in any event, there were not enough skilled portrait painters to serve the needs of this growing group of people. Their aspirations were therefore met by the photographic portrait studio, where the subject posed with the trappings of upper-class status, such as rich draperies and elegant furniture.

In the later decades of the century, new and cheaper methods of photography emerged to meet the demands of poorer yet increasingly affluent people, such as American immigrants who wanted portraits that could be sent back home. Today, the effective demand produced by a great mass of consumers has stimulated the development of a huge variety of photographic apparatus, ranging from ubiquitous mobile phone cameras to far more sophisticated digital cameras.

Good business practice is often implicitly based on the realization that successful technological development requires the presence of effective demand. One English study found that the key determinant of a firm's innovative success was an understanding of customer requirements. This meant that from its very inception, a new product or process had to be developed with an eye toward meeting the needs of actual or potential customers. This apparently is an infrequent occurrence; one study found that many inventions were commercial flops due to an inability to evaluate the true extent of demand. All too often entrepreneurs were so infatuated with an invention that they failed to realistically assess the nature of the market.²⁰ This kind of tunnel vision is a major reason that, at most, 2 to 3 percent of patents meet with any degree of commercial success.²¹

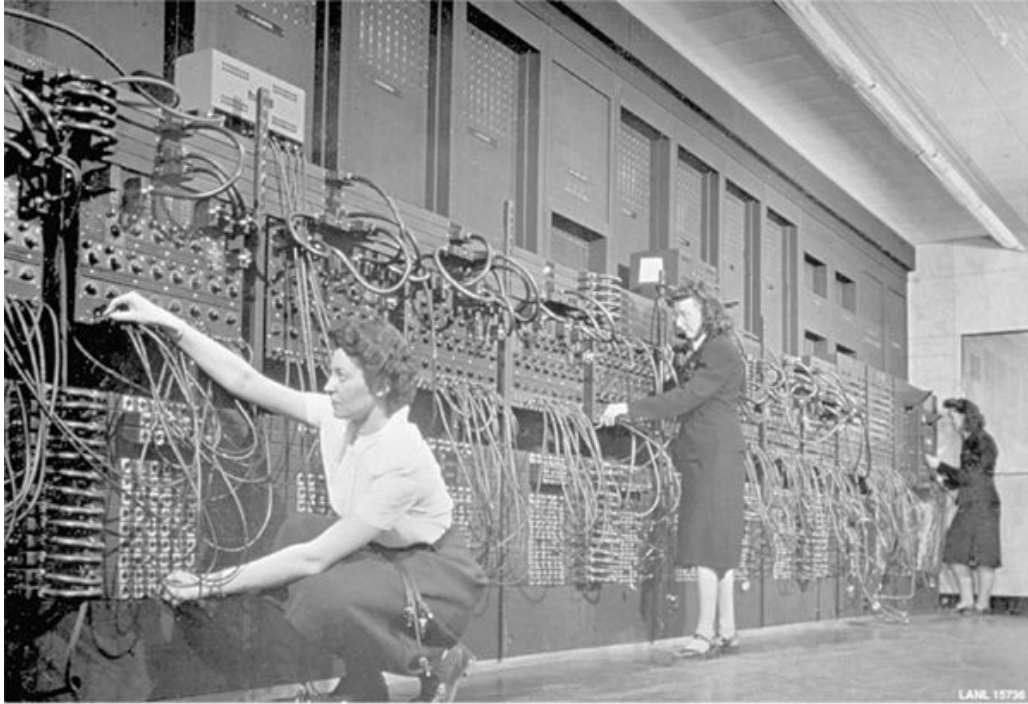


Corbis

The opulent interior of a nineteenth-century photographer's portrait studio.

Belated Demand: The Question of Market Timing

At the same time, however, gauging the potential demand for a new product can be a tricky task. Many of today's "essential" technologies were not at first recognized as such. When in the late 1930s Chester Carlson attempted to interest established business machine manufacturers in his photocopying device—the first Xerox machine—they were of the uniform opinion that there was no point in employing complicated apparatus and chemicals simply to replace carbon paper. And even inventors can badly misjudge the ultimate consequences of their own creations. Alexander Graham Bell initially thought that the telephone he invented would primarily be used to transmit operas and other musical performances from the concert hall to the home.²² Edison at first believed that one of the main applications of his phonograph would be to record the last words of dying men. We can also take note of the judgment of Howard Aiken, the director of the team that built one of the world's first computers, who in the early 1950s prophesied that in the foreseeable future, the total need for computers in the United States could be met by no more than a half-dozen machines. In similar fashion, before 1950, Thomas J. Watson, the president of IBM, was of the opinion that there would be no commercial market for computers.²³



Corbis

ENIAC, a first-generation electronic digital computer, was programmed by plugging and unplugging cables.

The history of radio also shows how a technology may be put to uses not envisaged by its inventors. When equipment for sending and receiving radio waves was first developed during the late nineteenth century, no one imagined that it would be used for commercial broadcasts. The first transmitters and receivers were devised for purely intellectual purposes—in order to test the validity of James Clerk Maxwell’s theories about the nature of electromagnetic waves. Only after the passage of more than a decade did some visionaries perceive a commercial use for radio apparatus, and then their imaginations were limited to the use of the radio for ship-to-shore communications. Decades passed before the idea of broadcasting to a mass audience emerged.²⁴

What are we to make of these examples? They seem to refute the theory that technologies are primarily the result of “demand-pull,” for all of the technological developments just described emerged in the absence of apparent demand for them. Perhaps we can salvage the demand-pull theory by distinguishing two different kinds of technological advances. The first kind consists of refinements and improvements to an existing way of doing

things, while the second (and far less frequent) is the truly revolutionary breakthrough—the internet, digital computer, radio, telephones, and the like. In cases such as these, the very novelty of a revolutionary breakthrough makes it difficult to determine what its ultimate uses will be and who, if anyone, might be a future customer. By contrast, advances of the first kind occur within a known context; the basic technology is already in use, and there are likely to be people and business firms that want, and are willing to pay for, the new wrinkles that promise to improve an existing technology. Manufacturers of smartphones, for example, introduce new models on a regular basis even though the enhancements may be relatively trivial. Improvements of this sort therefore have a predictable market. Conversely, radically new technologies confront a great deal of uncertainty. They may satisfy a latent need, or they may create a new one. They may also sink without leaving a trace. They are flights into the unknown, and it is hazardous to guess what sort of a reception they will meet. If nothing else, they confirm the old Chinese saying that it is dangerous to make predictions—especially about the future.

How Market Economies Drive Technological Innovation

The forces that “push” and “pull” technological advance do not exist everywhere or in equal measure. In many places and at many times, the distribution of wealth and power retarded these forces, resulting in a slow pace of technological advance. Moreover, the particular technological advances that do occur usually reflect a society’s general configuration of wealth and power.

In the European Middle Ages, the landowning aristocracy and Church officials controlled most of the wealth and wielded great power. The monastic orders often played an important role in land clearing, farming, and the construction of mechanical devices, but for the most part, the religious and secular establishment showed little interest in such matters. While the era gave rise to significant technological advances in water power, mechanical clocks, and weaponry, its most evident technological triumph was the great symbol of the traditional order: the Gothic cathedral.

As European history unfolded, the interests and demands of a growing merchant class led to the development of technologies that eventually surpassed even the soaring cathedrals. The great technological innovations that began in the mid-fifteenth century with improvements in shipbuilding and ocean navigation were closely associated with the rise of capitalism and the emergence of a market system. A market system organized around the principle of private property was of crucial importance for the stimulation and guidance of inventive and innovative abilities, as well as their application to production.²⁵

One of the strongest accolades to the technological dynamism of capitalist society can be found, of all places, in *The Communist Manifesto*. With unfeigned admiration, Karl Marx and Friedrich Engels note that²⁶

The bourgeoisie, during its rule of scarce one hundred years, has created more massive and colossal productive forces than have all preceding generations together. Subjection of Nature’s forces to man, machinery, application of chemistry to industry and agriculture, steam-navigation, railways, electric

telegraphs, clearing of whole continents for cultivation, canalisation of rivers, whole populations conjured out of the ground—what earlier century had even a presentiment that such productive forces slumbered in the lap of social labour?

In the time of Marx and Engels, and in our own era, a market economy driven by the activities of self-interested businessmen has produced the most receptive environment for technological innovation. There are several reasons for this. First, a market economy will stimulate inventive efforts, for it promises financial rewards to those able to meet the needs of consumers. For example, somebody invents a better mousetrap in the hope of selling it in the market. If the demand is there, eager customers will buy it. Everybody is better off: consumers have a better mousetrap, while the inventor gets rich and retires to Palm Springs, and nobody worries about how technological advance has lowered the quality of life for mice. Second, a market economy is characterized by the presence of numerous competitors. Under these circumstances, a producer is strongly motivated to develop and apply new technologies in order to make better products and to reduce production costs. Failure to do so may result in the eventual collapse of the enterprise, as the history of many once-successful firms demonstrates. Finally, a market system is particularly effective in eliciting the production of the auxiliary items necessary for technological innovation. A new technology will require special materials, components, and services. Because of its responsiveness to new sources of demand, a market economy is well suited to meet these requirements.

Obstacles to Innovation in Centrally Planned Economies

The advantages of a market economy in stimulating technological advance are further demonstrated by an examination of centrally planned economies. For decades, the economies of the Soviet Union and the People's Republic of China were organized through the mechanisms of central planning, but during the 1980s, it became painfully evident that these mechanisms were fatally flawed. One of the chief manifestations of that failure has been a retarded technology. It cannot be denied that the Soviet Union produced some impressive technological achievements, most notably in its space and military programs, while China made significant progress in industrializing an impoverished country, but taken as a whole their level of technological development remained stagnant while the United States, Western Europe, and Japan moved rapidly forward.

The backwardness of centrally planned economies has had significant political repercussions. In China, dissatisfaction with the pace of technological and economic advance led to a retreat from centralized planning and a much greater scope for market-based economic relations. In the Soviet Union, the fear of falling even further behind the West motivated the Gorbachev regime to introduce some elements of a market economy and to attenuate the role of central planning. But these efforts were not enough, and within a few years the Soviet Union ceased to exist. In the countries of the former Soviet Union and in China, it has become evident that market-based reforms have made major contributions to economic and technological development, albeit at the cost of greater economic and social inequality, as the recent histories of the two nations have shown.

Many of the difficulties experienced by centrally planned economies in achieving technological advance have been the result of a basic tension between their system of economic management and the requirements of technological innovation. Centrally planned economies rest on the assumption that economic activities can be reduced to predictable routines. But the course of technological innovation is notoriously difficult to predict.

The bureaucratic procedures that work tolerably well for the administration of routine productive tasks usually fail when they are applied to technological innovation. A planning agency can set goals and quotas for the production of established goods, and various ministries can oversee the actual operation of individual enterprises through routine bureaucratic administration. But these procedures work less well when innovation is the goal. Innovation is an activity full of risk and unpredictability, and it cannot easily be accommodated to preprogrammed structures and activities.

To make matters worse, centrally planned economies attempt to motivate workers and managers through the allocation of rewards that create disincentives for technological innovation. A factory manager typically receives bonuses for the fulfillment and overfulfillment of quotas for established products, as given by the central plan. The production of an innovative product is not rewarded, for it has not been stipulated by the plan. The uncertainties that surround technological innovations create risks for those who seek to develop new products and new ways of doing things, but these risks are not matched by commensurate rewards for those who take them.

Noneconomic Sources of Technological Advance

It is not the intention here to convey the impression that only market forces can produce technological innovation; as we shall see, government institutions have become increasingly important sources of technological advance. And no inference should be made that the historical superiority of a market economy in promoting technological advance makes it a superior system in general. There is more to life than technological advance, and, as we have already seen and shall see some more, both capitalism and the market have produced technologies that have been detrimental to people and the environment.

Furthermore, technological innovation cannot always be traced to economic motives or even to the desire to address practical problems. To be sure, we tend to think of technology as the result of efforts to solve problems of this sort; after all, technology has already been defined as the product of knowledge that is used in order to get something done. The very word “technology” conjures up images of useful devices, and technology’s practitioners—engineers, managers, and skilled workers—are often viewed as a serious bunch, sitting rigidly in front of computer terminals, making precise measurements, and, above all, applying their talents to the solution of practical problems that are usually tied to economic concerns.

The Spirit of Play and Curiosity

In fact, even the most practical of inventions may owe their origins to a spirit that seems more closely connected to play than to “productive” work. When Willis Whitney served as the first director of the research laboratory of the General Electric Company, he often asked his scientists and technicians there if they were “having fun.” For Whitney, “fun” was working on problems that had stumped everyone. Pursuing these problems was nothing less than the most exciting thing that a person could do.²⁷

Consider, too, one of America’s most famous inventors, Benjamin Franklin. With typical American pragmatism he wrote, “Utility is in my opinion the test of value in matters of invention, and that a discovery which can be applied to no use, or is not good for something is good for nothing.”²⁸ Franklin’s inquiries into the nature of electricity did result in one useful device: the lightning rod, which saved many a building from destruction. But his other inquiries had a less immediate payoff. Although Franklin devised a number of devices that helped him to learn more about the nature of electricity, decades passed before electricity had any practical value. Indeed, he was “chagrined a little that we have been hitherto able to produce nothing in this way of use to mankind.”²⁹

Later events proved him wrong, although he never shared in that knowledge. Still, the pursuit of useful innovations could not have been the prime motive for Franklin’s inquiries. Franklin was an amateur in the literal sense of the word: a person who pursues an activity for the sheer love of it. For many years, the leisure-time pursuits of amateur scientists such as Franklin sustained research into the nature of electricity despite the absence of direct applications, yet these “idle” intellectual efforts were essential to the subsequent invention of a great variety of useful devices.

A century after Franklin died, a young man of 17 climbed a cherry tree and turned his imagination to possibilities that only a few had dreamed of. The year was 1899, and the young man was Robert Goddard, who was to be the inventor of the liquid-fueled rocket. As he recalled in later years, “It was one of the quiet, colorful afternoons of sheer beauty which we have in October in New England, and as I looked toward the fields at the east, I imagined how wonderful it would be to make some device which had even

the possibility of ascending to Mars, and how it would look on a small scale, if sent up from the meadow at my feet.... I was a different boy when I descended the tree from when I ascended, for existence at last seemed very purposive.”³⁰ At that time, and for many years to come, Goddard could scarcely have imagined the products of that October vision: orbiting satellites for global communication links, weather prediction, global positioning systems, and the development of terrifying new weapons. Throughout his life Goddard continued to be energized by the dream of space travel for its own sake; practical consequences were at best a secondary concern.



Archive Photos/Getty Images; SpaceX/Alamy

The realization of a vision: Robert Goddard and his first liquid-fueled rocket, the progenitor of today's SpaceX rocket.

Government and the Promotion of Technological Advance

It also should be noted that even in a predominantly market-oriented, capitalist society such as the United States, not all technologies have been generated and shaped by market forces. Chapter 18 will take up this issue by examining the role of the government in promoting technological change. At this point, it will only be noted that technologies developed outside the constraints of the market system are less likely to be shaped by concerns about costs. Firms operating in a market environment know that minimizing costs is essential to success. Technologies that hold down production costs are quite appealing, as are technologies that expand sales by lowering the cost of the product itself. The Ford Motor Company during the glory years of the Model T is a striking example of a firm that owed its success to the use of new technologies in order to lower costs. This process also has been dramatically demonstrated in recent years as technological advances in the design and production of integrated circuits have led to sharp declines in the price of personal computers and a concomitant expansion of this market. At the same time, however, there are large sectors of the economy where prices and the costs of production are secondary concerns. As a result, the pattern of technological development can be quite different. This has been particularly evident in the defense industry, where the presumed dictates of national security have spurred the deployment of staggeringly expensive military technologies. To take a particularly striking example, a single Air Force F-22 fighter costs U.S. taxpayers \$412 million (when R&D and testing costs are taken into account) and requires 30 hours of maintenance and an expenditure of \$44,000 for every hour it is in the air.³¹ In a climate where only the presumed best will do, there are strong tendencies to “gold plate” weapons systems and to have little concern for cost constraints.

This tendency is not confined to the military sector. In recent years, there has been a mounting concern about the financial costs of modern medical technologies. Some medical technologies, such as antibiotics, have undoubtedly lowered the costs of medical care, but many others have had the opposite result. When faced with a choice between controlling medical expenses or saving lives and alleviating pain through the use of sophisticated technologies, it is difficult for any individual or society concerned with the

well-being of its members to put the former ahead of the latter. It is thus no surprise that about half the growth of health care spending that occurred during the second half of the twentieth century can be attributed to the use of new technologies.³²

The case of military and medical technologies brings us back to the necessity to consider the political and social context of technological choice. Economic considerations, important as they are, are not the sole basis of decisions regarding the development, selection, and use of particular technologies. Nor does technology develop according to its own internal dynamics. Technologies are social creations, and any successful attempt at understanding why particular technologies are created, chosen, and used must take into account their social context. Having made this basic point, we will pursue the matter a bit further by looking at the processes through which technologies spread and take hold. But before we do so, we need to consider one more source of technological change: scientific advance. This will be the topic of the next chapter.

QUESTIONS FOR DISCUSSION

1. In your opinion, how well does the social construction approach explain technological innovation? What technologies seem well suited to the application of this perspective? Which do not?
2. In times past, inventors like Edison, Morse, Tesla, and the Wright brothers were treated as celebrities. Can you name any contemporary inventors? Why do individual inventors appear to be less prominent today?
3. A person with a heart problem needs a pacemaker but is unable to pay for it. What, then, is the source of effective demand for this technology? Who ultimately pays for it, and why?
4. As a would-be inventor or entrepreneur, how would you go about ascertaining whether or not a new technology is likely to find a receptive market?
5. If you were the leader of a developing country, what sort of changes would you try to institute in order to accelerate the pace of technological innovation?

CHAPTER FOUR

Scientific Knowledge and Technological Advance

One of the most common beliefs about technology is that it is simply “applied science.” There are certainly many examples that can be cited in support of this view. Modern medical practices have been strongly influenced by fundamental discoveries in biology. The development of the transistor depended on a thorough understanding of quantum mechanics. Synthetic materials have been made possible by research into polymer chemistry. But one should not be content to rest with these examples. When the full spectrum of technological advance is considered, it becomes evident that science does not always play the decisive role in the development of technology. Indeed, many are the times when technological advances have taken place without the benefit of scientific knowledge. Conversely, on some occasions scientific advance has depended on prior technological achievements. In this chapter, we will look at the complex and shifting relationships between science and technology to come to a better understanding of how they differ, as well as the ways in which they have influenced each other.

The Historical Separation of Science and Technology

The definition of technology that was offered in the first chapter stressed that technology is based above all on the application of knowledge. But not all knowledge need be derived from scientific research. It is certainly true that today much of the knowledge required for technological advance is derived from scientific inquiries. Still, when the full history of technology is surveyed, it is apparent that most technologies have been developed and applied with little scientific input. The ancient Greeks made important contributions to many sciences—most notably astronomy, optics, and acoustics—as well as producing major advances in mathematics. Greek technology also progressed through innovations in agriculture, building construction, mining, the refining of metals, and military equipment. Yet none of these innovations drew to any significant degree on Greek science. Moreover, the Greeks' technological achievements were far less impressive than their scientific achievements, again indicating the lack of connection between the two. This lopsided pattern of development continued with the Romans, although in reverse. Roman engineering, manifest in the construction of great aqueducts and roads that are still in use today, reached a high level of development through the use of established principles.



Image Source/Getty Images

The Pont du Gard, an aqueduct near Nîmes, France, stands today as one of the triumphs of Roman civil engineering.

The European Middle Ages were a time of slow but significant technological advance. Improved agricultural practices were introduced, and the power of wind and falling water was used for everything from grinding grain to polishing metal. An effective horse collar allowed the literal harnessing of another important source of power. Soaring cathedrals were built in many parts of Europe, where they continue to be a source of awe and inspiration. Again, these achievements owed nothing to the scientific inquiries of the time. In fact, the designers and builders of the cathedrals apparently did not even have knowledge of multiplication tables. Then, too, there was little that technology could have drawn on, for medieval science exhibited little of the dynamism of medieval technology.

At about the same time, blacksmiths in parts of the Middle East were using steel superior to anything made in Europe. The swords and other edge weapons that they made from the steel first produced in Damascus (the capital of present-day Syria) combined a hard cutting edge with the flexibility necessary for an effective weapon. Yet it was only late in the twentieth century that the metallurgical principles underlying Damascus steel were

discovered. Although it was unknown to the swordsmiths of the time, minute quantities of impurities, vanadium especially, made an essential contribution to the unseen processes that gave the steel its desired qualities. Consequently, when the composition of imported iron ore changed, the steel made from it lacked the desired characteristics. Unable to draw on modern metallurgical knowledge, traditional swordsmiths could not make the necessary adjustments, and the “secret” of Damascus steel was lost for centuries.¹

The disconnect between scientific and technological development continued through the succeeding centuries, but there were some points of tangency. During the fifteenth and sixteenth centuries, the working methods of some “natural philosophers” (as scientists were so labeled in those days) benefited from an exposure to the practices of skilled artisans. In particular, the latter’s commitment to careful observation, accurate measurement, hands-on practice, and an empirical approach to seeking the truth eventually were assimilated into the process of scientific inquiry.²

From the seventeenth century onward, scientific knowledge expanded at an unprecedented rate, but technological practices remained stagnant, largely unaided by these advances. This disconnect between scientific and technological progress is evident when France and England, two of the wealthiest and most powerful countries in Europe, are compared. By the early decades of the nineteenth century, France led the world in the generation of scientific advances, yet it lagged behind England in the practical use of steam power and the application of mechanical principles.³ All in all, this historical record led one historian of science, Thomas Kuhn, to speculate that for the bulk of human history, technology has flourished in societies where science has remained undeveloped, and vice versa.⁴ It is possible that our era is unique in its apparent ability to simultaneously support scientific and technological advance, all the while forging strong connections between them.

Studies of Contemporary Science– Technology Relationships

Even today, when the connection between science and technology is much stronger than it was in the past, a great deal of technological change takes place without substantial inputs from science. The relative unimportance of science for many technological developments was highlighted by a study that was conducted by the U.S. Defense Department in the mid-1960s. Dubbed Project Hindsight, this study assessed the extent to which pure scientific research had been essential to the development of 20 major weapons systems. In conducting their study, the Hindsight researchers began with a weapon system and traced its history backward in order to determine the key “events” that produced the knowledge that had been essential to its creation and development. The results of the study gave little credence to the commonly accepted view that scientific knowledge is the primary basis of technological development. Of the 710 events surveyed, only 2 were the result of basic scientific research, a minuscule 0.3 percent of the total.⁵ Scientific research that was specifically directed toward a particular military project was of greater importance, accounting for 6.7 percent of events, while 2 percent were the result of scientific research directed toward commercial or nondefense needs. The greatest portion of events, the remaining 92 percent, owed little to concurrent scientific research, and relied almost entirely on established scientific concepts and principles.

Nearly 40 years later, a group of researchers conducted a similar study, dubbed Project Hindsight Revisited, in which they surveyed the processes involved in the design of the Apache helicopter, the Abrams battle tank, the Stinger antiaircraft missile, and the Javelin antitank missile. Although the researchers did not attempt to determine the role of basic scientific research in the design of these weapons, their report noted that most of the relevant research had been done well before these projects were initiated, and that very little basic research had been done in order to address specific design issues.⁶

Although it showed that technology’s connection to science had not been

as straightforward as is often assumed, one should not draw sweeping generalizations from this study. The authors of the original Hindsight project, as well as a number of its critics, were quick to note that the long-term influences of scientific research were not captured by the study's methodology. Project Hindsight considered only the effects of scientific research conducted for the most part after 1945, thereby removing from consideration the immense body of scientific knowledge that had accumulated before that time. The study's researchers found that a median delay of nine years separated the completion of a scientific research project from its technological application, even when research efforts targeted at specific missions were included. It was therefore not surprising that basic scientific research had few technological consequences during the 20-year span covered by the study.⁷

By taking a longer chronological view, another study, entitled *Technology in Retrospect and Critical Events in Science (TRACES)*, contradicted Project Hindsight by determining that a number of innovations, ranging from oral contraceptives to videocassette recorders, had been directly tied to prior scientific research.⁸ But even here, the researchers were obliged to point out that the sequence from scientific discovery to technological innovation is not linear, and that "a better understanding needs to be achieved concerning the two-way influence between science and technology."⁹

How Technology Differs from Science

If nothing else, these studies show that the connection between science and technology is not adequately captured by the common belief that technology is simply applied science, and that scientific discoveries quickly and easily give rise to technological applications. Some technologies draw directly on scientific research, while others make little use of it. This is rather obvious. Of greater significance is the fact that science and technology are quite different in their basic natures. This makes the translation of scientific knowledge into technological application a difficult and complex process.

The Pure versus the Practical

Whereas science is directed at the discovery of knowledge for its own sake, technology develops and employs knowledge in order to get something done. The content of the knowledge may be rather similar, but different motivations underlie its pursuit and application. Here, of course, we are on slippery ground; it is often extremely difficult to discern the motivations underlying a person's activities, and it may well be the case that a particular engineer may be driven by the same desire to understand something for its own sake that animates the work of a pure scientist. Motives are often mixed and complex.¹⁰

Much of the prestige accorded to science is the result of its supposed purity; science is thought to be an intellectual venture free from political, organizational, and economic constraints. The insulation of scientists from the demands of their patrons confers a sense of higher ethical standards; scientists are beholden to nothing but the internal demands of science. A great deal of recent scholarship has sharply questioned this assumption. As has been the case with some current studies of the history of technology, science has been described and analyzed as a social construction. From this standpoint, scientific inquiry is not a disinterested, fact-driven search for truth, but a human creation that has been shaped by cultural patterns, economic and political interests, and gender-based ways of seeing the world.¹¹ For uncompromising social constructivists, successful scientific outcomes may have more to do with negotiation, the support of designated authorities, and resonance with prevailing attitudes than theoretical elegance or experimental evidence. Under these circumstances, the idea that science is a "pure" intellectual endeavor cannot be supported.

The social construction of a science approach remains controversial, and, in any event, few social constructivists believe that scientific facts and theories are purely social creations that have nothing to do with underlying realities. Moreover, social constructivism is a largely academic enterprise, and most laypeople still believe in the objectivity of science and the purity of scientific motives. These qualities give individual scientists a claim to autonomy not enjoyed by other employees. Scientists are thus in a particularly favorable situation. The assumption that scientific progress leads

to material progress confers an aura of practicality on their work, while at the same time they are in a good position to resist the overt control of their work by their sponsors.

In contrast, most engineers work under tighter constraints. Their employers expect results that have immediate applications and fall within a narrowly defined range of possibilities. A scientist may abandon a theory or an experiment in order to pursue a line of inquiry that unexpectedly arises during the course of his or her research. An engineer, however, rarely has this opportunity; there may be some room for serendipity, but the bridge has to be built within a given time frame and under definite budget constraints. For this reason, what separates scientific and technological inquiries may not be the motivations of individual practitioners but the motivations of their employers and patrons.¹²

Scientific Knowledge and Technological Knowledge



AFP/Getty Images

Superconductive magnets kept at extremely low temperatures are essential components of magnetic levitation, which is demonstrated by this high-tech skateboard. Although there are several other technological applications of low-temperature superconductivity, the underlying physics of the phenomenon is not well understood.

Technology differs from science in the type and depth of knowledge it employs. The ultimate question asked of scientific knowledge is “Is it true?” For technological knowledge, the key issue is “Will it work?” Technological

problems can often be solved with no understanding of what is going on. As we have seen, throughout history many technologies were effectively applied even though the basic principles underlying their operation were poorly understood, if they were understood at all. A similar situation can be found today; high-temperature (which, in this case, means 130 K or minus 418°F) superconducting materials are beginning to be used in motors and other devices, even though the physics of the process remains something of a mystery. It is also instructive to consider the story of the great scientist Johannes Kepler (1571–1630), who developed and employed the calculus of variation in order to derive optimum dimensions of wine barrels—only to discover that these dimensions were already being employed by the coopers who actually built the barrels!¹³

Many other technological innovations seem to fall into this pattern. Although scientifically derived principles may emerge after the fact, many technologies have been guided almost exclusively by trial and error, with the successful ones informed by an intuitive sense of the right solution, and not by scientific truths.¹⁴ As Eugene Ferguson has observed, at the end of the nineteenth century there were no scientific principles that could be invoked during the design of the first motorcycles; the placement of the engine, fuel tank, and other major components could be determined only through the actual construction and operation of motorcycles, without the benefit of scientific principles or other forms of existing knowledge. Ferguson therefore makes the point that “there is often no a priori reason to do one thing rather than another, particularly if neither had been done before. No bell rings when the optimum design comes to mind.”¹⁵

How Technology Facilitates Scientific Discovery

Although we tend to think of science as the leading factor in technological advance, the reverse often occurs: scientific knowledge and discovery may be a by-product of technological achievements. The most obvious examples of technological developments playing a vital role in fostering scientific advance can be found in the provision of devices and instruments. From early telescopes and galvanometers to today's electron microscopes and computers, the products of technology have steadily increased our ability to observe and analyze the phenomena that science presents as objects of inquiry. To take only a few recent examples, the scanning tunneling microscope has allowed a much better imaging of plant and animal cells; the Hubble Space Telescope has given us new insights into the age and size of the universe and how it was created; particle accelerators have enabled physicists to obtain a better understanding of the basic constituents of matter; and magnetic resonance imaging, complemented by powerful computers, has played a key role in the rapid development of neuroscience, the study of the brain and how it functions. All in all, it is thus no exaggeration to claim that scientific "instruments shape research, determine what discoveries are made, and perhaps even select the types of individuals likely to succeed as scientists."¹⁶

Less obvious are instances where scientific advance was stimulated by a technology already in operation that defied accepted scientific explanations and theories. This process is exemplified by the story of how the steam injector contributed to the abandonment of a popular scientific theory regarding the nature of heat.¹⁷ In the mid-nineteenth century, many scientists believed that heat was the result of the presence of a substance known as "caloric." According to this theory, when caloric combined with other materials those materials became hot. Also, caloric particles were supposedly self-repellent; thus, when sufficient quantities of these particles came into contact with water, their repulsive quality resulted in water turning into steam.

While this theory had its uses, it could not explain the operation of the

steam injector that was patented by Henri Giffard in 1858. The injector used steam from the boiler to lift water into it, an operation that seemed to mimic perpetual motion for those who subscribed to the caloric theory. In fact, Giffard, who was well trained in academic science, based his injector on the Bernoulli principle, which postulated that the pressure of a fluid (in this case, steam) drops as its velocity increases. The operation of the injector was therefore the result of expanding steam producing a partial vacuum that sucked water into the boiler.

Giffard's injector was no perpetual motion machine; it used a quantity of heat that was equal to the quantity of work expended in raising water into the boiler, plus the losses due to radiation and contact with surrounding surfaces. Its operation therefore made sense only when the interconvertibility of heat and work was understood. This idea rested on the kinetic theory of heat, and it followed the first law of thermodynamics (which stipulates that, quantitatively, energy cannot be created or destroyed). The kinetic theory of heat was formulated several years before Giffard's invention but had been slow in winning acceptance. The rival caloric theory had many adherents in the scientific community, and it took the apparent anomaly of the injector to convert many of them to the now universally accepted kinetic theory of heat.

The steam injector illustrates the often subtle interactions between science and technology. The operation of the injector provided a strong stimulus for the acceptance of one scientific theory and the rejection of another. At the same time, another scientific theory had been essential to the invention of the injector. But scientific theories by themselves were not enough; the design and effective use of the injector still depended on the experiments and modifications performed by practicing engineers, for no set of theories was powerful enough to guide its design. Again, we have an example of a technology that worked even though existing scientific principles did not completely explain its operation.

This example and many others that could be cited indicate that science and engineering are still separate enterprises, although there are certainly linkages between them. Scientific knowledge can result in technological advances, while at the same time new and extant technologies can create opportunities and motivations for new scientific inquiries. Many technological developments reach a plateau due to a lack of scientific knowledge, thereby generating a clearly perceived need for fundamental

scientific research. The knowledge obtained through technological practices and applications is thus the raw material of many scientists, whose work centers on explaining technological practices at a deeper level.¹⁸

One example of this process is the invention of the laser. During World War II, the United States and other countries were engaged in a major effort to develop radar as a means of detecting enemy ships and aircraft. While participating in the development of radar technology, scientists used the knowledge that they had gained to make significant advances in microwave spectroscopy, which allowed a more accurate determination of molecular structures. One of the main developers of microwave spectroscopy, Charles Townes, although nominally a physicist, continued to work on technologies for the generation of microwaves. In 1954, he and his co-workers created a device they called the “maser” (for “microwave amplification by stimulated emission of radiation”). In 1958, he and a former student published a paper that outlined how the principle of the maser could be extended into the region of infrared, visible, and ultraviolet light. These ideas were the foundation for the laser (the acronym for “light amplification by stimulated emission of radiation”). At first, the laser was the classic example of an invention looking for an application. But in succeeding years, the laser became the basis for a host of technologies ranging from scanners used at checkout counters to devices used for the surgical rejoining of detached retinas. In short, the development of one technology (radar) gave rise to scientific advance (the determination of molecular structures through microwave spectroscopy) and at the same time provided a scientific foundation for an entirely new technology (the laser).¹⁹



O. LOUIS MAZZATENTA/National Geographic
Creative

One of the unanticipated uses of the laser is its use as a surgical instrument for the correction of faulty vision.

As this example indicates, the relationship between science and technology, far from being linear, may be one characterized by considerable back-and-forth movement. This feedback between science and technology may be a fundamental source of their dynamism.²⁰ This complex reciprocal relationship can be seen in the highest accolade for scientific achievement, the Nobel Prize. Although there is no prize for technology per se, a large portion of the prizes for chemistry, physics, and medicine have in fact been awarded for the invention of new devices and techniques. Some of them eventually resulted in commercially viable products, while others were used for further scientific inquiries.²¹ In sum, when science and technology have gone their separate ways, as has been the case for most of human history, they develop more slowly than when they interact with each other, as they have done to an increasing degree during the present era.

Legitimizing Science through Technology

There is a final and less immediately evident contribution that technology has made to scientific progress. Although an effort has been made here to demonstrate that science has not always been decisive in the development of new technologies, the opposite is widely believed. To a significant degree, this faith in the practical consequences of scientific research has given science the immense prestige and legitimacy that it enjoys today. Many areas of scientific inquiry have become increasingly expensive propositions. To take two admittedly extreme examples, the James Webb Space Telescope, which is slated to replace the Hubble Space Telescope in 2018, is expected to cost \$8.7 billion over a 5-year period, while Europe's Large Hadron Collider carried an initial price tag of \$4.9 billion. Expensive programs need sponsors with deep pockets. Although neither project is expected to generate technological spinoffs, many other high-priced research programs would die for lack of funding without the promise of some practical paybacks. Over the years, quite a lot of sophisticated and expensive biological research has been justified on the grounds of its potential contribution to curing cancer—a hope that has yet to be realized. Biological research is hardly unique in this aspect, as scientists have become quite proficient in writing grant applications that stress the potential useful outcomes of their abstract inquiries.

Financial support, however important it is to the maintenance of scientific inquiry, is only part of the picture. The willingness of government agencies to grant money for scientific research and of citizens to have their taxes used in this manner is indicative of a widespread belief in the legitimacy of scientific research. This legitimacy is in large measure the product of the presumed ability of science to ultimately produce practical results. These ascribed powers of science have been analyzed by Langdon Winner:²²

[The ultimate success of science] must be accounted to its fulfillment of Baconian ambitions—the delivery of power. Other modes of knowing have been able to give an intelligible, systematic, aesthetically pleasing picture of reality. If science had only been able to accomplish this and

nothing more, it is likely that it would have been supplanted by yet another philosophy of inquiry. But in the West at least, the test is not so much what do you know? or how elegant is your interpretation of worldly phenomena? but rather, what can you actually do? This is the conclusive factor, the reason that, for instance, social science has never fully established its credentials in the halls of science.

Science succeeds over rival ways of knowing—poetry, religion, art, philosophy, and the occult—not by its ability to illuminate, not even by its ability to organize knowledge, but by its ability to produce solid results.... In the last analysis, the popular proof of science is technology.

This expected ability of science to “deliver the goods” is somewhat paradoxical, for science as a system unto itself responds rather poorly to economic needs. This has even been made into a virtue by many scientists who pride themselves on their insulation from the crass demands of the marketplace. As we have seen, the autonomy of scientists has been legitimized by the conception of science as a detached exercise in free inquiry. But it is also the case that the unpredictable nature of scientific discovery often precludes the possibility of useful discoveries being produced to order.

Scientific research, especially when directed at the discovery of basic principles, is an uncertain endeavor that cannot be guided by schedules and routinized procedures. This is illustrated by the response of one researcher who was offered more research funds by an officer of his company in the hope that the conclusion of a particular project could thereby be hastened. The researcher replied that it would be just as logical to expect that eggs could be made to hatch in half the normal time if twice as many hens were recruited to sit on them. Not only are the paths of scientific discovery full of twists and turns, but many of them terminate in dead ends. Of course, technology may also be incapable of solving the problems presented to it. If it were otherwise, we would have a cure for cancer by now. But most technology is directed toward the solution of specific problems, which narrows its scope and makes it a more predictable enterprise than science.

Scientific knowledge often ends up being extremely useful to technology, but in most instances that is not why it was produced. Scientists typically

create knowledge for other scientists. Their efforts are focused on the testing of theories and the solution of problems that have been generated by previous scientific inquiries. If scientific knowledge is used for technological applications, it is because engineers and other technologists have appropriated it for their own use. In most places where science and technology meet, engineers and technicians “pull” knowledge out of science. Only in rare instances is knowledge directly relevant to technological application “pushed” by science itself.²³

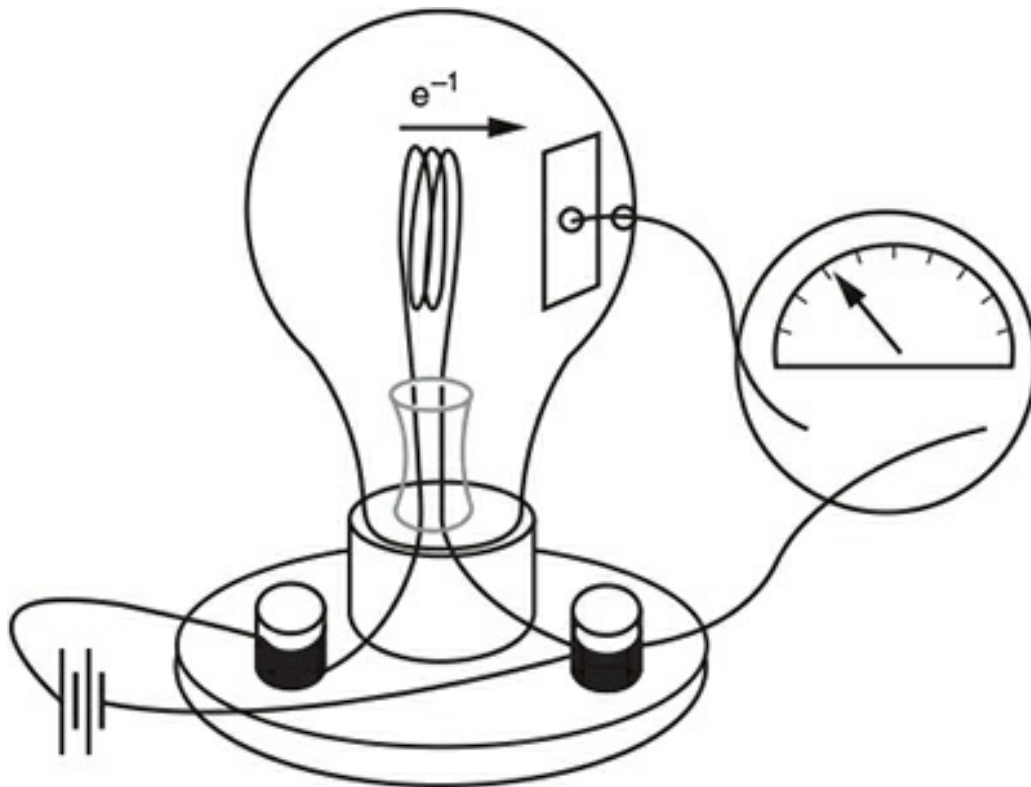
When knowledge is “pushed” from science into technology, it often happens indirectly. The transfer of knowledge from science to technology can be a subtle process, with scientific research motivating technological change by pointing out unseen problems and at the same time suggesting new opportunities. This happened in the 1930s when the evolving science of aerodynamics showed how the behavior of aircraft changed dramatically at high speeds. This research clearly indicated that conventional propeller-driven airplanes would encounter an insurmountable velocity barrier as they approached the speed of sound. At the same time, aerodynamic research indicated that proper streamlining could greatly increase the speed at which airplanes could fly, provided they had a different method of propulsion. In making these discoveries, aerodynamic researchers generated a powerful impetus for the development of jet engines that produced more power and did not have the inherent limitations of existing power systems.²⁴

The Translation of Science into Technology

Today, many technologies make heavy use of the products of scientific inquiry. Much of this use, however, is indirect. A great deal of scientific information finds its way into technological practice through the education of engineers.²⁵ The findings of basic scientific research eventually appear in handbooks, university courses, and textbooks. Much of the scientific knowledge presented in these ways is eventually drawn on during the course of technological development.²⁶

Even here there can be problems. It has been argued that a significant amount of engineering education has been distorted by overreliance on science-based instruction. This has led to a devaluation of nonverbal thought, an excessive stress on mathematics, and an unwillingness to tackle problems that do not have a single unique solution.²⁷ Scientific thinking converges toward a single (if temporary) set of theories, while the history of technology is replete with examples of the old saying that there's more than one way to skin a cat. An excessive focus on the principles and methods of science may therefore restrict creativity and lead to an overly rigid approach to the solving of technological problems.

There is no getting around the fact that despite all that they have in common, science and technology usually operate in different worlds. If the two are to share in a productive symbiosis, they must be sustained by continual efforts to span the differences that separate them. In many cases, technological development has been stimulated by the presence of individuals and organizations that simultaneously participate in scientific and technological communities. Their primary role is to serve as translators, "decoding information generated in one system and transforming it into information usable in another."²⁸



Volti, Society and Technological Change, 8e, © 2017
Worth Publishers

The Edison effect: Thomas Edison inserted a metal plate into a bulb and noted that when the power was turned on, a meter attached to the plate indicated that current was flowing through the air between the glowing filament and the plate.

This process can be seen in the events that culminated in the invention of the vacuum tube, which in the pre-transistor era was an essential part of radio and television technology. The story began with Edison's invention of the light bulb.²⁹ While trying to determine why dark deposits were forming on the interior walls of the bulbs, Edison found that the needle of a galvanometer deflected when a wire probe was placed in a circuit between the galvanometer and the bulb's glowing filament. Edison did not understand what was producing the flow of electrical current through thin air, although he patented the modified bulb for use as a voltage indicator. (Many years later, the realization came that the current was produced by the migration of electrons from the negatively charged filament to the positively charged probe.)

Nothing practical came of Edison's discovery until John Ambrose Fleming renewed his acquaintance with the modified bulbs. During the 1880s and 1890s, Fleming had conducted a number of experiments using them; his sporadic efforts produced useful scientific knowledge, but no technological applications. Things began to change in 1899 when he became technical adviser to Guglielmo Marconi's Wireless Telegraphy Company. At that time, the chief need of the infant radio industry was for a detector that could efficiently convert the weak oscillatory current of radio waves into direct current. After a few years' work with other devices, in 1904, Fleming came to the sudden realization that the specially equipped light bulbs with which he had previously worked might be used for this purpose. His hunch proved to be correct, and the "oscillation valve," as he named the device, began to be commercially used for the detection of radio signals a short time later.

Fleming had not been the only one to experiment with modified light bulbs, but he had been uniquely situated to act as a "translator" between science and technology. He was not an inventor like Edison or a full-fledged scientist like other experimenters. Rather, he was a scientifically trained engineer and teacher who was closely associated with the electrical industry and with engineering-training institutions. These separate but interrelated roles gave him the knowledge and the motivation to convert a scientific curiosity into a practical technology.



Corbis

John Ambrose Fleming with a vacuum tube diode.

The Commonalities of Science and Technology

Up to now, this chapter has stressed the differences between science and technology, but they also share common characteristics. Both science and technology are based on the gathering of knowledge, and they both advance through the cumulative development of that knowledge. Isaac Newton is reputed to have said that he could see farther because he stood on the shoulders of giants. That is, his scientific discoveries were based on knowledge produced by earlier scientists. The same holds true for modern technology. Just as the scientific achievements of an individual chemist owe a great deal to the past research efforts of other chemists, the work of an aerospace engineer draws upon the accomplishments of other aerospace engineers.

More generally, science and technology have been nourished by a supportive culture at least since the days of the early Industrial Revolution. Although science provided few direct inputs into early industrialization, the values and attitudes of engineers and mechanics had much in common with those of scientists. As Peter Mathias has described this era:³⁰

Together, both science and technology give evidence of a society increasingly curious, questioning, on the move, on the make, having a go; increasingly seeking to experiment, wanting to improve. So, much of the significance [of the cultural climate] impinges at a more diffused level, affecting motivations, values, general assumptions, the mode of approach to problem-solving, and the intellectual milieu rather than a direct transfer of knowledge.

A key component of the shared culture of modern science and modern technology is their reliance on the rational thought processes described in Chapter 1. Although the development of both science and technology requires intuitive and other nonrational modes of thought, rationality is essential to the general methodology of science and technology. In general, a rational approach includes a propensity to challenge traditional intellectual authorities; a willingness to settle questions through observation, testing, and

experimentation; and a desire to develop exact methods of measurement.³¹

Some of the basic elements of this mode of inquiry are described by Robert Pirsig in *Zen and the Art of Motorcycle Maintenance*, where he explains how even a clearly technological task like determining why a motorcycle won't start is addressed through the use of procedures that have much in common with scientific inquiry.³² As a first step, a mechanic might formulate the hypothesis that the battery is dead; he or she will then try to honk the horn to see if the battery is working. If the horn honks, the mechanic concludes that the problem doesn't lie with the battery and proceeds to other parts of the electrical system. Should tests performed on these components show them to be in good shape, the mechanic may hypothesize that the problem lies with the fuel system and conduct tests (experiments) to check them out. And so it goes, with the formulation of a series of hypotheses and the conducting of experiments to test them. In the end the problem is isolated and perhaps fixed; if nothing else, you know what is wrong as you push your motorcycle along the side of the road.

Of course, one shouldn't take this analysis too far. Although both science and technology make heavy use of rational modes of thought, neither can be properly characterized as the embodiment of rationality. Scientific theories must be logically consistent and rationally articulated, but their ultimate source is human creativity and imagination—qualities often at a considerable distance from rational thought processes. At the other end of the scientific enterprise, the testing of these theories, there are no perfectly rational means of determining the criteria through which theories can be validated or disproved. Even empirically derived “facts” can be subject to interpretation, and general worldviews can strongly affect what is acceptable as “proof.”³³ In similar fashion, a great deal of technological advance is also the product of nonrational thought. And, as was noted earlier, the benefit or harm of a particular technology cannot always be adjudged according to criteria based on rationally determined principles; a great deal hinges on values and ethical standards that have been derived through other means.

Other commonalities between science and technology can be noted. Mathematics is important to both as a kind of language and as an analytical tool. The practice of both science and technology requires university-based training that can stretch out for many years. Also, engineers and other

technological practitioners employ organized knowledge that is presented and diffused through journals, books, blogs, and professional meetings that have many similarities to those found in the realm of science. And although engineers usually work for firms that try to retain exclusive use of innovative products and processes that were developed in-house, there can be a surprising willingness on the part of engineers to share their knowledge with engineers employed elsewhere, just as occurs between scientists.³⁴

Although the sharing of information has long been a characteristic of science, in recent years an increasing number of scientific discoveries have come to be treated as proprietary information. This tendency has been particularly evident in biotechnology, where basic research is often essential for the rapid development of biological and medical technologies. Under these circumstances, the usual distinction between basic science and technological application no longer has much meaning.³⁵ In this field, and in a growing number of others, the distinction between science and technology has become so blurred that both can be subsumed under a single rubric, “technoscience.” Since innovative, biologically based technologies can generate very large profits for the firms that develop them, these firms are likely to be reluctant to share their discoveries with the scientific community as a whole. It is not just for-profit private firms that have a reason for keeping scientific knowledge under wraps; universities are major players in industries based on cutting-edge technologies. Consequently, the research conducted in their laboratories may eventually generate substantial revenues. For universities and private firms alike, the lucrative coupling of basic research with technological application may seriously inhibit the sharing of new information, substances, and devices. These restrictions violate a basic canon of scientific culture—the free distribution of ideas and research findings—and, in the long run, they may result in a slower rate of progress for both science and technology.

Finally, at the core of the common culture of science and technology is a sense of optimism and progress within their own realms. Science and technology are dynamic enterprises that build on past successes, but they also make profitable use of their failures. An inadequate scientific theory may lead to the formulation of a better one, and a collapsed bridge is likely to provide valuable lessons that help to prevent future failures.³⁶ Above all, science is

predicated on the belief that the world is knowable, while technology is animated by a conviction that it will always be possible to do something better. Both of these beliefs contribute to the dynamic, essentially optimistic spirits of science and technology.

Although there are broad similarities between science and technology today, their coexistence is problematic, much as it has been in the past. For Melvin Kranzberg, their coexistence has been marked by the same kind of tensions and attractions that characterize the marriage of a man and a woman. In Kranzberg's words:³⁷

History suggests that science and technology, though wedded today, went through a long, indifferent courtship. They grew up independently, either oblivious to each other's existence or taking scornful note of the other's presence. When they reached the age of puberty—the scientific revolution in the case of science and the Industrial Revolution in the case of technology—a mild flirtation ensued.

The marriage, when it came at last, was a marriage of convenience and necessity, certainly no love match. Insofar as military needs helped to bring about many a daring and secretive meeting, the ceremonies when finally reached, could be called a shotgun wedding; and the couple, predictably, has not lived happily ever after.

Each partner has retained a good deal of independence, though lately both have been having identity problems. There are constant bickerings about who is contributing more to the marriage. They quarrel over mutual responsibilities, the education of their offspring, and, as might be expected, the household budget.

It is a very modern marriage. Science and technology live independently, yet coordinately, as if they had but one joint bank account and one car. Divorce is frequently discussed. It is invariably rejected, however, because the scandal would surely deface the public image of the parties, and because, I suspect, of the indisputable pleasures and the learned frivolities of the bed.

This chapter began with the assertion that technology is not simply applied science, and went on to provide some evidence for this statement. It is undeniable that technology today makes extensive use of scientific knowledge. But as we have seen, scientific knowledge often makes its way into technological practice in a very roundabout way. At the same time, a considerable amount of scientific advance stems from prior achievements in technology. Science and technology have evolved along separate paths that often intersect. At these points of intersection, each has often contributed to

the other's development. Both science and technology seem to do best when they remain in close contact, but this should not obscure the fact that in most instances they remain very different enterprises.

QUESTIONS FOR DISCUSSION

1. In 1993, the U.S. Congress canceled one of the most ambitious scientific research projects of all time, the superconducting supercollider for high-energy physics. One of the major reasons for canceling the project was its cost, which was estimated to be at least \$8.5 billion. In the years that followed, the U.S. government continued to support the International Space Station, a project that will end up costing more than \$100 billion by the time it is completed. Why has one project received financial support while the other was killed? Was the perceived scientific value of the projects the paramount concern of congressional decision makers?
2. Why have science and technology been so closely associated in popular thought? How does each of them gain from this association?
3. Monetary considerations aside, which would you find more personally satisfying: making a scientific discovery or inventing a useful technology? Why?
4. Quite a few research projects in chemistry, physics, and biology receive grants for millions of dollars, whereas most researchers in the social sciences and humanities consider themselves lucky to receive a few thousand dollars in grant aid. Why is this so? Does it represent a proper distribution of research funds?
5. Students in engineering programs typically take a substantial number of science and mathematics courses. Should some of these courses be eliminated and replaced with different kinds of courses? If so, which courses should be taken instead?

CHAPTER FIVE

| The Diffusion of Technology

A technology is of no use unless it is put to use. This is a crushingly obvious statement, but it does serve to remind us that a technology that never makes it out of a laboratory or an inventor's basement might just as well not exist. The past two chapters have examined some of the ways in which technologies have come into being; the task of this chapter is to describe how they are adopted by the individuals and organizations that actually put them to use. Our concern here is the diffusion of technologies—that is, the processes through which they spread from their initial sources into homes, factories, offices, and so forth. To begin, we will consider the diffusion of technologies from one country to another. In the second part, the focus will narrow as we look into the process of technological diffusion at the level of the individual business firm.

Technology on the Move

There is an understandable human tendency to believe that progress, technological or otherwise, is largely the result of efforts of one's own people. We exalt native scientists, entrepreneurs, and inventors, and see in their efforts the major source of our technological advance. The Soviet Union in the Stalin era carried this to ridiculous lengths when its historians claimed that their countrymen had invented everything from the steam engine to baseball, but many other countries have exhibited strains of technological nativism. The truth of the matter is quite different. Although indigenous skills and achievements are an indispensable part of technological advance, few technologically dynamic countries have been isolated from the influences of other lands. Continued technological advance requires an infusion of ideas, tools, and materials from other places, coupled with an ability to make good use of them.

Consider the world in the year 1500. There can be little doubt about what country had produced the most technological innovations up to that time. It was not England, nor was it France, Italy, or Germany. The country with the greatest heritage of inventive achievements was China. By 1500, Chinese technologists had produced not only the compass, paper, and gunpowder—the familiar textbook examples of Chinese inventive ability—but also had been responsible for such inventions as the segmental arch bridge, the chain drive transmission, the spinning wheel, watertight bulkheads for ships, printing, fishing reels, paddle wheel boats, the differential gear, earthquake detection devices, and of course the fine porcelain that takes its name from its country of origin.¹ Europe, too, could claim some significant technological advances by the beginning of the sixteenth century, most notably in mining and cathedral building, but on the whole, there could be little question where the greater degree of inventiveness had been residing.

Yet within less than two centuries, China's lead had dissipated, and the European continent exhibited the greater degree of economic and technological vitality. Much of this dynamism could be attributed to the successful adoption of Chinese inventions by European countries. Paper was

an essential complement to printing; together they made possible the rapid circulation of new ideas and stimulated the growth of literacy, which in turn directly contributed to major historical changes such as the Protestant Reformation and the spread of capitalism. The magnetic compass greatly aided transoceanic navigation and allowed the spread of European economic power throughout the world. And gunpowder helped to conquer and secure that world for the benefit of Europe.

The successful use of foreign technologies in early modern Europe was very much in accordance with long-standing historical patterns. Many of the most significant inventions used by the Western world up to that time did not originate there. The stirrup, which initiated major changes in medieval warfare and in so doing reshaped the social system, was not a Western invention, but diffused from Persia sometime after the eighth century, although it too probably originated in China.² Another vital innovation involving equine power was the horse collar; horses could not be used effectively as draft animals until it diffused from Asia to Europe at about the same time.³

Much of the economic progress of the Western world therefore can be traced to the willingness of its people to accept and make good use of technologies that originated elsewhere. By contrast, China was far less open to foreign inventions. Secure in the belief that they inhabited the “Middle Kingdom” (the literal translation of *Zhong Guo*, the name by which the Chinese called their country), the Chinese looked at the outside world with more than a trace of condescension. This attitude was particularly evident when China came into contact with the expansionary nations of Europe. During the late eighteenth century, English merchants and officials scoured the world in search of customers for the products of English factories, but they found no takers in China. The emperor made it very clear to one envoy of King George III that “there is nothing we lack.... We have never set much store on strange or ingenious objects, nor do we need any more of your country’s manufactures.”⁴

China’s ruling elite persisted in this attitude. Toward the end of the nineteenth century the scholar Kang Youwei advocated the combination of Western techniques with traditional Chinese culture. Although he won the support of the emperor, the reform movement that was initiated in 1898 was

aborted in a few months when the emperor was deposed and replaced by the reactionary dowager empress, Cixi (T'zu-hsi in the older Wade-Giles system of Romanization). The early years of the Chinese Republic (1912–1949) saw a considerable infusion of Western ideas and technologies, but these were eclipsed by Chiang Kai-shek's New Life Movement, which stressed a return to Confucian virtues as the cure for China's weakness.

Even the emergence of a Communist state in 1949 did not result in a wholehearted acceptance of foreign ideas and ways of doing things. Although a considerable amount of technology transfer from the Soviet Union took place during the early 1950s, the Chinese were offended by Russian arrogance. The political rift between the two countries closed off China's main source of advanced technology, while at the same time, Maoist ideology contributed to an increasing aloofness to the outside world and stressed self-reliance in technological matters. This attitude has changed dramatically in the years following Mao Zedong's death in 1976. In the words of one Chinese journalist, "No nation has a monopoly on culture. Cultural exchanges between nations are inevitable and irresistible.... Whatever will facilitate China's material modernization and its cultural advancement is welcomed."⁵

In contrast to China's historical ambivalence and even hostility over the use of foreign technologies, Japan after the Meiji Restoration in 1868 pursued a policy of aggressive industrialization based on imported technologies. During its early stages, Japanese industrial drive was propelled by the importation of locomotives, textile equipment, and other industrial goods. Foreign technical advice was also avidly sought; during the early years of the new emperor's reign, the salaries of foreign technicians absorbed 6 percent of the central government's budget, and 40 to 50 percent of the budget of the Ministry of Industry for the duration of its existence.⁶

As Japan's industrial enterprises began to emerge, their products were often outright copies of foreign products. At times, Japanese attempts to copy foreign artifacts produced comic results, as exemplified by the factory with a sawtooth roof that faced the wrong way so no light shone through the windows, or the tailor who stitched together a Western-style suit complete with a patch on the pants. But with mounting experience, Japanese workers and managers were able to effect substantial improvements until some of

their products were the equal of Western manufactured goods. An early example of this was the Toyoda automatic loom; it marked such an advance over existing looms that England's Platt Brothers & Co., a major manufacturer of looms, paid the 1929 equivalent of 1 million yen to obtain the patent rights.⁷ Certainly no one laughs at Japanese technology today, although the accusation is occasionally still made that the country excels in the refinement of existing technologies but produces few completely new ones.

The importation of foreign technologies also plays a large role in the story of early American industrialization. One could practically date the start of America's industrial revolution to the year 1790, when Samuel Slater, who had recently emigrated from England, used his accumulated know-how to construct the first successful mechanized spinning factory in the United States. In the years immediately following, the United States was so deficient in indigenous technological capability that many implements and techniques had to be imported. American civil engineers found it necessary to secure from England drawings and examples of devices as simple as a wheelbarrow in order to successfully construct early canals.⁸

These were not simply instances of a young and economically immature nation relying on imported technologies due to temporary incapability. Modern, quintessentially "American" innovations such as automobiles, radios, jet airplanes, compact discs, and the World Wide Web all owe their existence to pioneering efforts that were undertaken in other lands. And along with imported implements, materials, and processes, American technological development has been spurred on by an even more valuable import: people. Although a large reservoir of "Yankee ingenuity" cannot be denied, many of America's greatest technological achievements were produced by immigrants. It would take many pages simply to list some of the most prominent of these, but a small sample can illustrate the debt that American technology owes to immigrant scientists, inventors, and engineers. One of the first plastics, Bakelite, was the work of a man born and educated in Belgium, Leo Baekeland. The mathematical and engineering work of Charles Steinmetz, a transplanted German, was essential to the development of the American electrical industry. The science of aerodynamics owes much of its early development to an immigrant from Hungary (via Germany), Theodore

von Karman. The television camera was invented by a Russian exile, Vladimir Zworykin.



Ewing Galloway/Alamy

Two key figures in the history of American technology, one native born, the other an immigrant: Thomas Edison and Charles Steinmetz.

This pattern continues today. According to one study, between 1995 and 2005 more than a quarter of new engineering and technology firms had foreign-born founders, CEOs, or chief technology officers, as exemplified by Sergey Brin of Google and Pierre Omidyar of eBay.⁹ Equally important, inventors and entrepreneurs, both immigrant and homegrown, have benefited

from the services provided by legions of unsung men and women who brought their skills from other lands and in so doing helped to push American technology to new heights.

Today, a considerable amount of technology transfer occurs when firms in the economically advanced nations of the world establish factories in developing countries, some of them engaged in the manufacture of highly sophisticated electronic equipment such as computers and smartphones. For critics, the appeal of these offshore enterprises centers on the availability of cheap labor; their output consists of assembled products that require few skills on the part of the assemblers. As a result, these enterprises are little more than enclaves of modernity with few if any connections to the host country's economy and society. In contrast, a more optimistic assessment of these enterprises stresses their positive role in stimulating the development of workers' skills and technological advance. Governments that are committed to economic and technological advance know that labor gets more expensive as a country develops and workers demand their share of a rising national income. Under these circumstances, low-cost labor ceases to be a nation's main advantage. Consequently, countries like Taiwan, Korea, and China (as well as Japan in an earlier era) have made concerted efforts to upgrade the skills of their labor forces, so the quality of their employees makes up for the higher wages paid to these workers. No less important, these countries—China especially—have used multinational firms as sources of up-to-date technologies by requiring the transfer of these technologies as preconditions for allowing these firms to set up shop on their soil.¹⁰ And although it is hardly a commendable business practice, many firms, especially Chinese ones, have gained a fair amount of technological know-how through outright piracy.



Bloomberg/Getty Images

A fair amount of technology transfer may occur when advanced production lines are established in developing countries, as with this computer factory in Brazil. Whether or not these can be considered examples of appropriate technology is a matter of debate.

Clever Copyists

In calling attention to piracy and to less flagrant forms of technological borrowing, there is no intention to attribute the achievements of the United States, Japan, and today's China to technological plagiarism. It is not an easy matter to copy a technology that was produced somewhere else. Having an example of a machine or a material in front of you helps, but it hardly guarantees success. Life would be simpler and easier if technological advance were simply a matter of importing a prototype and then engaging in "reverse engineering." It does work occasionally, but all too often the process ends in frustration, as when the Chinese government built two jet airliners that may not have been direct copies of the Boeing 707 but had many similarities with it. The planes were overweight and very sensitive to changes in their center of gravity when loaded. The Y-10, as it was named, never went into series production nor was it flown in scheduled service.¹¹

The very nature of technology makes copying a difficult enterprise. As was stressed in earlier chapters, technologies have to be considered as systems, and if one element is missing or deficient, even seemingly simple tasks such as copying a particular item may be impossible. A successful technology transfer requires numerous complementary inputs, many of which have to be developed and produced by the recipient.¹² There are occasional possibilities for "leapfrogging" over whole stages of development through the importation of foreign technologies. For example, in many parts of the world, cell phones have given millions of people access to telephone service by eliminating the need for an expensive wired infrastructure. But this is an exception; more often than not, the successful use of advanced imported technologies depends on the preparation that comes through involvement with well-established technologies.

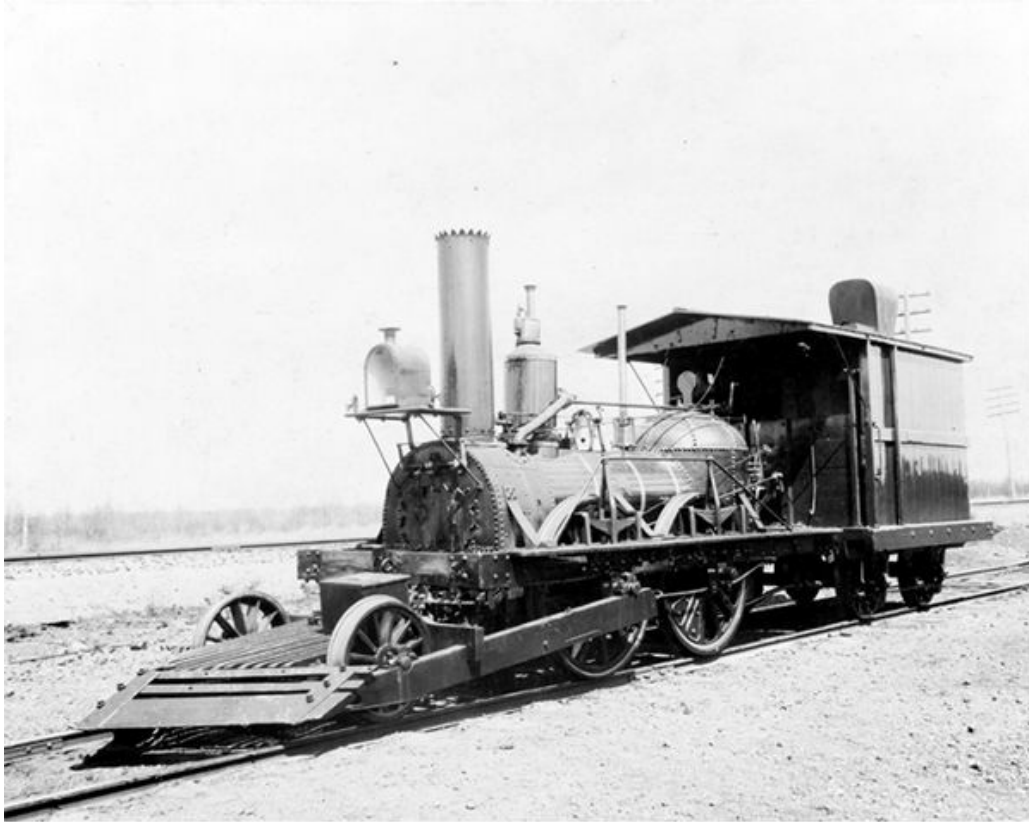
This brings us to a related point. The effective use of foreign technologies requires a labor force with a broad range of skills. It is essential that native managers, engineers, technicians, and ordinary workers are capable of making the best of opportunities that imported technologies present. To do so often entails significant modifications to an imported technology. Under

these circumstances, the application of imported technologies is combined with indigenous innovative efforts to the point where the two are in fact part of a single process.¹³

A successful user of imported technologies must therefore have a reasonably high level of indigenous capability. As noted by Vernon Ruttan, “The ability to screen, borrow and adapt scientific knowledge and technology requires essentially the same capacity as is required to invent new technology.”¹⁴ This is demonstrated by one study that found that the countries most successful in using foreign technologies tended to be the ones with high levels of indigenous research and development.¹⁵ It is also significant that countries with the highest innovation rate make the quickest use of technologies developed elsewhere.¹⁶ A country (or an individual firm) that draws on technologies developed elsewhere is spared the expense of “reinventing the wheel,” but making effective use of imported technologies—even if only direct copying is required—often requires a stock of indigenous skills that cannot always be easily found.

Adaptation and Adoption

In some cases, the diffusion process may result in a technology emerging as something fundamentally different. This is exemplified by the aforementioned transfer of gunpowder from China to Europe. The Chinese at first regarded gunpowder as a medicinal substance, and only after hundreds of years of experimentation did they begin to employ it for fireworks and on occasion for military rockets, bombs, and mines. By the end of the thirteenth century, the Chinese were using gunpowder to fire projectiles from vase-shaped guns, but development seems to have stopped at this point. A few decades later, Europeans began using gunpowder for weapons of steadily increasing destructive power, thereby transforming the nature of warfare and ultimately society as a whole.¹⁷



Library of Congress

The John Bull had to be fitted with leading wheels to guide it through the sharp curves of an American railroad.

The changes made in the course of the diffusion of gunpowder from China to Europe were monumental, for the nature of the technology changed along with the purposes to which it was put. In most cases, however, the modifications are far less dramatic. A process of “fine tuning” takes place as the technology is transferred from one place to another. As has been noted above, many successfully diffused technologies succeed only because of alterations and improvements made during the process of diffusion. Some of these changes may be done in order to adapt an imported technology to local conditions. In the late nineteenth century, Japanese entrepreneurs set up textile factories that used ring-spinning machines that had been invented in Europe. Unlike in Europe, however, these machines were supplied with a combination of high-quality long-staple cotton and cheaper short-staple cotton. The thread that was produced was lower in quality, but it was less expensive, an important consideration in a nation that was still poorer than

most European countries.¹⁸ Another adaptive change occurred when the railroad, an English invention, crossed the Atlantic. Railroad systems were built in the United States with great haste because there were huge expanses of frontier to be opened up as quickly as possible. One consequence of these conditions was that curves were much sharper than in England. This in turn necessitated changes in locomotive design as American engines were equipped with pilot wheels placed ahead of the driving wheels to guide them through the curves.

Learning to Make Steel in Old Japan

The early development of the Japanese steel industry provides another illustration of a successfully diffused technology that required many adaptations wrought by native workers and technicians.¹⁹ Although the Japanese had been making small batches of high-quality steel for centuries, their indigenous industry was incapable of making iron and steel in large quantities. Japanese steelworkers therefore looked to Europe for better ways of producing steel. The first Japanese attempts to draw on foreign techniques occurred in the 1850s when they attempted to produce cannons by using methods described in a Dutch book on steel production. Success was slow in coming. Numerous trials resulted in the production of cannons that burst the first time they were fired. Yet underlying these failures was a highly useful learning process. At first, the native ironworkers were incapable of melting even half of the required pig iron, but by the fifth attempt a complete cannon was cast, albeit not with complete success. Still, even this limited achievement required strenuous efforts to learn how to treat the raw material and to develop devices and techniques to bore the barrel of the cannon. Within about 20 years of the original attempt, the foundry had successfully cast approximately 200 cannons. In accomplishing this, the cannon founders had been able to draw on indigenous capabilities in such things as the production of firebricks for use in the reverberatory furnace in which pig iron was melted, the construction of waterpowered boring machines, and the employment of high-temperature furnaces for melting the iron.

Although their efforts represented an attempt at imitating foreign products and techniques, more was involved than mere copying. What began as an effort to imitate a foreign technology ended successfully only when indigenous capabilities were applied to the solution of production and design problems. The process continued in 1880 when foreign engineers were recruited to oversee an ambitious effort to increase steel production. Initially this too was a failure, largely because the foreign experts did not take into account the special characteristics of Japanese coal and iron ore. But even this failed attempt to produce steel through the importation of foreign

materials and experts ultimately met with success 12 years later when a Japanese engineer and one of his students reopened the dormant blast furnace after solving the problems created by the use of native coke and iron ore.

The point of this brief narrative is simply that Japan's successful nineteenth-century attempt to create a modern iron and steel industry was the result of importing foreign equipment, techniques, and expertise while at the same time developing and making full use of the native capabilities that were required for their successful employment. This example shows that technological diffusion is not a one-way process; without active participation by the recipients of the foreign technology, an imported technology may end up an expensive failure. In turn, effective participation often is the product of previous efforts at indigenous technological transformation. The issue is not one of "imitation" versus "self-reliance," but of how to achieve an effective blending of the two.

Appropriate Technology

Up to this point, there has been an unspoken assumption that the use of technologies developed in advanced nations is essential to the technological and economic modernization of developing countries. Modifications may have to be made to these technologies, but, on the whole, technologies of foreign origin are a sound basis for indigenous development. This assumption can be challenged by noting that the countries receiving foreign technologies today are not like nineteenth-century Japan and the United States. Most are far poorer, not just in terms of wealth, but also in regard to human skills; this creates numerous problems in effectively using the sophisticated technologies that have been created for the developed nations of the world. Moreover, poor countries have large and growing populations, making the creation of jobs one of their prime needs. Although in recent years the rate of population growth has slowed in many poor countries, there still remains a huge cohort of new entrants to the labor force. As a result, youth unemployment rates are still stubbornly high; according to a recent estimate by the International Labor Organization, 88 million young people around the world are struggling to find a job.²⁰

Unfortunately, many of the technologies that have been developed in the economically advanced nations have been designed to save labor, not to maximize its use. Labor is often saved by using technologies that allow the substitution of capital for labor, yet one of the distinguishing features of poor nations is that they are critically short of capital. And finally, is it reasonable to expect that the world as a whole can sustain the global diffusion of the technologies that have been developed by the rich nations of the world? It is hard to imagine China or India consuming resources at the rate the United States does. To take one notable example, according to the World Bank, in 2009 India had a ratio of 12 cars for every 1,000 persons.²¹ If India, a nation of 1.25 billion people, were to achieve a car-to-population ratio equal to the 439 cars per 1,000 persons found in the United States, the prospects for resource depletion and environmental pollution would be grim indeed.



Courtesy hipporoller.org

Women and children in poor countries often expend a lot of time and effort to bring water to their homes. One appropriate technology, the Hipporoller, makes the task easier.

Due to the drastically different circumstances of today's underdeveloped countries, technologies that have worked well in the rich nations where they originated may fail when they are taken to a different setting. Even worse, they may seriously distort the course of a nation's development and leave it poorer than when it started out by concentrating human and financial resources in a few privileged segments of the economy and society, leaving much of the population, especially those in rural areas, as poor as ever. To take one particularly notorious example, after Western experts introduced large tractors into Pakistan, farm owners replaced farm laborers with the new machines. In one region, 40 percent of these workers lost their jobs and thus were forced to migrate to the cities and live in dire poverty. Per-acre crop yields hardly increased at all.²²

According to critics of conventional technology transfers, what poor countries need is a set of technologies appropriate to the conditions prevailing in these countries.²³ Sometimes they are called "alternative technologies," sometimes they are called "intermediate technologies" (because they stand in an intermediary position between modern and traditional ways of doing things), and sometimes they are simply called appropriate technologies. These technologies, it is claimed, do more than boost production; they increase employment, help to redress the maldistribution of wealth and

income, empower people, contribute to economic independence, and preserve the environment.

Examples of appropriate technologies in developing countries include hand-powered nut shellers, bicycle-powered pumps for irrigation and water distribution, and rolling drums for transporting water. Appropriate technologies less directly connected with production include shelters made out of concrete and canvas, solar-powered lights, and inexpensive laptop computers for schoolchildren.²⁴ The utility of these technologies seems evident, and few could take issue with the general goals of appropriate technology. The difficulty lies in their actual development and implementation.

Consider the first goal: increasing employment. As noted earlier, in poor countries there is good reason to select technologies that use relatively more labor than capital. But adopting a technology simply because it requires the employment of lots of workers is likely to be a poor strategy. If it makes sense to hire a few dozen workers with shovels rather than employing one operator of an earthmover, why not hire a thousand workers with teaspoons? This *reductio ad absurdum* reminds us that creating jobs is a laudable goal, but it is also necessary to take output and costs into consideration. In regard to the latter, large numbers of workers, even if they are poorly paid, may be more expensive than a small number of workers using modern technology. The resulting higher cost of production will cause higher prices for the product, which in turn will diminish sales and employment. Alternatively, purchases may not decline, but there will be less money spent on other goods and services, and fewer jobs in the firms that supply them. In sum, the use of highly labor-intensive production methods in one firm or industry may actually diminish employment in the economy as a whole.

Many economists would argue that a free market system, with its realistic reckoning of capital and labor costs, will naturally result in the use of productive technologies that optimize both labor and output. But the choice of technologies is not always governed by economic calculations. Technologies may be selected because they meet the requirements of powerful segments of the society, as when ultramodern hospital technologies are installed to serve the urban upper class of a country that lacks basic medical services for most of its people. At the same time, even practical,

profit-oriented businessmen in underdeveloped countries can be charmed by the technological sophistication of foreign technologies that do not make good economic sense. For example, according to one study of business firms in Indonesia, there were available intermediate technologies that lowered costs and maintained product quality, but they were often rejected in favor of advanced technologies of foreign origin. This was especially likely to happen in firms that had oligopolistic control over their market. Under these circumstances, the aesthetic appeal of sophisticated technologies and the prospect of managing machines instead of people overrode the economic advantages of more appropriate technologies.²⁵

Finally, a consideration of alternative technologies that is confined to economic matters is incomplete, for the appropriate technology movement has been motivated by a deep concern with how technologies are connected to larger issues. In the final analysis, a technology can be adjudged appropriate or inappropriate only by reference to particular values, and these cannot be defined exclusively in economic or technological terms. The appropriate technology movement also has directed attention to the role played by powerful groups and institutions in the choice of technologies. Choices are likely to be seriously constrained when donors of foreign aid, international lending agencies, and multinational corporations occupy positions of dominance. It is also likely that the emergence of appropriate technologies is seriously hindered by the international distribution of R&D expenditures. In 2011, North America, Europe, and East Asia accounted for 90 percent of research and development expenditures; the remaining 10 percent was undertaken in the poor countries of Central and South America, Central Asia, the Middle East, and Africa.²⁶

Appropriate technologies, however defined, cannot be a panacea for poverty and backwardness. At the same time, the transfer of sophisticated technologies from developed countries may cause more harm than good. Choices must be made, and in poor countries as well as in rich ones, the selection of technologies reflects many larger issues. One of the most important of these is *sustainability*. Today's technologies have enriched our lives in many ways, but can we continue to degrade the natural environment while also expecting the perpetual availability of energy supplies and other resources? In this context, technologies are appropriate when they save

energy, require minimal resources, and relieve stresses on the environment. Examples of sustainable technologies include products that lend themselves to recycling, building designs that require little energy for heating and cooling, and road systems that are safe and convenient for cyclists and pedestrians.

Organizations and Technological Diffusion

Many of the same processes that characterize the diffusion of technology from one country to another also manifest themselves when new technologies are acquired by organizations within a country. Be they business firms, government bodies, charities, or schools, the same factors affect the speed with which new technologies diffuse and the extent to which they take hold. According to Everett M. Rogers, the likelihood of their success rests on the following attributes:²⁷

Relative advantage	The degree to which the innovation is perceived as being better than the existing way of doing things
Compatibility	The extent to which the innovation is perceived as being consistent with existing values and needs
Complexity	The ease or difficulty of understanding and applying the innovation
Trialability	The extent to which an innovation can be applied on a limited, experimental basis
Observability	The degree to which the results of an innovation are apparent.

When considering these attributes, it should be apparent that *perceptions* play an important role in the adoption or rejection of an innovation. The go/no-go decision is made by people, and these decisions are likely to be based on a combination of objective and nonobjective factors. Moreover, individual decisions are usually forged in a social setting; once again we see that the technologies being adopted and used reflect social institutions and processes.

In addition to fulfilling at least some of the requirements just listed, effective technology transfer often requires a learning process as a new product or process moves from one environment to another, such as from a laboratory to a factory. Technologies are based on knowledge, but knowledge that is readily comprehensible in one setting may be a great mystery in another. As with the conversion of scientific knowledge to technological

practice noted in the previous chapter, successful diffusion sometimes requires the services of a kind of “translator”—a person capable of functioning in both settings so that information can be transferred from one to the other.

As Hugh Aitken’s study of the early days of radio indicates, the efforts of “translators” were crucial to the development of that technology and its adoption by commercial enterprises. The history of radio begins with the work of Heinrich Hertz, who in the 1880s “translated” James Clerk Maxwell’s theory of electromagnetic radiation into a laboratory technology that allowed an empirical examination of the theory. Following Hertz, Oliver Lodge moved beyond the laboratory experiment through his development of an imperfect but workable method of using radio waves for actual communication. The first stage in the development of radio was essentially completed by Marconi, who took the embryonic technology and converted it into a practical (and highly lucrative) commercial business.²⁸ Throughout the course of radio’s history, information was put into a new form, pushing the technology to the next stage of development. In Aitken’s summary, “At each stage in the process of translation, information generated in one system was converted into a form that ‘made sense’ in terms of another; and at each stage new information was blended with what was already known to create something essentially new.”²⁹ This is a process we can see today when the 20-year-old technology of the Web is used to stream music, movies, and other forms of artistic expression that have been around for many decades.

A Risky Business

Some technologies, especially those involving military matters, are sponsored by governments, but the majority of technological innovations are adopted by private businesses pursuing their economic goals. Firms may adopt new technologies in order to cut their costs, improve their products, bolster their profits, penetrate new markets, or achieve some combination of any or all of these. The speed and extent of diffusion are therefore strongly influenced by expectations of costs and benefits.

Expectations, however, are not always met. Along with the opportunities presented by a new technology come uncertainties that cannot be assessed through conventional economic analysis. No new technology is a “sure thing.” Some end up embarrassing failures; just ask Apple about the Newton personal digital assistant, Sony about Betamax, Microsoft about its Zune media player, or Google about Google Glass. Even with a technology that is ultimately successful, its immediate advantages may be slight and its benefits may be a long time in coming. On a more positive note, some new technologies may exceed expectations when they are complemented by other technologies. Under these circumstances, new products and processes are more than the sum of their parts, as when a combination of the laser and the computer gave birth to supermarket scanners, printers, and robotic surgery.³⁰

It is often the case that the potential of an emerging technology is what matters, and this may be the hardest thing of all to assess. Many years may elapse before a technology passes from laboratory feasibility to commercial success, that is, from invention to innovation. Although some inventions made the transition rapidly—only one year in the case of Freon refrigerants—others have taken much more time. In the case of the mechanical cotton picker it was 53 years, and for the zipper, 27 years.³¹ Sometimes an invention appears on the scene, is quickly forgotten, and then reemerges decades later, as happened with the pneumatic tire.³²

The decision to adopt a technology represents an organization’s assessment of the likely benefits accruing from the use of the new technology, weighed against the uncertainties that attend its use and the speed

at which these uncertainties can be dissipated.³³ Given the nature of technological innovation, uncertainties will rarely vanish completely, but as information is gathered and experience gained, *uncertainties* can be converted into *risks*.³⁴ More than terminology is involved here; according to a distinction made by economists and game theorists, “uncertainty” indicates an inability to predict an outcome, whereas “risk” implies at least a rough notion of the probability of success or failure.³⁵ The ability to make calculations of this sort does not ensure accurate predictions of success or failure, but at least it enables decision makers to make informed judgments of their likelihood.

Not all risks are technological in nature. Although any new way of doing things can be presumed to have its share of bugs and other unanticipated problems, these may be minor when compared to the commercial uncertainties of a new venture. Uncertainties of this sort can be particularly problematic, for decision makers usually find it easier to assess the probability of technical success than the probability of marketing success.³⁶ “Will it fly?” is easier to determine than “Will anybody pay money to fly in it?” This was the literal problem for the Anglo–French supersonic airliner, the Concorde. A stunning technological achievement that required the solution of countless complex problems, the Concorde was a commercial failure. An extraordinarily expensive aircraft to fly and maintain, it never generated revenues commensurate with the costs of its development and operation. No private business could have survived this sort of failure. Only the financial support of the governments of France and Great Britain, motivated by considerations of national pride as much as anything else, kept the Concorde aloft until it was retired in 2004.

The NIH Syndrome

The inherently uncertain or at best risky nature of many technological innovations may explain the presence of one persistent block to the diffusion of new technologies, the Not Invented Here syndrome, or NIH for short. People and organizations exhibiting this syndrome are reluctant to make use of technologies that were invented elsewhere. The corrosive effects of the NIH mentality were bemoaned by Henry Ford II: “There’s too much NIH—not invented here [in the automobile industry].... Lots of times a guy brings something in, and unless the improvement is rather dramatic, nothing happens. The status quo is a hell of a lot easier than making changes.”³⁷

Internal resistance to technological innovation, while frustrating to some, is certainly understandable. As was noted, innovation is at best a risky process that can generate a great deal of discomfort, and this discomfort will be especially intense when the innovation has not been the work of those who are affected by it. It is also the case that internally generated technologies are likely to be more compatible with established organizational structures and activities. Moreover, an internally generated technology will probably have a “champion” within the organization who seeks its utilization, and management may be more inclined to pay attention to the ideas of their organization’s own personnel.³⁸

These are explanations for the presence of the NIH syndrome, but not excuses. A dynamic firm can ill-afford to ignore useful new technologies just because they were developed elsewhere. We have already seen that a receptivity to “foreign” technologies has been crucial to the development of Europe, the United States, and Japan, and that a resistance to them was a major reason for the economic retardation of imperial China. An individual firm that chooses to resist or ignore new technologies because of their source may ultimately find that security and pride have been purchased at a very great price. Its comfortable routines and organizational structures are retained, right up to the day that it goes out of business.

Efforts to Restrict the Diffusion of Technology

The exclusive possession of a particular technology can confer great advantages on those who have it. Individual firms or whole countries may therefore go to great lengths to block the diffusion of these technologies. During the sixteenth century, the glassmakers of Venice sought to prevent others from learning the secrets that went into the production of Venetian glass, and they even sent assassins to poison Venetian expatriates who had set up glassworks abroad.³⁹ England enacted a law in 1719 that forbade the emigration of skilled artisans, such as the aforementioned Samuel Slater, whose knowledge of British equipment and practices was a crucial element in the early development of the American textile industry.

Today, technologically advanced nations attempt to prevent the export of advanced technologies through export licensing requirements. Licenses may be denied if national security could be compromised by the transfer of a particular technology. The transmission of knowledge alone can also be deemed a threat. In 2012, the potential danger of scientific information falling into the wrong hands led to requests by the U.S. federal government to request two groups of researchers to temporarily withhold the publication of some research results involving the genetic manipulation of the virus responsible for bird flu. Although the research was conducted in order to aid in the prevention of future epidemics, it was feared that the data it generated could become the basis of a future bioterrorist attack.⁴⁰

Past efforts to suppress the outflow of technology and the knowledge upon which it rests have rarely been successful, and there is little likelihood that contemporary efforts will fare any better. The transfer of plans, equipment, data, and products are extremely difficult to stop, even with rigorous attempts at policing. Also, as exemplified by the case of Samuel Slater, the movement of people has historically been the main vehicle for the transfer of technologies. This sort of movement is very hard to stop, especially in a free society.

Attempts to stem the outward flow of technology may even be

counterproductive. A country that attempts to bar the export of technology may end up damaging itself more than anyone else. Technological development often requires the interchange of information from numerous sources. The attempt to seal off a technology will restrict the flow of information from both domestic and foreign sources, and thereby result in a slower pace of technological advance.

Finally, it is often the case that the most important “secret” is that a technology exists. During the late 1940s and early 1950s, there was a great deal of anguish in the United States after the Soviet Union exploded its first nuclear bomb. The general belief was that the Soviets had obtained our “atomic secrets,” and two Americans were executed for their role in passing on these “secrets.” But the Soviets had long known the most important thing: that a massive explosion could be produced through the fissioning of atomic nuclei. Once this fact was known, it was only a matter of time before the Soviets learned how to do it themselves, with or without the clandestine transfer of American technology. Knowing that a problem can be solved sometimes is the most important step in its solution.

Patents and the Diffusion of Technology

Individuals and managers in business firms naturally want technological diffusion to take place on their own terms. If it has developed a novel technology, it wants the benefits of that technology to accrue only to themselves, and not to others who might be able to copy an invention that likely required a great deal of effort and expense. This is a legitimate desire, and it has been recognized as such by the establishment of the patent system. The possession of a patent confers exclusive use of an invention; it is a legal monopoly. Without the prospect of such a monopoly, it is believed, there would be a diminished motivation to invent, and in the long run society as a whole would suffer from a slower rate of technological advance.

Although it is aimed at restricting the sale or use of a particular technology to a single individual or firm, there are some ways in which the patent system may stimulate technological diffusion. The filing of a successful patent application makes the invention public, for the basic design and specifications are open to inspection by anyone willing to pay a small fee. In fact, the word “patent” is derived from the Latin verb *pateo*, which means “to open.” One of the chief justifications for awarding a patent is that the inventor has not attempted to keep his or her invention secret, but rather has revealed its workings to the public. In summarizing a number of previous decisions, the U.S. Supreme Court noted in 1933 that an inventor “may keep his invention secret and reap its fruits indefinitely. In consideration of its disclosure and the consequent benefit to the community, the patent is granted.”⁴¹

Although direct copying is of course forbidden, access to the public record may give a clearer sense of how a technological problem may be addressed and may stimulate alternative approaches to its solution.⁴² Then, too, patent holders often pass their inventions to other firms in return for a licensing fee. This arrangement may allow for the more rapid diffusion of a technology because the licensing agreement often facilitates the transfer of supplementary material necessary for the best use of the device or process.⁴³ In some cases, a licensing arrangement may result in a better product, as

happened when DuPont developed waterproof cellophane after being licensed to produce the original version.⁴⁴

At the same time, however, patent protection may inhibit technological advance. A well-entrenched firm may hold a patent in order to suppress an invention that could seriously shake up existing routines or even threaten the firm's existence. It seems as though everybody has a brother-in-law who knows a man who invented a way to make his car run on water straight from the garden hose, but "of course the big oil companies bought up all the patents." One shouldn't put much credence in these stories, but it is true that dominant companies have at times used their control of patents to restrict innovation, as happened with the design of light bulbs when General Electric held the key patents.⁴⁵

The use of patents to directly suppress certain technologies poses less of a threat to innovation than the widespread use of patenting as a strategic weapon against potential rivals. Patents are supposed to motivate individuals and business firms to create innovative products and processes, but according to critics, their primary purpose is to allow patent holders to harass competitors, collect undeserved royalties, and bolster the value of financial portfolios.⁴⁶ Critics of the present patent system have also called attention to the monopoly power that has been conferred by a recent upsurge in the patenting of products and processes that in the past were not entitled to patent protection, most notably computer software, genes, and business methods.⁴⁷ Finally, and most fundamentally, the significance of patents in stimulating invention is by no means certain. According to critics, the correlation between a strong patent system and the rate of invention is weak at best.⁴⁸

Although it may confer considerable power in the marketplace, the holding of a patent does not necessarily confer an overwhelming competitive advantage, since there may be considerable scope for "inventing around" the patent. Moreover, there are no industries where a key technology is covered by a single "master patent" that can be used to repulse potential competitors. There have been attempts to dominate an emerging industry through the wielding of a patent, most notably when, in 1895, George B. Selden was granted a patent for the automobile. What Selden held was a classic "submarine patent," a vague claim held in reserve for a later time when others had made the invention a practical reality. Although he had not built an actual

automobile at the time when the patent was granted, through it, Selden and the subsequent holders of the patent were able to extract licensing fees from most automobile manufacturers. One manufacturer who refused to go along was Henry Ford, who successfully challenged the validity of the patent in court and won a great deal of public acclaim as a result.⁴⁹

G. B. SELDEN.
ROAD ENGINE.

No. 549,160.

Patented Nov. 5, 1895.

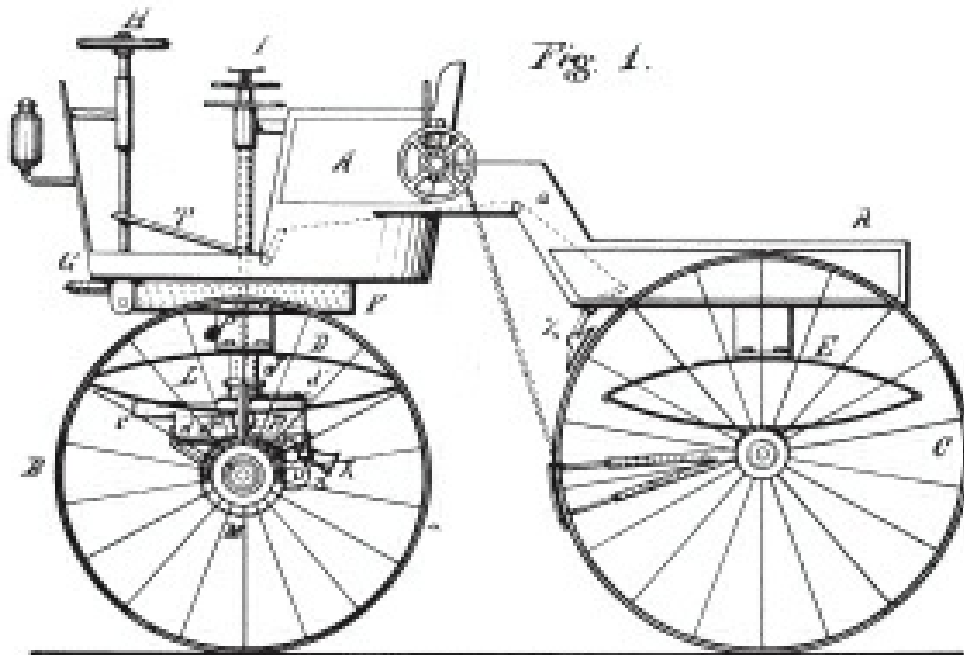


Fig. 1.

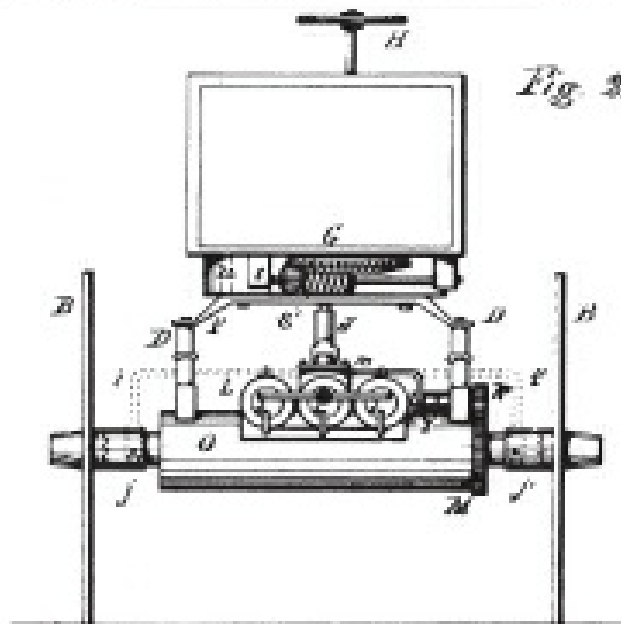


Fig. 2.

WITNESSES
Wm. Roby, Jr.
Geo. Eastman

INVENTOR
Geo. B. Selden.

Granger, NYC — All rights reserved.

The patent illustration for the automobile that George Selden claimed to have invented.

It also has to be recognized that a patent never confers ironclad protection for inventors; it may be little more than a “license to sue.” In recent years, most patent holders have successfully waged court battles against individuals and firms who have been accused of infringing upon their patents, but both sides may incur sizable costs in terms of time, talent, and money. As a result, many individuals and firms have been content to exploit their unpatented invention until the copiers are able to seize a large share of the market. In other cases, patented products and processes are quickly outmoded by the advance of technology, and a temporary monopoly position is soon lost. On the other side of the coin, parties who have been charged with patent infringement may feel that they are in the right, but they will nonetheless elect to pay royalties to the patentee in order to avoid an expensive and drawn-out courtroom battle.

Whether the patent system serves as an overall stimulus or hindrance to technological advance is a matter of considerable debate, and one not likely ever to be settled. Like many social institutions, as much as anything it owes its existence to inertia and the efforts of parties with a direct interest in maintaining it. Under these circumstances, the status quo usually prevails.

QUESTIONS FOR DISCUSSION

1. What sort of skills are required for the successful copying of a technology developed elsewhere? Why do you think that the Japanese have been so successful at making effective use of technologies that first appeared elsewhere? How might other countries duplicate their success?
2. Most economically advanced countries have technical assistance programs that are used to upgrade the technological levels of poorer countries. Under what circumstances might these programs be harmful? How might these programs be shaped to better meet the needs of poor countries?
3. If you were the leader of a poor nation, what general policies would you formulate in regard to the importation of technology? Where might you expect to find opposition to these policies?
4. Suppose that you are the CEO of a firm that has a choice between two new technologies: one that promises a modest profit with very little risk, and another that may yield a very high profit but at considerable risk. What would your choice be? Who in your company might support the first technology, and who might support the second?
5. Does the patent system encourage or discourage technological innovation? What would happen if it were abolished? Can you think of an alternative that would better serve the needs of both inventors and the general public?

PART THREE

How Technology Affects the Health of Earth and Its Inhabitants

The following three chapters illustrate how technological change can create both problems and solutions. Chapter 6 describes how technological innovations have, at times, been the source of two general categories of environmental damage: pollution and depletion. The record isn't altogether depressing, however, as the chapter presents several examples of successfully addressing these problems through the development of new technologies. As is often the case, technological fixes are only part of the story, however. Any fix must be carried out amidst a set of social and economic forces, which, along with governmental policies, can help or hinder the solution of environmental problems.

Chapter 7 turns from environmental health to human health. It describes the many ways in which medical technologies have cured our ills and extended our lives while at the same time creating new problems and challenges. The most serious of these is escalating health care costs. Many medical procedures can be described as “halfway technologies” that extend lifespans and alleviate pain but leave patients in a state of permanent—and expensive—dependence on medical care. On another front, sophisticated diagnostic technologies give physicians more data, but at the expense of marginalizing important diagnostic skills based on personal relationships with patients.

Chapter 8 looks into the development of medical technologies based on advances in genetics and assesses recent developments in the genetic engineering of food crops, once again noting that technological advances are not necessarily unmixed blessings. This theme is continued with an exploration of recent developments in genetic technologies that are being applied to humans now and may be employed in the future. Perhaps no set of technologies has a greater potential for transforming our lives for good and for ill. The benefits and possible pitfalls of these technologies are discussed, along with an examination of the legal and ethical issues they raise.

CHAPTER SIX

Technology, Energy, and the Environment

Although technological advance has been blamed for a variety of ills, its most obvious and long-lasting negative consequence has been the degradation and even the destruction of the natural environment. For most of human existence, people left the environment pretty much as they found it. But beginning with sedentary agriculture and accelerating with industrialization, the use of new technologies has at times left a ruined environment as its legacy. And there is a strong possibility that environmental problems will worsen as more nations make greater use of industrial technologies. Today, the United States, with less than 5 percent of the world's population, consumes about 25 percent of the world's resources. If the poor countries of the world, which contain the majority of Earth's population, used resources at the current U.S. level, the consequences for the environment could be dire. This will not happen in the near future, but the general trend is inescapable. For example, according to the U.S. Energy Information Agency, global consumption of energy from 2010 to 2040 is projected to increase by 56 percent, with the developing countries of the world expected to account for most of the increase.¹ The rich countries of the world should not begrudge the efforts of poor countries to pursue better lives for their people, but for all countries, rich and poor alike, the sustainability of the earth's environment must be an essential goal.

The deleterious consequences of technological advance can be grouped into two broad categories: pollution and depletion. In the former, the environment is damaged by the addition of harmful substances, resulting in

polluted skies, acid rain, poisoned soil, contaminated water, and climate change. In the case of the latter, the unchecked application of technology leads to the permanent loss of resources, deforestation, and the extinction of plant and animal species. On many occasions, of course, the two go together; a mining operation could extract all of the available ore and leave a devastated environment in its wake. Either separately or together, pollution and depletion threaten the sustainability of the environment.

But there is some cause for optimism. Technology is not just a source of environmental problems; it can also be part of the solution. In this chapter, we will look at some of the environmental consequences of technological advance, review some technologies that can alleviate the degradation of the environment, and briefly consider how governmental policies affect the natural environment.

Fossil Fuels, Air Pollution, and Climate Change

The use of fossil fuels (petroleum, coal, and natural gas) has vastly extended the amount of available energy. At the same time, cars, power plants, factories, and other sources emit immense quantities of carbon compounds, sulfur, and oxides of nitrogen. In 2010, more than 33 billion tons of carbon fuel exhaust were discharged into Earth's atmosphere, a figure that has continued to rise, and will certainly do so in the immediate future.²



Getty Images News/Getty Images

Beijing's historic Temple of Heaven can barely be discerned through the thick smog enveloping the city.

The blanket of smog now choking many of the world's cities makes the consequences of the use of fossil fuel all too evident. Potentially more

dangerous in the long run is the accumulation of the main product of carbon combustion: carbon dioxide (CO₂).

CO₂ is produced when the carbon in gasoline, diesel fuel, coal, or natural gas unites with oxygen during the process of combustion. This creates quantities of CO₂ significantly greater than the original carbon; burning 1 pound of gasoline generates more than 3 pounds of CO₂.³ To look at it in a different way, a car traveling 100 miles produces about 100 pounds of CO₂.

CO₂ is a clear, odorless gas that by itself presents no threat to health. It is the normal product of any animal's respiration, and without it drinks like beer and soda pop would be unpalatably flat. The danger presented by CO₂ emerges only when large quantities of it accumulate in the atmosphere along with two other products of an industrial society, methane (CH₄) and nitrous oxide (N₂O). As light rays from the sun pass through the atmosphere containing these gases, the radiant energy warms the surface of the earth, but most of the heat cannot pass back through the atmosphere. This is known as the "greenhouse effect." Just as a greenhouse is warmed by the light of the sun on a cold winter's day, Earth's temperature begins to rise as greenhouse gases accumulate in the atmosphere. Concentrations of these three greenhouse gases have increased to a marked degree as industrialization advanced. In 1750, at the dawn of the Industrial Revolution, concentrations of CO₂, the most important greenhouse gas, stood at 280 parts per million (ppm); by 2014, that figure had climbed to 395.4 ppm.⁴

Continued warming due to increasing CO₂ emissions seems likely. As noted by the United Nations Intergovernmental Panel on Climate Change, average temperatures rose about 1.53°F (0.85°C) from 1880 to 2012. Taking a shorter time span, the years from 1983 to 2012 were probably the warmest 30-year period of the past 14 centuries.⁵ Projections of future trends indicate substantially greater increases, but as a general principle, the reliability of any kind of prediction diminishes as it moves further into the future. In regard to Earth's climate, predicting the course of global warming is a complex exercise because the many variables affecting Earth's climate have complex interactions. Predictions are further complicated by the need to estimate increases in the production of greenhouse gases resulting from economic growth and consequent energy use in the developing countries in the decades

to come.

For all the uncertainties surrounding global warming, it still seems highly likely that significant changes to Earth's climate will take place if present trends continue. Temperature increases will not be uniform, and some regions may even end up with colder climates due to changes in ocean currents. Rainfall patterns would shift to the advantage of some areas and to the detriment of others. In conjunction with increases in CO₂ and other greenhouse gases, global warming could increase agricultural yields in certain regions but reduce them elsewhere. It also seems certain that climate changes will result in the loss of some plant and animal species, and the relocation of others. One of the consequences of the latter could be the spread of insect-borne diseases to previously unaffected parts of the world. Most troubling, significant global warming is leading to partial melting of glaciers and the northern polar ice cap. It is also causing water to expand in volume as the oceans warm. Over the long term, this will result in a rise of sea levels, and potentially catastrophic floods in low-lying areas. One particularly vulnerable place is the nation of Bangladesh; according to a United Nations report, a three-foot rise in sea level would inundate a quarter of its coastline, resulting in the displacement of 30 million people.⁶

Atmospheric scientists are learning more and more about the complex interactions that govern Earth's climate, but many unanswered questions remain. In the meantime, the buildup of greenhouse gases could reach a potentially catastrophic tipping point in a few decades. Reducing the emissions that contribute to climate change will require the expenditure of billions if not trillions of dollars over the decades to come, but the costs of doing nothing will likely be even greater. Effectively addressing the causes of climate change also requires taking some painful actions today to forestall problems that lie well in the future, a difficult course of action for business and governmental leaders who necessarily have short-term horizons. Moreover, decisions (or nondecisions) must be made amid considerable uncertainty, although the most fundamental issue, the reality of human-induced climate change, can no longer be questioned.



John MacNeill Illustration

The development of technological fixes to prevent or mitigate climate change is known as geoengineering. One example is a proposed fleet of wind-powered vessels that would generate clouds of seawater droplets, which in turn, would block some of the sunlight that is the source of the greenhouse effect.

A Planet under Stress

While the burning of carbon-based fuels is making the largest contribution to global climate change, deforestation also contributes. Particularly serious has been the loss of forested areas in Africa and Latin America, much of it occurring in tropical regions. From 1990 to 2005, the world was being deforested at a rate of 0.18 percent per year, while losses in Africa and Latin America came to 0.62 and 0.51 percent, respectively.⁷ Deforestation affects climate change in two ways: the burning of forests and the rotting of fallen trees release CO₂, while the loss of trees removes an important source of CO₂ capture. Through these processes, deforestation contributes about 17 percent of human-caused greenhouse gases.⁸

In addition to affecting the skies above, human activities are generating massive amounts of refuse, a significant portion of which is hazardous. According to the U.S. Environmental Protection Agency, in 2010, Americans generated 249.9 million tons of municipal solid waste, which comes to an average of 4.43 pounds per person every day, along with a much greater volume of industrial and other waste products.⁹ About one-third of household wastes are composted or recycled, and most of the remainder is nontoxic. However, some of the materials discarded by households and industrial enterprises reside in inadequate disposal facilities that threaten adjacent communities. Already, some areas have been so badly contaminated that they had to be abandoned for a number of years while the mess was being cleaned up. Many other places contain dump sites that are only slightly less hazardous. Restoring toxic sites is and will be an expensive proposition; in 2011, the Environmental Protection Agency estimated that it would cost \$335 million to \$681 million per year to clean up the most contaminated areas, those that have been designated as Superfund sites.¹⁰

While pollution, global warming, the massive generation of trash, and the other negative consequences of industrial production cause problems on one front, depletion of the resources that provide energy and raw materials pose another set of challenges. Fossil fuels have been essential to the process of industrialization since at least the middle of the nineteenth century, and

petroleum-based fuels are the basis of the world's transportation systems. Supplies of fossil fuel are necessarily finite, although many uncertainties attend efforts to estimate their size, especially in the case of petroleum. According to some experts, we have already reached "peak oil" and inevitably face a future of declining petroleum extraction.¹¹ Other experts, however, take a contrary view. In recent years, the extraction of petroleum from shale deposits through hydraulic fracturing or "fracking" has at least temporarily repudiated the "peak oil" thesis. Whether or not this trend will continue is open to debate. Although fuel prices were low in the middle of the second decade of this century, the increasing costs of employing new technologies, environmental damage, and concerns about climate change may reinstate peak oil as the dominant way of looking at petroleum supplies.¹²

Neither the peak oil thesis nor its antithesis can be settled once and for all. Determining the amount of oil still remaining underground entails considerable guesswork, and there is not even universal agreement on how to define petroleum "reserves." The amount of oil that can be economically extracted from a known reservoir depends on the prevailing market price. The price of oil will increase as supplies dwindle, so the rate at which oil is extracted will depend on what users are willing to pay. At the same time, high oil prices will motivate the development of new extraction technologies, and a consequent increase in supplies and lower prices. The complex interaction of supply, demand, and technology make projections of future supplies of oil a hazardous enterprise. Oil shortages will likely still occur, just as they did during the energy crises of 1973–1974 and 1979, but it has to be remembered that they were triggered by political actions, and not by an abrupt decrease in the world's petroleum supplies.

The energy crises of the 1970s were a painful reminder of our dependence on key natural resources. No similar drama has attended the decline of another vital resource, the earth's topsoil. Since 1945, 1.2 billion hectares of agricultural land have been degraded by moderate to extreme soil erosion, the equivalent of the total land area of China and India. This trend has not abated; somewhere between 24 and 75 billion tons of soil are being lost annually around the world.¹³ In the past, the loss of topsoil could be offset by moving to virgin lands, but this option is no longer available in most parts of the world. Not only is new land unavailable, erosion and land

degradation are removing about 1 percent of existing arable land annually. In many parts of the world, the loss of topsoil has increased the costs of farming, but in some places, the consequences have been far more serious. Severe loss of topsoil has converted some regions into deserts, bringing widespread famine in its wake. Elsewhere, topsoil loss coupled with climate changes induced by global warming could have dire consequences for agriculture, even as the continual growth of the world's population calls for the production of more food.

Is Technology the Problem or the Solution?

The previous pages have presented a depressing catalog of environmental ills. Pollution, climate change, species extinction, and resource depletion pose multiple threats to our standard of living and, perhaps, even to our continued existence. The reliance on fossil fuels has left our atmosphere contaminated by various pollutants, and the earth threatened by climate change. Irresponsible agricultural practices have poisoned groundwater with pesticides and other chemicals while depleting the topsoil. Industrial processes produce thousands of tons of toxic wastes, and nuclear power plants leave behind radioactive wastes that will pose potential health hazards for thousands of years. In the opinion of some critics, the technological advances of the past few centuries seem to have produced only temporary benefits that will ultimately be overwhelmed by the consequences of environmental stress. In the long run, it may be argued, technology generates more harm than good.

Is a modern economy, supported by advanced technologies, doomed to destruction, leaving us with no choice but to retreat to the simpler technologies of the past, perhaps even back to the era of hunting and gathering? Or can technology itself provide us with the solutions to technologically induced problems? In addressing these questions, it is useful to first gain some historical perspective. If nothing else, some acquaintance with the past should convince us that damage to the environment is not solely a phenomenon of modern times and modern technologies. Entire civilizations have collapsed due to excessive land clearance, overgrazing, withdrawal of groundwater, and eventual desertification. Epidemic diseases of catastrophic proportions have been spread by the careless disposal of household wastes. There are some scholars who believe that a major factor in the collapse of the Roman Empire was sterility and premature death brought on by the widespread use of lead in pipes and utensils. Air pollution existed long before the invention of fossil fuel-consuming engines; those suffering from twenty-first-century smog can find a seventeenth-century counterpart in John Evelyn, who decried the growing use of coal for energy and warmth:¹⁴

In London we see people walk and converse pursued and haunted by that infernal smoake. The inhabitants breathe nothing but an impure and thick mist, accompanied by a fuliginous and filthy vapour, which renders them obnoxious to a thousand inconveniences, corrupting the lungs and disordering the entire habit of their bodies, so that catarrs, phtisicks, coughs and consumption rage more in that one city than in the whole earth besides.

Some Technological Fixes of the Past

These examples of past environmental ills provide little comfort, for they can be seen as a preview of what might be in store for us. But there are other examples of environmental threats that have been successfully countered. One example is the deforestation that had become a serious problem in England during the sixteenth century. By that time, vast quantities of wood had been consumed by the demands of an expanding population and the growth of shipbuilding, construction, and iron manufacture (which required large quantities of charcoal). Within a century, the depletion of timber was perceived as a serious problem, as seen in the complaint of one contemporary writer that “at this present, through the great consuming of wood as aforesaid, and the neglect of planting of woods, there is so great a scarcitie of wood through the whole kingdom.”¹⁵

England’s forests were never fully restored, but fuel shortages were alleviated by burning coal in the place of wood. Although there were misgivings about the noxious vapors given off by burning coal, it came to be widely used for domestic heating and as a source of process heat for the production of beer, sugar, bricks, soap, glass, and iron. More than simply a substitute for wood, by the end of the nineteenth century coal had become the basis of industrial civilization, as the rich coal deposits of Britain significantly contributed to that country’s unique position as “the Workshop of the World.” Much of the industrial age was the era of coal, as coal-fired steam engines powered factories, hauled railroad trains, generated electricity, and propelled ships to distant destinations.

Yet just when coal had established its primacy as the most important energy source for industrial society, hard questions were being asked about the continued viability of coal-based technologies. By the end of the nineteenth century, it was becoming evident that stocks of coal, while still large, were being depleted at ever-increasing rates. The projection of established trends seemed to offer indisputable proof that the day of reckoning was not far off: Britain was running out of coal. In the words of the contemporary English economist, W. Stanley Jevons, “There is no reasonable

prospect of any relief from a future want of the main agent of industry. We must lose that which constitutes our particular energy.”¹⁶

Coal was king, and in Jevons’s estimation, as well as those of other informed students of the British economy, there was no hope that anything could take its place. In Jevons’s gloomy appraisal, “All things considered, it is not reasonable to suppose or expect that the power of coal will ever be superseded by anything better.”¹⁷ His pessimistic assessment of potential substitutes is exemplified by his quick dismissal of petroleum as a fuel: “Its natural supply is far more limited and uncertain than that of coal, and an artificial supply can only be made by the distillation of some kind of coal at considerable cost. To extend the use of petroleum, then, is only a new way of pushing the consumption of coal. It is more likely to be an aggravation of the drain than a remedy.”¹⁸ Natural gas, another possible substitute, was an equally forlorn hope. Jevons approvingly quoted the assessment of an American steel executive: “Of late years the supply of gas has been decreasing ... and it would seem that before many years this fuel would cease to be a factor in the large operations of a steel works.”¹⁹

One can smile at the remarkable wrongheadedness of these assessments, but it is easy to be wise after the fact. After all, the true extent of oil and gas reserves were only dimly perceived at the time Jevons was coming to his gloomy conclusions. The third edition of Jevons’s book that contains the passages quoted was published in 1905, four years after the Spindletop field demonstrated the vast oil reserves of East Texas. There, a single well produced twice as much oil as the entire state of Pennsylvania, until then the center of the American oil industry.²⁰ And it was not until three decades later that the immense oil deposits of the Middle East began to be explored.

The essential point here is that a problem such as resource depletion can often be solved by the use of substitutes, just as coal substituted for wood, and oil replaced a great amount of coal. This does not happen easily or automatically, of course; it requires the invention, development, and application of many new ways of doing things. The large-scale employment of petroleum fuels required a host of new technologies: seismic exploration devices, casings and bits for rotary drilling, new compounds for the cementation of bore holes, and so on. Equally important, the use of a new source of energy must be complemented by the emergence of new energy-

using technologies. In the early 1900s, the coal-fired reciprocating steam engine was a proven technology, while the gasoline-fueled internal combustion engine was cranky and unreliable, and the diesel engine had scarcely emerged from the laboratory. The rapid strides made by these new engine types in the ensuing years was both a product of the availability of new fuels as well as a stimulus to their accelerated extraction.

Alternatives to Fossil Fuels

The example of the widespread substitution of petroleum-based energy for coal-based energy applies to many other diminishing resources. It demonstrates that at one level of analysis, the cure for depletion and environmental damage can be found in new technologies that successfully address the problems generated by old technologies. Still, this is not the end of the matter. Historical analogies have their place, but like all analogies, they must be treated with caution. The fact that technological solutions have been found in the past is no guarantee that they will be found in the future.

Nuclear Energy: From Panacea to Peril

The limitations of technological solutions to energy shortages are all too apparent when nuclear energy is examined. Beginning in the 1950s, nuclear energy was heralded as the next stage in the evolution of energy sources. In the words of a former head of the U.S. Atomic Energy Commission, nuclear power would produce electricity that was “too cheap to meter,” (it has been argued that this phrase has been misleadingly taken out of context),²¹ In any event, nuclear power has not been an energy panacea. Although it now provides about 10 percent of the world’s electricity and 4.5 percent of total energy²² its future is uncertain at best. In addition to costing twice as much per megawatt as a coal-fired plant and five times as much as one using natural gas,²³ the generation of nuclear power requires considerable expenditure of energy for uranium mining and transportation, equipment manufacture, plant construction, maintenance and administration, and waste disposal. When all of these energy inputs are taken into account, nuclear plants make a much smaller contribution to net energy supplies than their output indicates, and a number of years will go by before the cumulative contributions of a nuclear facility exceed the energy that went into its construction and operation.

Second, the product of nuclear plants is electricity, and electricity has its limitations. Electricity is not a source of primary energy; it is a means of transmitting energy, and as much as 10 percent of the energy used to generate electricity is lost in transmission. This means that, if possible, it is always better to produce energy close to where it will be used. Although rooftop solar panels are not the most efficient way of generating electricity, they may outperform a large power plant situated hundreds of miles away when transmission losses are taken into account. Also, electrical energy cannot be used for all purposes. Although fossil fuels are an important source of electrical power, the substitution of nuclear plants for conventional generating facilities would diminish but not come close to eliminating the need for energy derived from fossil fuels. Nuclear power is sometimes offered as an effective way of slowing global warming through the replacement of power plants fueled by coal or gas. Again, its contribution would be significant, but limited. Depending on the type of conventional

power plant being replaced, tripling the present generating capacity supplied by nuclear power would reduce greenhouse gases by between 11 and 26 percent.²⁴

Finally, accidents at nuclear plants are rare but potentially catastrophic. In 2011, an earthquake and subsequent tsunami caused a partial core meltdown and hydrogen explosion at the nuclear facility near Fukushima, Japan. In addition to the massive economic losses incurred by the region and the nation as a whole, the disaster resulted in hundreds of immediate deaths and will lead to the eventual loss of thousands more due to greater-than-normal incidences of cancer.



*/AP Images

Although nuclear power plants do not produce greenhouse gases, they present other dangers, as was demonstrated when a tsunami led to a catastrophic explosion at the Fukushima Daiichi nuclear power plant in 2011. The severely damaged No. 4 reactor building, shown here, housed 460 tons of nuclear fuel in a storage pool in its upper floors.

Less dramatically, nuclear wastes present serious long-term problems.

The processing of ores into nuclear fuel has left a residue of hundreds of millions of tons of radioactive waste, while thousands of tons of radioactive materials remain as by-products of civilian and military nuclear programs. In addition, large quantities of low-level radioactive wastes are generated through medical and industrial applications of nuclear technologies. In the United States, these dangerously radioactive materials now reside in 131 “temporary” storage sites while efforts to open a permanent waste facility near Yucca Mountain, Nevada, have been stymied by technical problems and political opposition.²⁵

Problems with the disposal of nuclear wastes are not confined to the United States, and they will only intensify with the expansion of nuclear power. If global production of nuclear energy went from its current annual output of 350,000 megawatts to 1 million megawatts, the resultant waste material would fill a disposal facility the size of Yucca Mountain in only three-and-a-half years.²⁶ Alternatively, nuclear plants could use a “closed cycle” process through which nuclear wastes are recycled into nuclear fuel. This method, however, entails additional costs. More ominously, it results in the production of large quantities of plutonium that could be the basis of a nuclear weapon if only a small amount fell into the hands of terrorists or hostile states.

Renewable Sources of Energy

Lest it be thought that nuclear energy is being singled out as an especially problematic source of energy, it should also be noted that other alternative energy sources have their own shortcomings. The energy of the sun offers a fantastically large source of potential energy; the solar energy that strikes the earth in 40 minutes equals the world's annual consumption of energy. The trick, of course, lies in effectively using even a modest fraction of that energy. Significant strides have been made in that direction. In 1970, electricity produced by photovoltaic cells cost \$60 per kilowatt-hour (kWh). By 1980, the cost had fallen to \$1 per kWh, and by 2009, it stood at 46.9 to 70.5 cents per kWh.²⁷ By the second decade of the twenty-first century, the price had fallen further to 12 to 30 cents per kWh for small to medium installations.²⁸ An alternative, more centralized form of solar technology uses the sun to heat troughs of water or oil that is then routed to a heat exchanger that in turn produces steam to drive a turbine. Yet another solar energy technology uses a steam-powered turbine by focusing sunlight on a "power tower" filled with liquid sodium. Up to now, the economic and technical limitations of solar technologies have inhibited the widespread adoption of power derived from the sun, but solar power has been making steady gains in costs and efficiency, and it will likely become more significant as conventional energy sources become increasingly costly.

Wind power, a very old technology, has been increasing in importance in recent years. When sited in the proper location, the most efficient wind turbines can produce electricity for as little as 2.35 cents per kWh.²⁹ As with solar energy, this price reflects the operating cost of generating electricity; when construction costs are included the price is necessarily higher, but putting an exact value on these costs is complicated when interest rates and subsidies are figured in.

As with solar energy, the use of wind power will increase as more efficient turbines are developed and the costs of carbon-based sources rise, although complaints about noise and the degradation of landscape aesthetics will limit or prevent the construction of wind turbines in some areas. Wind power also shares with solar cells the problem of episodic operation. This means that some way to store energy is needed for times when the sun

doesn't shine and the wind doesn't blow. Wind and solar also suffer from a fundamental mismatch: areas of maximum sunlight or wind are usually far from the places that consume the most electricity. Redressing this situation will require substantial upgrading of electrical transmission lines, the design of which goes back a hundred years.³⁰ At the household and small business level, it may be possible to use batteries for the provision of supplemental electricity. Batteries are the obvious choice, but despite substantial progress in recent years, batteries remain expensive and space-consuming sources of electricity.

At present, the most important source of renewable energy is hydropower, which accounts for about 10 percent of electrical generation in the United States. In recent years, however, it has come under considerable criticism because dams alter the ecology of river systems, often to the detriment of the plants and animals that live in them. It is unlikely that massive new hydropower projects will appear in the years to come.



Sylvain Sonnet/Corbis

Wind turbines and nuclear power plants are alternatives to the use of fossil fuel, but each carries disadvantages as well as advantages.

Other sources of renewable energy might take on more significance as reserves of fossil fuels are depleted and their environmental consequences become unacceptable. Among these are biomass (plants and other organic sources), geothermal, methanol (methyl alcohol) produced from coal and gas, ethanol (ethyl alcohol) produced from plants, and nuclear fusion (although not for many decades, if ever). Still, for the immediate future, none of them can rival petroleum and natural gas as relatively cheap and convenient sources of energy. These fossil fuels will continue to be of central importance for many decades. The key issue will be using them efficiently.

Doing More with Less

The generation and use of massive quantities of energy is the cornerstone of industrial society. Much of the expansion of production (and of course consumption) that has taken place since the Industrial Revolution has come through the development of technologies dependent on external sources of energy. Countering the depletion of fossil fuels as well as their adverse consequences will require the use of new sources of energy. Still, it must be remembered that new sources will generate new problems, as will the employment of effective pollution-control strategies; in both cases, there are few, if any, cost-free technological fixes. In the early twentieth century, the replacement of the horse by the automobile was widely applauded because it promised a far cleaner urban environment—in those days horses in New York City deposited 2.5 million tons of manure annually.³¹ One might speculate on which source of pollution is preferable, the emissions of cars or of horses.

Instead of substituting one source of pollution for another, a better course of action is to try to reduce pollution by cutting back on energy use. Here, it is useful to distinguish *conservation* from *curtailment*. The former implies doing the same sorts of things with fewer inputs of materials and energy, while the latter implies an actual loss of output and consumption. Fortunately, most of the advances in recent decades have in fact come from conservation. In the United States, energy intensity (the ratio of energy used to productive output) peaked during the second decade of the twentieth century and has been declining ever since.³² The total amount of energy used has increased, but the emergence of more fuel-efficient sources of energy (primarily the shift from wood and coal to oil and natural gas), changes in the structure of the economy, and the development of more energy-efficient technologies allowed the rate of economic growth to outstrip by a comfortable margin the rate of energy use.

A portion of the improved output-to-energy ratio can be attributed to the growth of services (which use relatively little energy) and the relative decline of industrial production (which uses a lot of energy). It should be pointed out,

however, that the growth of the service sector has been accompanied by increasing energy use in developing countries, most notably China, that have become major producers of manufactured items bought by economically advanced nations.³³ The rest of the improvement in energy intensity has been the result of increased efficiency. New technologies along with better management of heating, lighting, and ventilation systems have reduced energy costs by billions of dollars.³⁴

Relatively modest changes in everyday items such as refrigerators and freezers have produced large benefits. Refrigerators sold today use only one-quarter the energy of those made in 1974. Were it not for this substantial improvement, operation of the 150 million refrigerators and freezers in the United States would require the generation of an additional 40,000 megawatts of electrical power.³⁵ Similar savings have been gained by replacing incandescent bulbs with compact fluorescent lamps (CFLs) and light emitting diodes (LEDs). CFLs use about one-third the energy of conventional incandescent bulbs, and they produce far less heat than incandescents. LEDs are even better; they use 75 percent less energy while lasting 25 times as long as incandescent bulbs. According to the U.S. Department of Energy, by the year 2027, widespread use of LEDs will save the equivalent annual electrical output of 44 electric power plants, each generating 1000 megawatts.³⁶

A multitude of other energy conservation measures can also be applied to commercial and residential buildings. Many of them require nothing in the way of advanced technology. Intelligent site selection and proper orientation of buildings and the windows in them can result in structures staying warmer in the winter and cooler in the summer while making use of natural light. Adequate sealing and insulation prevents the loss of hot air in the winter and cool air in the summer, while the provision of thermal storage in buildings allows the use of electricity for air-conditioning to be shifted to off-peak hours, thereby obviating the need to build new generating facilities.³⁷ At the same time, there are many electronic technologies that can produce significant energy savings. Microprocessor-based integrated controls for heating, ventilation, and cooling can keep temperatures within narrow limits that are optimal for different rooms in a building, so during the summer a computer room can be kept cooler than a storage room.³⁸

Additional gains could come through more intensive recycling efforts.

One noteworthy example comes from a prodigious user of energy, the aluminum industry. Aluminum smelters consume 3 percent of the world's electrical supply, and the electricity used to produce one ton of aluminum would run a typical U.S. household for nearly 18 months. Much less energy is required to convert aluminum beverage cans back into raw aluminum, making these cans a valuable part of the waste stream, as is demonstrated by the fact that 75 percent of these cans were recycled in the United States in 2013.³⁹

More Miles to the Gallon

Even greater savings follow when the fuel consumption of private vehicles is reduced. Gasoline, which is primarily used by cars and light trucks, accounts for about 45 percent of the petroleum refined in the United States.⁴⁰

American automobiles are also responsible for 20 percent of CO₂ production in the United States, an amount greater than the total emissions of CO₂ from all but three of the other nations of the world.⁴¹ Improving automotive technology to produce greater efficiency would thus be a major step in arresting both resource depletion and global warming.

There are essentially three ways of enhancing the fuel economy of cars and trucks: reducing weight, improving aerodynamics, and making engines and accessories perform more efficiently. All of these have contributed to the substantial gains in fuel economy scored by American automobiles after the first energy crisis in 1973. For the 1975 model year, American cars averaged about 13.2 miles per gallon (mpg); by 2013, fuel mileage had nearly doubled to an average of 25 mpg.⁴² An even more impressive advance—if it can be achieved—will come with the 2025 model year, when each automobile firm's fleet will be required to average 54.5 mpg.

The largest share of this improvement was effected by reducing weight. Cars became smaller and lighter, but the shift to front-wheel-drive designs for many models maintained interior space. Better aerodynamics also helped, while under the hood, fuel injection, turbochargers, computerized engine controls, variable valve timing and lift, and detail improvements allowed engines to squeeze more mpg while actually increasing performance.⁴³ It is not certain that these ongoing improvements to fuel mileage and performance can continue at the same rate. Still, there are many promising technologies that could result in considerably more fuel-efficient vehicles. Greater use of aluminum and plastics can make cars lighter, as can the use of more space-efficient designs. More aerodynamic improvements will be made, for they promise substantial rewards; a 10 percent reduction of a car's air resistance can improve fuel economy by 3.5 percent, while a 10 percent weight reduction yields only a 2.5 percent gain.⁴⁴ Many of today's cars are

aerodynamically “cleaner” than automobiles of the past; the original Volkswagen Beetle had a coefficient of drag (cd) of 0.48, while the cd for a 2010 Toyota Prius was only 0.25.⁴⁵ Still, there is considerable room for improvement; experimental vehicles have been built with drag coefficients as low as 0.14, better than that of an F-15 fighter.⁴⁶ Production cars will not likely approach this figure in the near future, but considerable aerodynamic gains are possible.

Although the internal combustion engine is not likely to be replaced anytime soon, other parts of the automobile’s power train could undergo significant changes, such as the widespread use of continuously variable transmissions that allow engines to run at their most efficient rotational speeds. Even more radical concepts, such as cars powered by fuel cells, have already been sold to customers in small numbers. It is possible that in a decade or two, these vehicles will be on the road in substantial numbers. Several automobile manufacturers now produce battery-powered electric vehicles and more will be offered in the years to come. Even more successful have been hybrid vehicles that use both an internal combustion engine and an electric motor to optimize fuel consumption. Hybrids are now a common sight on the world’s highways; by the middle of 2015, Toyota had sold eight million Prius hybrids since their launch in late 1997.⁴⁷

Fuel-efficient cars will become more attractive as rising gas prices make them increase in appeal, and rising corporate average fuel economy (CAFE) standards required by the federal government will mandate more miles per gallon of gasoline. It is far from certain that the days of the conventional automobile are numbered, and it is likely that new automotive technologies will be able to at least partially compensate for the environmental problems caused by rising car populations worldwide.



Wolfram Steinberg/Newscom/Picture Alliance/Berlin/Berlin/Germany

This Volkswagen experimental car is able to go up to 235 miles on one gallon of gasoline. Some of the technology it embodies will eventually be used for cars sold to the public.

Economic Systems, Government Policies, and the Environment

Just as technological advances affect energy supplies and energy-conservation measures, so too are there a substantial number of innovative technologies that can help to control toxic wastes, pollutants, and other undesirable by-products of modern technology. Many new technologies can be used to substitute for hazardous materials and processes, make more efficient use of potentially toxic materials, and counteract existing hazards. But as important as these technological advances are, one would be overly optimistic to think that new and improved technologies are the solution to all of our environmental ills. As Chapter 1 argued, technological fixes have their place, but when major problems are involved they must be complemented by social, political, and cultural changes. Some of these changes may occur spontaneously, but many of them must be encouraged by laws, regulations, and other government interventions. Even when a technological fix can be developed, it is often necessary to stimulate its use through the formation and implementation of effective policies.

During the energy crisis brought on by the OPEC oil embargo in 1973, some scholarly observers came close to panic. As they saw things, the massive reduction in oil supplies was the latest symptom of a massive crisis. Combined with population growth and environmental destruction, the contraction of energy supplies was forcing major changes in industrial societies. Democratic procedures would have to be replaced by powerful, even authoritarian, government mandates. One influential economist looked toward a dangerous future and reluctantly concluded that “the passage through the gauntlet ahead may be possible only under governments capable of rallying obedience far more effectively than would be possible in a democratic setting.”⁴⁸ His assumption, one shared by many others, was that in the face of a massive crisis, the only salvation lay in a government’s ability to force people to sacrifice their individual interests in favor of the collective good. A highly centralized government was inescapable, for only such an authority could bring sufficient expertise to bear on the shaping of the

necessary policies and at the same time stifle individual actions contrary to these policies.

There may be a surface plausibility in these ideas, but they are easily refuted by an examination of the performance of centrally planned economies like the Soviet Union and the People's Republic of China during the years of Maoist ascendancy.⁴⁹ Inefficient and wasteful production along with massive environmental destruction were painfully evident in these and other centrally directed economies.

While the inefficient use of energy and environmental degradation was endemic in these economies, the converse, that an unfettered market economy is environmentally benign, is no less problematic. The history of capitalist economic development has been marred by numerous examples of pollution, contamination, and heedless exploitation of natural resources. This is to be expected; a pure market system, engine of economic growth though it may be, is by its nature a threat to the environment. Markets generally do a good job of coordinating production and consumption, but they are not effective in dealing with consequences that lie outside the transactions of individual buyers and sellers. The problem lies in what economists identify as "negative externalities." These occur when the cost of a commodity sold by one party and bought by another does not take into account the costs borne by other parties, such as the damages suffered by downstream residents when a paper mill dumps its wastes into a river.

In similar fashion, a transaction may not take into account the loss of an irreplaceable resource to future generations. The price of a commodity may reflect some depletion costs, but time lags may prevent adequate corrective actions. In many cases, the price of a dwindling resource will increase at too slow a rate to signal its rapid depletion. The result is an overshoot-and-crash situation. This situation resembles a car driven by someone with slow reflexes; by the time the driver perceives a problem ahead and decides to apply the brakes, it is too late to avoid a collision.⁵⁰

As will be noted in greater detail in Chapter 18, the imperfections of a market system can be alleviated by intelligent regulations and tax policies, government-sponsored research programs, and educational efforts. The consequences of governmental policies have been particularly evident in the development and application of energy technologies, although the results

have not always been benign. Critics of the nuclear industry argue that atomic power would never have gained a foothold without loan guarantees, limits on liability in the event of accidents, and financial support for the disposal of wastes.⁵¹ Renewable energy has also depended to a significant degree on government subsidies. From 1992 to 2014, wind power installations received a tax credit of 2.2 cents per kWh of electricity generated for their first 10 years of operation, while until recently, the solar industry was supported by cash grants that amounted to 30 percent of the construction costs of new projects.⁵² The oil and gas industry does not receive direct subsidies, but according to critics, tax breaks of a sort that only an accountant or lawyer could understand and love have been worth \$70 billion over a 10-year period.⁵³

Less controversial is governmental support of scientific and technological research relating to the environment. Providing economical and environmentally friendly sources of energy will require an increased pace of research and development (R&D) efforts on a variety of fronts. Although private industry has been an important source of energy-related R&D funding, governments have also been essential, if erratic, providers. Federal government-sponsored R&D expenditures on nonfossil sources of energy rose sharply in the wake of the energy crises in the 1970s, but only temporarily. R&D for nuclear energy continued at a high level in the 1980s, but R&D for other sources of energy underwent a sharp decline and then more or less leveled off from the mid-1980s onward.⁵⁴

The federal budget for the 2013 fiscal year allocated \$1.051 billion for renewable energy R&D.⁵⁵ By comparison, defense R&D expenditures for that year came to more than \$130 billion.⁵⁶ There is no guarantee, of course, that higher levels of R&D support would have resulted in an array of technological breakthroughs on the energy front or for the benefit of the environment as a whole. Still, it does seem likely that we would be in better shape today if R&D on conservation and renewable sources of energy had been supported at least a bit closer to the level of military expenditures.

At the same time, it should be recalled that the availability of a potentially superior technology does not ensure that it will be used. The development of technologies that could help us use energy more efficiently, reduce pollution, and make fewer demands on a fragile environment is only part of the

solution. Individual choices, corporate and governmental policies, the general distribution of income and power, and the willingness to forsake short-term advantages for longer-term benefits are at least as important as any combination of technological fixes. These will be the ultimate determinants of our ability to maintain and even improve our material standard of living while at the same time preserving the environment that has sustained us through centuries of carelessness, neglect, and exploitation.

QUESTIONS FOR DISCUSSION

1. What do you consider to be the greatest environmental threat facing the world today? What sort of measures need to be taken to counter it? What will be the major sources of resistance to these measures?
2. The long-term environmental consequences of CO₂ emissions cannot be known for sure. Earth's atmosphere is an extremely complex system that is driven by a great multitude of variables. Predictions of climate trends are, and probably always will be, based on data that are not completely adequate. Are we justified in enacting laws to enforce significant reductions in the use of fossil fuels on the basis of imperfect scientific information? At what point can we decide that the assessment of risk is exact enough to warrant taking firm actions?
3. In the text, a distinction was drawn between conservation and curtailment. Are the energy-saving measures taken in the past 15 years primarily examples of conservation or curtailment? Will future energy-saving strategies be based on the former or the latter?
4. The continual extraction and use of natural resources does not result in their being completely "used up," but eventually the costs of extracting a diminishing resource exceed the value of the resource; barring improvements in extraction technologies, the resource is as good as gone. This may not happen for a long time, perhaps not until we as individuals are long departed from this earth. Is there anything immoral about using large quantities of Earth's resources for our own benefit? Do we owe anything to future generations? If so, by how much should we restrict our use of resources? How should these restrictions be mandated?
5. A considerable improvement in the fuel economy of automobiles has been the result of "downsizing." Yet all other things being equal, smaller cars are not as safe as larger ones in the event of an accident. Can a substantial savings in fuel justify the likelihood of more traffic-related injuries and fatalities? At the same time, more fuel-efficient automobiles also produce fewer pollutants, leading to fewer pollution-induced deaths and illnesses. Is it possible to construct a

balance sheet that takes into account all of these factors in order to determine if smaller cars improve or threaten our physical health?

6. A major issue in environmental analysis is sustainability. Is our present economy and society sustainable over the long run? In what ways do present technologies undermine sustainability? Are there any that promote it?

CHAPTER SEVEN

Medical Technologies

Some may doubt the overall benefits of technological advance, but almost everyone would agree that improvements in medical technologies have made our lives better. Who would want to go back to the not-so-good old days, when vast numbers of children died in infancy, epidemic plagues wiped out millions, and pain and suffering were an inevitable part of everyday life? Not too long ago, medicine's ability to cope with sickness was severely limited at best. In many—perhaps most—cases, medical intervention only made bad situations even worse. The knowledge base of medical technology was pathetically underdeveloped, rendering the majority of therapies ineffective or worse. As Lewis Thomas describes this unhappy situation:¹

Bleeding, purging, cupping, the administration of infusions of every known plant, solutions of every known metal, every conceivable diet including total fasting, most of these based on the weirdest imaginings about the cause of disease, concocted out of nothing but thin air—this was the heritage of medicine up until a little over a century ago.

More recently, technological advance supported by an expanding knowledge base has extended the lives of many, while eliminating or at least reducing a great deal of agony. How could anyone quibble with such positive results? And yet, it should be apparent by now that, in aggregate, technological advance is never an unmixed blessing. Problems are solved or at least alleviated, but at the cost of a new set of difficulties, many of them unforeseen. Medical technology is no exception. As we shall see, for all its unquestioned benefits, technological advance has generated some vexing

problems. Understanding the nature of these problems is important in its own right, and at the same time it may help us come to a deeper understanding of how technological advance can take with one hand as it gives with another.

In assessing the significance of modern medicine, it is important to bear in mind that not all historical improvements in mortality and morbidity are the result of advancing medical technologies. During the past 200 years, dramatic advances have taken place in medical care: immunization for the prevention of infectious diseases, antiseptic surgery, anesthetics, antibiotics, and the transplantation of organs. However, the positive impact of all these advances has been comparatively small. The real gains in life span and improvements in the physical quality of life have been due to better nutrition, sanitation, and personal hygiene, along with higher standards of living in general.²

Recent decades have seen the development and application of many new medical treatments, but it is not at all certain that they have had their intended effect. In fact, there may even be a negative correlation between the use of these treatments and patient health. This is strongly suggested by a recent study of Medicare patients conducted by researchers at Dartmouth University's Medical School. The study found considerable regional variations in the treatment of patients with serious illnesses during the last two years of their lives, with aggressive medical treatments being much more common in some parts of the country than in others. Paradoxically, however, patients in these regions were less satisfied with their care, ended up no better in terms of day-to-day function, and died at a slightly higher rate than patients in regions with less aggressive care. There are a number of reasons for this anomaly, but chief among them is the higher concentration of medical specialists in regions that have the most aggressive medical practices. Medical care in regions with large proportions of specialists is characterized by an excessive use of tests and procedures, extended periods of hospitalization, and a fragmented approach to patient care that sharply contrasts with the holistic approach of primary-care physicians.³

This is not to say that technological advances in medicine have been of no value. Many people are alive today because of kidney dialysis, computerized tomography (CT), and antibiotics. Modern medical technologies have generated new possibilities and new hopes. Instead of accepting sickness and

death as the inevitable product of fate or God's will, we increasingly expect that cures will be found, and that they will be made available when we need them. But along with rising expectations come rising costs. We do not have to suffer and die quietly (and inexpensively); new medical technologies allow life to be extended for long periods of time. As a result, medical advances and their associated costs have the potential to expand without limit, for as long as people are subject to sickness and death, there will be no lack of demand for new medical interventions. Moreover, unlike other goods and services, expenditures on medical care are not usually weighed against other possible expenditures. You may decide to defer the purchase of a new car to make a down payment on a house, but indefinitely deferring a quadruple bypass operation is not an option when it is all that stands between you and a life of progressive debilitation.

While the costs of medical care have been escalating, they have become largely irrelevant to most individuals because government and private insurance programs have paid for the bulk of medical expenditures, a trend that has been reinforced by the implementation of the Affordable Care Act ("Obamacare"). In 1960, one-half of U.S. health care costs were directly borne by patients and their families. The years since then have seen a major expansion of private insurance plans, as well as the creation and expansion of government-supported Medicare and Medicaid programs. In 2013, of the nearly \$2.5 trillion in personal health care expenditures, private insurance plans paid for 34.3 percent. Medicare and Medicaid were responsible for 22.3 and 16.6 percent of expenditures, respectively. Other private and government programs accounted for another 13.5 percent, leaving only 13.7 percent of medical costs to be borne by individuals.

While patients are insulated from much of the cost of medical care, far more medical treatments are available than was the case 50 years ago. Under these circumstances, there has been a strong tendency to provide increasing amounts of medical care and for a country's medical costs to increase with no apparent endpoint. As one analyst put it, "When benefits do not have to be weighted against costs—when the only criterion is that there be some benefit—the number of good things that can be done in medical care is, for all practical purposes, unlimited."⁵ All of these "good things" have created a situation in which 40 to 50 percent of the increase in medical costs over

recent decades can be attributed to new medical technologies and the increased use of preexisting ones.⁶ Although it is difficult to do so, especially when life and well-being are at stake, choices eventually have to be made. Increasingly sophisticated medical technologies offer many benefits, but they can also generate costs that threaten to spiral out of control. Items of high-technology medicine should not be applied indiscriminately; like any other claim on our financial and other resources, they need to be evaluated in terms of the benefits they provide and the costs they incur. A useful starting point for evaluating the appropriateness of particular medical technologies has been provided by Bryan Jennett, a British neurologist. According to his analysis, a medical technology can be deemed inappropriate for a number of different reasons:⁷

- Unnecessary** The patient has a condition too advanced to respond to treatment, as would be the case with attempting an extended treatment of metastatic cancer.
- Unsafe** Complications outweigh the probable benefit, as with some invasive investigations and dangerous therapies.
- Unkind** The quality of life after treatment is not good enough or its duration long enough to have justified the intervention.
- Unwise** It diverts resources from activities that would yield greater benefits to other patients.

These are useful analytical categories, but in actual practice it may be very difficult to determine which of these categories apply to particular cases. Doctors still need to have the ability to make accurate prognoses, and compassion always has to be combined with informed judgment.

New Medical Technologies: Choices and Trade-offs

It is not always easy to scrutinize a particular medical technology in terms of costs, benefits, and general appropriateness—especially when it applies to us or someone close to us. Still, it is worth making the effort, if only to better comprehend the dilemmas often posed by the advance of medical technologies. The brief studies that follow should help to make the key issues more concrete.

The Case of Kidney Dialysis

Sophisticated technologies may be of limited importance to the population as a whole, but for many individuals, they are literally the difference between life and death. The benefits of recent technological advances are nowhere more evident than they are to people suffering from kidney disease. In a healthy individual, the kidneys regulate the body's acid–base concentration, maintain proper water balance, and concentrate metabolic wastes that are subsequently excreted as urine. Complete or substantial kidney failure (known in medical jargon as “end-stage renal disease”) usually results in incapacitation and premature death. Many are afflicted: Urinary diseases are the nation's fourth-largest killer, right behind cardiovascular diseases, cancer, and pneumonia.



Corbis

Dr. Willem Kolff (center) with the prototype of a kidney dialysis machine intended for home use.

In the early 1940s, a Dutch physician used a bathtub and parts salvaged from a foundry to construct the first device to successfully take the place of the kidneys. The inventor, Dr. Willem Kolff, later immigrated to the United

States, where his device inspired the development of more refined versions at a number of hospitals. At that time, cleansing the blood by means of an artificial kidney (a process known as dialysis) was confined to short periods of time. Use of dialysis as a substitute for functioning kidneys became possible in the early 1960s through equipment improvements and the invention of a connecting tube that obviated the need to tap into a new artery and vein every time that a patient was hooked up to the machine. This made long-term dialysis a practical proposition, but at the same time, it generated a host of nonmedical problems that have yet to be resolved.

When dialysis first became an accepted medical practice, the number of patients who could potentially benefit from it far exceeded the number of available machines. It was therefore necessary to select some patients for dialysis and to reject others. To make these choices, the nation's pioneering dialysis institution, the Seattle Artificial Kidney Center, established an Admissions and Policy Committee to screen applications and determine who would get dialyzed and who would not. The committee was intended to reflect the community as a whole, being initially comprised of a lawyer, a minister, a housewife, a labor leader, a government official, a banker, and a surgeon, as well as two physician-advisers.⁸ The members of the committee made their first selective cut by accepting patients only from the state of Washington, and by eliminating children along with adults over the age of 45. Having done this, the committee then applied a set of criteria that took into account the personal characteristics of prospective patients. According to one report, these included the "sex of patient, marital status, and number of dependents; income; net worth; emotional stability, with regard to patient's ability to accept the treatment; educational background; nature of occupation; past performance and future potential, and names of people who could serve as references."⁹

As might be expected, making life-or-death decisions on the basis of the presumed worth of the patient generated a fair amount of indignation in some quarters. According to two critics, a psychiatrist and a lawyer, the published accounts of the selection criteria "paint a disturbing picture of the bourgeoisie sparing the bourgeoisie, of the Seattle committee measuring persons in accordance with its own middle-class suburban value system: scouts, Sunday school, Red Cross. This rules out creative nonconformists, who rub the

bourgeoisie the wrong way but who historically have contributed so much to the making of America. The Pacific Northwest is no place for a Henry David Thoreau with bad kidneys.”¹⁰

The problem of controlling access to a potentially lifesaving technology was mitigated as the number of machines increased and they were made easier to operate. It even became possible for a patient to routinely dialyze himself or herself at home. But formidable cost problems remained. In 1970, a twice-weekly dialysis cost \$3,000 to \$5,000 and required start-up expenditures of \$9,000 to \$13,000. For most patients, these expenses produced grave financial pressures, and for some, they were impossible to meet. The problem was apparently solved in 1972 when the U.S. Congress authorized payment for dialysis treatments through the federal government’s Medicare insurance program.

The process whereby this policy was enacted illustrates the capricious way in which technologies are sometimes supported. The government’s assumption of payments for dialysis treatments was in large measure the result of intense lobbying, an effort that was made all the more effective by connecting an abstract ailment with actual people. In one instance, the vice president of the National Association of Patients on Hemodialysis and Transplantation not only testified but dialyzed himself in the presence of members of the House Ways and Means Committee.¹¹ The provision of Medicare payments for dialysis was only a small portion of a larger piece of legislation; only 30 minutes of debate on the floor of the Senate took place, culminating in a lopsided vote in support of the measure at a time when close to half of the senators were absent. The conference committee of the House and the Senate took only 10 minutes to discuss the measure, which was only slightly modified as a result. Both houses subsequently accepted the conference committee’s report, and the bill including the dialysis provision was signed into law by President Nixon two weeks later.¹²



Javier Larrea/AGE Fotostock

Kidney dialysis has become a common procedure that has saved many lives while at the same time contributing to rising medical costs.

Payment for dialysis through the Medicare program addressed a real need, but at considerable cost. Initial estimates of annual expenditures of \$135 to \$250 million were far too low. In 2014, annual hemodialysis costs in the United States came to \$42 billion; \$34 billion of this sum was absorbed

through the Medicare budget. The rest was either covered by Medicaid, private insurance, or paid by the patient.¹³ Of course, it is not some abstract entity that we call the federal government that pays for most of the costs of dialysis; these expenditures are ultimately borne by individual taxpayers, the vast majority of whom are not afflicted by end-stage renal disease. There is nothing inherently unreasonable or unfair about this. A catastrophic organ failure could happen to any of us, and we shouldn't begrudge helping people who have been less fortunate than ourselves. Still, questions remain about the equity of paying for dialysis and not for other ailments, especially since people suffering from end-stage renal disease comprise 1 percent of Medicare enrollees while absorbing 7 percent of the Medicare budget.¹⁴

Today, about one-third of the patients receiving dialysis are over the age of 65. As the population ages, it can be expected that the demand for dialysis will increase apace, putting further financial strains on the health care system. This may not occur in some countries where government insurance programs do not always cover dialysis for patients with other serious medical problems. In Great Britain, the government-run National Health Service always has operated under tight financial constraints. Consequently, certain treatments have been restricted, dialysis included. During the early years of dialysis treatment, patients over the age of 55 were rarely given the opportunity to receive dialysis because it was believed that their physical constitutions would not allow them to survive and flourish under a regimen of daily dialysis. One British physician candidly stated that people over the age of 55 were not suitable candidates, for they were all "a bit crumbly."¹⁵ This may be true in a statistical sense, but in fact, there is greater variation in overall levels of health among the elderly than there is in any other age group. Using age as a means of limiting access to an expensive medical technology is administratively convenient, but it dodges the issue of making choices on the basis of more relevant criteria. In any event, in Great Britain, increasing numbers of people over the age of 65 are now receiving dialysis. As in the United States, dialysis takes a disproportionate share of the overall medical budget; the cost of providing dialysis for 0.05 percent of the population with end-stage renal disease absorbs about 1 to 2 percent of the National Health Service budget.¹⁶

Is the American policy of giving universal access to dialysis the correct

one, or is the former British policy more defensible when financial resources are limited? There are no easy answers. At the same time, the problems of distributive justice posed by the use of artificial kidneys are only a preview of what will have to be faced as new and even more expensive medical technologies become available and medicine gains the ability to successfully address hitherto untreatable conditions.

Replacing Broken Hearts

The dilemmas engendered by the advance of medical technologies are further illustrated by the prospect of using new technologies to counteract the number one killer in the United States, heart disease. In recent decades, many victims of clogged arteries and weakened hearts have gained a new lease on life through coronary artery bypass grafts. This procedure is now routine in many hospitals, but once again, questions of cost and benefits have to be confronted.

Open-heart surgery became feasible in the early 1960s with the development of devices that could take over the heart's functions during surgery. By 1970, the efficacy of these procedures was attested to in several papers appearing in medical journals. Over the following years, bypass surgery became a common surgical intervention. In bypass surgery, a segment of a vein is removed from the leg or chest and spliced into one or more of the five coronary arteries that transport blood from the heart. In extreme cases, all five arteries may receive this treatment. This procedure was effective in reducing early mortality, but only for a limited amount of time and primarily for patients with generally poor health conditions. Negative findings, however, did not alter the incidence of bypass surgery; in 2011, more than 165.6 thousand of these operations were performed at a total cost of more than \$6.4 billion.¹⁷

For patients with less severe blockages, percutaneous transluminal coronary angioplasty, commonly known as "balloon angioplasty," has been widely employed. This procedure threads a tiny balloon into a coronary artery to break up a blood clot that is obstructing the flow of blood to the heart. This procedure has saved the lives of many men and women who would otherwise have succumbed to heart failure. The total cost of angioplasties amounted to more than \$9.7 billion in 2011.¹⁸ Although many lives have been saved through these procedures, questions have been raised about their possible overuse. One study of angioplasties performed on a sample of 828 Medicare patients found that only about one-third of the patients benefited from the procedure. It was deemed completely

inappropriate for 14 percent, and it could not be determined whether or not the remaining patients were helped by the procedure.¹⁹ These unimpressive results were mirrored in another study conducted in 2007, when 2,287 patients with stable coronary artery disease were divided into two groups. About half underwent balloon angioplasty, while the others received nonsurgical medical therapy that entailed the administration of statins (to reduce cholesterol), beta-blockers, diuretics (to lower blood pressure), and aspirin or other blood thinners (to prevent excessive clotting). The latter group had more chest pains (which could be controlled by medication), but there was hardly any difference among the two groups in the frequency of strokes and heart attacks.²⁰

Although this study seriously called into question the massive employment of balloon angioplasty with its attendant financial costs and patient discomfort, it seems to have had limited influence on actual practices. The ratio of balloon angioplasty operations to nonsurgical interventions hardly changed after the publication of the study. In summarizing their results, the authors of the study noted that more attention needed to be paid to nonsurgical treatments: “These findings represent a significant opportunity for improvement and a limited effect of an expensive, highly publicized clinical trial on routine clinical practice.”²¹

For many cardiac patients, even effective and appropriate angioplasties or bypass operations are of no use because the heart has been so weakened as to be barely functional and is in danger of failing completely. The transplantation of another person’s heart offers one solution, but demand exceeds the supply. Back in the mid-1960s, the implantation of artificial hearts seemed to offer a way out of this impasse. At that time, a consulting group reporting to the federal government assumed that the major technical impediments were well on the way toward solution, and that before too long, many people would have a diseased heart replaced by a mechanical one. According to this optimistic scenario, recipients of these hearts would be able to return to the work force, adding \$19 billion to the gross national product over a 10-year period. It was even asserted that the taxes paid by artificial heart recipients would more than offset the federal government’s expenses in supporting the program.²²

In the 1960s, these hopes seemed close to realization. Artificial hearts

began to be used for brief periods of time while patients were awaiting a heart transplant, and efforts to develop a permanent artificial heart accelerated. An apparent breakthrough occurred in 1982 when the Jarvik-7 artificial heart was used for the first time. Unfortunately, the first recipient of the device, a Seattle dentist named Barney Clark, underwent great suffering as a result of the immaturity of this technology. Seizures, severe nosebleeds, pneumonia, kidney disease, gout, epididymitis, and an intestinal ulcer followed the implantation of the artificial heart.²³ Clark's postoperative existence for 112 days could hardly justify the expense and pain of the operation. Subsequent implants met with hardly any greater success. One patient lived for 620 days, but during that span, he suffered four strokes and a series of infections that severely eroded his physical and mental capacities.²⁴ Despite these setbacks and the bad publicity that attended the use of the Jarvik-7, about 90 more patients received the device in subsequent years. In 1990, the Food and Drug Administration (FDA) banned the Jarvik-7 as a permanent replacement for a human heart because most of the recipients lived for only a few months after its implantation. A more successful device is the SynCardia artificial heart. In early 2015, the firm reported that their product had kept 47 patients alive for more than a year. Of this number, 34 patients eventually received a heart transplant; 12 patients died while being supported by the device; and one patient was still being supported.²⁵

Artificial hearts are the epitome of high-tech, high-cost medical technology. They can save lives, if only temporarily, but they come with substantial price tags. Should a widespread program of heart replacement become feasible, the costs of implanting artificial hearts, along with subsequent therapy and follow-up care, would surely run into many billions of dollars. A small portion of these expenditures might be recovered when some recipients return to the labor force, but most patients would not have this option. Whatever the exact figures might be, extensive use of artificial hearts would make a significant contribution to a national medical bill that already absorbs more than 17 percent of the national income of the United States.

Extensive use of these technologies would engender some very difficult choices. The primary beneficiaries would be those who could afford an artificial heart either through insurance coverage or personal resources.

Alternatively, some sort of rationing system could be set up, as had occurred during the early years of dialysis. This is clearly a distasteful prospect for the great majority of citizens. And if rationing were to be implemented despite public resistance, what sort of criteria might be used? Ominously, criteria could include those invoked by the Seattle Admissions and Policy Committee five decades ago, including the “worth” of a prospective recipient, that is, how much the person had contributed or was likely to contribute to society. Whatever the criteria invoked, the decision to use an expensive medical technology in a world of finite resources necessitates making decisions. In many cases this can be akin to “playing God,” a role that few humans are eager to assume.



Getty Images News/Getty Images

An AbioCor heart being implanted in a patient.

The selection or exclusion of recipients is not the only equity issue that the use of expensive medical technologies pushes to the forefront. In a world of necessarily limited resources, there is no escaping the fact that an

expenditure in one area of health and medicine means the foreclosing of an expenditure in another. The tens of billions of dollars that would be required for the large-scale implantation of artificial hearts could be used to produce significantly higher levels of overall well-being through other means. To cite one example, at least a portion of the funds absorbed by an artificial heart program could instead have been used for antitobacco education campaigns. According to the Centers for Disease Control and Prevention, more than 480,000 deaths can be attributed to cigarette smoking and exposure to cigarette smoke. Smoking has been identified as a major contributor to heart disease; consequently, even a relatively small reduction in tobacco use would produce life-extending benefits considerably in excess of those offered by artificial hearts.²⁶ But as we have seen, technological fixes can be easier to implement than changes in individual behavior.

In general, the use of high-tech medicine is understandable; physicians are reluctant to take on the responsibility of deciding when to withhold treatment, and it would be foolish to deny the value of many advanced medical technologies. But whatever the outcome, there is no getting around the fact that their use contributes to the escalation of medical costs that have been painfully evident in recent decades. The contribution of modern medical technologies to ever-higher medical expenditures is particularly evident during the last year of life, when an average of about 25 percent of Medicare expenditures are incurred.²⁷ For some critics, the treatment of aged patients with advanced medical technologies is a misallocation of resources; as they see it, much of the money spent on expensive care would be better applied to the elimination of poverty among both the elderly and nonelderly, improving nutritional awareness, or promoting fitness programs.

Diagnostic Technologies

The escalation of medical costs is one of the most problematic consequences of the advance of medical technologies, but hardly the only one. To take another example, a variety of diagnostic technologies have substantially advanced physicians' ability to determine the source of medical problems. At the same time, however, they have altered the nature of medical practice, sometimes with unfortunate results.

For centuries, medical diagnosis had been based on the observation of external symptoms, patients' narratives of their illness, and the application of dubious theories that explained illness in terms of such things as imbalances in four bodily "humors." A major reorientation began in the 1820s when doctors began to use a simple tube to hear the heartbeat and other sounds within the patient's chest. Dubbed the "stethoscope," the new instrument allowed more accurate diagnosis by amplifying and focusing the sounds produced by the circulatory system. Within a few years, other instruments for apprehending hitherto hidden parts of the body were invented, such as the ophthalmoscope for observing the interior of the eye and the laryngoscope for the throat. A series of sophisticated diagnostic technologies such as X-ray machines and electrocardiographs followed. By the beginning of the twentieth century, physicians were using instruments for measuring everything from blood pressure to the electronic currents generated by the nervous system. The accuracy of diagnosis was further advanced by the development of laboratory tests for such disparate medical issues as high cholesterol levels and the presence of the organism that causes syphilis.

The use of diagnostic tests exemplifies the tendency of technologies to create their own needs. Many of the tests routinely performed today seem to be unnecessary; according to one study of a teaching hospital, 47 percent of tests performed could have been eliminated with no evident loss in the quality of patient care.²⁸ Fetal heart monitors have had few discernable benefits; their main consequence seems to have been an increase in the number of deliveries using a cesarean section.²⁹ On the other hand, the increase in lab tests is not solely the result of the availability of these tests.

Some of the increase is directly attributable to the practice of “defensive medicine.” Doctors are justifiably nervous about the threat of malpractice suits, so the safest course seems to be the overprescription of tests to avoid accusations of not having used every available diagnostic tool.



Everett Collection/SuperStock

Rene Laennec holds an example of his invention, the stethoscope, while using a more traditional method for conducting an auditory examination of a patient’s chest cavity.

The overuse of tests can produce more than financial pain. According to a past president of the Association of American Physicians, “As our interventions have become more searching, they have also become more costly and more hazardous. Thus, today it is not unusual to find a fragile elder who walked into the hospital, [and became] slightly confused, dehydrated, and somewhat the worse for wear on the third hospital day because his first 48 hours in the hospital were spent undergoing a staggering series of exhausting diagnostic studies in various laboratories or in the radiology suite.”³⁰

It can be reasonably argued that the physical and financial discomfort produced by diagnostic tests is outweighed by the greatly expanded ability to understand and treat illnesses. But another, more subtle consequence of sophisticated diagnostic technologies is that they have encouraged the treatment of specific disorders rather than human patients. In many cases, a physician, by examining an X-ray plate or a microscope slide, can produce an accurate diagnosis even when the patient is not physically present; indeed, the physician does not even have to be personally acquainted with the patient.

In going about their diagnostic work, few physicians today trouble themselves with obtaining lengthy narratives from their patients regarding their patients' ailments. The physician's personal diagnostic skills are often slighted in favor of more "objective," scientifically based knowledge attained through the use of sophisticated tests and instruments. This is a process that began with the stethoscope; although a very simple device, it changed the nature of the interaction between doctors and their patients. As Stanley Joel Reiser explains, the use of the stethoscope "helped to create an objective physician, who could move away from involvement with the patient's experiences and sensations, to a more detached relation, less with the patient but more with the sounds from within the body."³¹

A similar story could be told of the sphygmomanometer, the ubiquitous instrument used for the measurement of blood pressure. After its introduction in the late nineteenth century, physiologists praised the instrument's capacity to produce objective, quantitative, and precise data. Many practicing physicians saw things differently, however, fearing that the sphygmomanometer would "intervene between patients and doctors, dehumanize the practice of medicine, and replace the delicate art of medicine with mere technical proficiency."³²

The use of increasingly sophisticated diagnostic technologies illustrates the mixed blessings of technological advances in medicine. On the positive side, far more data can be gathered and analyzed, allowing physicians to identify illnesses that might otherwise have been misdiagnosed, or to catch a disease in its early stage when it can be more easily treated. Standard tests also help to promote a standardized medical practice, removing the biases and blind spots of individual practitioners. Consequently, medicine is more "scientific" and less tied to the variable skills of individual practitioners. At

the same time, however, other kinds of medical skills are in danger of being lost. Not every aspect of a functioning organism can be reduced to “objective” data. Treating illnesses often requires more than the ability to process information of this sort and use it as the basis of treatment. Judgment, experience, and even “intuition” can be of vast importance for a successful medical practice. Ideally, the use of sophisticated diagnostic technologies frees doctors from tedious work, leaving them with more time for personalized interactions with patients and more accurate diagnoses. Unfortunately, this is not what always happens. A fixation on the use of modern diagnostic technologies can easily result in the denigration of diagnostic skills that historically rested upon more personal relationships with patients. Consequently, a focus on “objective” data such as blood pressure or hormone deficiency to the exclusion of all else can lead a physician to miss some crucial clues regarding the source of a patient’s illness.

This has a significance beyond diagnosis. Sick people usually have something physically wrong with them, but organic disorders may be only part of the problem. Illnesses often have psychological components as well, and the successful treatment of these requires more than the application of medical techniques; communication, the ability to build a bond of trust with the patient, and some measure of empathy are also necessary. An overreliance on “objective” data can obscure and even drive off these qualities, to the detriment of medical care as a whole. As Reiser notes, a physician must resist the tendency to place an excessive reliance on diagnostic technologies and the information they provide: “Accuracy, efficiency, and security are purchased at a high price when that price is impersonal medical care and undermining the physician’s belief in his own medical powers.”³³

Medical Technologies and Medical Ethics

While contemporary medical training has emphasized the objective, “scientific” dimension of medical care, it has also conferred the belief that the highest duty for members of the medical profession is to preserve life. On the face of it, it is hard to take issue with this principle. At the same time, however, advances in medical technology have rendered the creation and preservation of life increasingly problematic. At all stages of life, medical practitioners along with their patients and their patients’ families may have to grapple with major ethical dilemmas that are closely related to the application of contemporary medical technologies. These dilemmas have given rise to the field of medical ethics, a discipline that has emerged in recent decades in an effort to systematically address the issues that have attended advances in medical technology.³⁴

New Ways of Making and Sustaining Babies

Technological advances have created ethical issues that arise long before birth. One important threshold was crossed in 1978 with the birth, in England, of the first baby to have been conceived through in-vitro fertilization. Since that time, hundreds of thousands of babies have been born worldwide through the use of this procedure, although the exact number is difficult to determine. In-vitro fertilization entails bringing sperm and egg together in a petri dish (the term *in vitro* literally means “in glass”). The sperm can be supplied by the husband or partner of the woman whose eggs are to be fertilized, or it can be provided by a donor, anonymous or otherwise. After the fertilized egg is cultured for three to four days and develops into an embryo with at least four cells, the embryo is transplanted into the uterus of the egg donor or a surrogate. Because each procedure entails the fertilization of more than one egg, in-vitro fertilization results in the production of many surplus embryos every year. These can be kept viable for long periods of time, but many are simply discarded. Alternatively, the embryos can be a source of stem cells, the basis for an emerging technology that will be discussed in the following chapter.

In-vitro fertilization is most commonly used to circumvent blockages of a woman’s fallopian tubes or a man’s insufficient sperm production. A different reproductive issue occurs when a normal pregnancy is impossible or undesired. Under these circumstances, a surrogate mother can be implanted with an embryo that has resulted from the fertilization of another woman’s egg. Alternatively, a surrogate mother can be artificially inseminated with sperm that fertilizes her own egg. The latter process led to a court battle in the 1980s when a surrogate mother refused to give the baby she had carried through pregnancy to the couple who had contracted for her services. Although the case was eventually resolved largely in favor of the couple who had hired the surrogate, the present legal status of surrogate motherhood has been described as being “in a state of flux and confusion.” Some states ban the practice entirely, while others enforce surrogacy contracts. Other states allow them under certain circumstances, while others have no applicable laws

at all. In the last case, it is up to the courts to determine parenthood when these contracts are subjects of disputes between the various parties involved in the process.³⁵

More generally, new reproductive technologies have muddled accepted notions about a fundamental constituent of human society, the family. Whether through artificial insemination, in-vitro fertilization, or surrogate motherhood, the ability to bypass the usual methods of procreating children has called into question the very definition of a family. It is now at least possible for a child to have several parents: two fathers (the sperm donor and the man taking on the conventional social role of father) and three mothers (an egg donor, a surrogate to carry the embryo through pregnancy, and the woman who ends up occupying the social role of mother).

While controversy still surrounds nontraditional reproductive methods, a different set of issues comes to the fore with the birth of babies who have been born prematurely. On the one hand, the ability to preserve the lives of prematurely born infants has been all to the good, as many “preemies” have gone on to lead healthy and productive lives as a result of these interventions. Unfortunately, some prematurely born infants are afflicted with major medical problems that result in lack of function, continual pain, and early death. As with the end-of-life issues about to be discussed, the value of preserving the lives of infants destined to a lifetime of pain and sickness can be debated at considerable length. And, as with the case of many modern medical technologies, it is at least open to question if the hundreds of thousands of dollars sometimes spent on preserving the life of one severely premature infant might better have been used for prenatal care, which continues to be inadequate for many expectant mothers.

Some of the medical problems that potentially afflict all newborns, premature or otherwise, can be forestalled through the use of prenatal and postnatal testing. Many of these procedures do not entail ethical or financial issues. For example, the genetically based illness phenylketonuria (PKU) causes seizures, intellectual disabilities, and hyperactivity by affecting the ability of the body to metabolize a particular enzyme. It can be successfully treated through dietary restrictions, but only when there is an awareness that the disorder is present. To this end, newborns are customarily screened for possible PKU through an easily administered blood test, and a potential

individual and social problem is averted.

Other tests are more problematic and give rise to a number of ethical questions. The target of these tests is the genetic abnormalities associated with particular illnesses. From the late 1960s onward, amniocentesis (testing of the amniotic fluid in the uterus) has allowed the detection of genetically linked abnormalities such as Down syndrome and spina bifida. Unlike PKU, however, treatment of these conditions is difficult or nonexistent. Should a serious disability of this sort be discovered, prospective parents have to decide if the fetus should be aborted or be allowed to survive, a difficult decision for many. Amniocentesis also makes it possible to determine the sex of a fetus, thereby bringing another ethical issue to the fore: Is the desire for a boy or girl a sufficient basis for aborting a fetus of the “wrong” sex?

The decision to abort a medically abnormal fetus can be circumvented through the use of in-vitro fertilization in conjunction with a process known as preimplantation genetic diagnosis (PGD). This is done by analyzing the DNA of one cell that has been extracted from an embryo to determine if there are chromosomal abnormalities associated with diseases such as cystic fibrosis and Tay-Sachs. Only an embryo without this abnormality would then be transferred to the uterus. PGD obviates the need to abort an abnormal fetus, but the disposal of embryos is still unacceptable to those who believe that life begins at the moment of conception. Ethical issues of this sort will become more common in the near future as the ability to detect potential problems increases. Further complicating matters will be the emergence of in-utero tests that may not be definitive, providing only statistical probabilities of future disorders. What might expectant parents decide if a test indicates that there is a 50 percent chance that their child will be stricken with cancer before the age of 20? The rapidly developing science of genetics will surely raise many issues of this sort, some of which will be explored in the next chapter.

When Does Life End? When Should It?

While medical technologies have raised a host of ethical issues regarding how life is to be created, they also have been the source of new ethical dilemmas that emerge at the other end of the life span. One centers on the very conception of when life has become unsustainable. In the not-too-distant past, the failure of one or more vital organs was tantamount to death. Today, however, organ failure and even multiple organ failures can be circumvented by devices such as feeding tubes, respirators, and dialysis machines. Even a major and irreversible loss of brain function can no longer be taken to be an unequivocal indication of death.

The issue of determining when death occurs received a great deal of national attention from 1998 onward when family members took opposing sides over the removal of a feeding tube that was sustaining a 34-year-old woman named Terri Schiavo. Although she had been in a “persistent vegetative state” for more than eight years, her parents strongly resisted her husband’s efforts to terminate their daughter’s life through the removal of the tube. What had been a family matter was then thrust into the political arena when it was taken over by politicians with opposing values about the prolongation of life through artificial means. In 2005, after many court hearings, legislation that was overturned by the Supreme Court, political posturing, and a great deal of acrimony, the tube was removed, and Terri Schiavo died at the age of 41.

A feeding tube is not a particularly sophisticated item of medical technology, but in some circumstances it helps to maintain organic functions for an indefinite period of time. Whether or not the maintenance of these bodily processes is the same thing as preserving a life lies at the center of the ethical debate over the use of modern medical technologies for this purpose. This issue is not easily resolved, and it will become more prominent in the years to come as emerging technologies make it possible to preserve organic functions for longer periods of time and under increasingly difficult circumstances. At the same time, end-of-life issues are becoming increasingly salient as the elderly comprise a large and growing portion of the total

population of the world's industrially developed nations. As with costly medical technologies in general, measures to extend the lives of elderly patients are in competition with alternative uses of scarce medical resources. Economic calculations cannot substitute for ethically based judgments, but both will have to be taken into account as advanced medical technologies solve one set of problems while giving rise to others.

Halfway Technologies

The dilemmas presented here demonstrate the decidedly mixed blessings bestowed by medical technologies that are only palliative. A kidney dialysis machine does not cure the disease that led to kidney failure in the first place, just as a heart bypass operation comes into play only after the damage has been done. Many of the apparent breakthroughs of recent years are nowhere near as efficacious and cost-effective as the dramatic advances of the past. For example, relatively inexpensive vaccination campaigns completely eradicated smallpox as a human disease, significantly contributing to longevity and a better quality of life. In contrast, despite decades of intensive efforts, we have made only marginal progress in overcoming cancer, the second-largest cause of death in the industrial world. Many of today's technological advances in medicine have extended life spans and eased pain but have done little to address the causes of disorders themselves.

For a patient suffering from organ failure, the availability of dialysis or a heart transplant can be the difference between life and death. But for the society as a whole, the escalating costs of medical care driven by these "halfway technologies" constitute a formidable problem. No one is comfortable with putting a dollar value on a human life, but the years to come may see the emergence of more explicit efforts to balance the costs of new technologies with their benefit to society as a whole. Far from offering across-the-board advantages, the development of new medical technologies will force us to grapple with increasingly difficult choices concerning their application. Financial considerations aside, new and emerging medical technologies will also intensify existing ethical quandaries while creating some new ones as well. As we shall see in the next chapter, the rapid development of genetic technologies will allow the successful treatment of many illnesses and infirmities, and may allow the complete eradication of some others. But to repeat a now familiar theme, these advances will give rise to a new set of issues that will demand our attention.

QUESTIONS FOR DISCUSSION

1. As noted in this chapter, about one-quarter of Medicare and Medicaid expenditures are incurred during the last year of life. Given the increasing financial burdens of both programs, should anything be done about this situation? If so, what?
2. When the demand for a new medical technology exceeds the supply, what should be used to determine who gets it? A lottery? The ability to pay? The “merit” of the recipient? Might it be better to limit the development of new technologies in order to forestall the need to make these choices?
3. Attempts at developing devices to completely replace human hearts have not been successful, but many technologies require a long development period before they are successfully employed. Should R&D for artificial heart technologies continue? If so, how should it be financed? Are there some ongoing medical programs that are less deserving of financial support than the development of an artificial heart?
4. Who should make the decision to terminate life support when a person is in a permanent vegetative state, and has left no instructions concerning the indefinite prolongation of his or her life? Should government officials, elected or otherwise, have a role in making this decision?
5. Some medical procedures can be characterized as “halfway technologies,” while others are at least close to being completely effective. What accounts for the difference? What “halfway technologies” of the past have become much more effective today? Why has this advance occurred?

CHAPTER EIGHT

| Genetic Technologies

As was noted in the previous chapter, many of the dilemmas that surround the use of medical procedures such as dialysis and the implantation of artificial hearts are a consequence of their status as “halfway technologies.” They offer the prospect of survival and some relief from a potentially fatal disease, but they do not cure it. The practice of medicine is badly in need of technologies that are more than palliatives. This is not a vain hope, for we may be on the threshold of medical advances equal to vaccination or antiseptic surgery. In recent years, much has been learned about the structure and mechanisms of cellular reproduction, giving rise to the prospect of eventual cures for a host of ailments. Yet when we consider the possible impact of technological breakthroughs in this area, we are confronted with a familiar theme: every advance is both a solution and a problem.

The Genetic Fix

The fundamental scientific insight underlying many emerging medical technologies is that the growth and reproductive mechanisms of each cell are governed by the basic unit of heredity, the gene. Humans have about 20,000 genes arrayed along the 46 chromosomes found in the nuclei of every cell, other than red blood cells (which have no nuclei) and sperm and egg nuclei (which have 23 chromosomes). The human genome consists of long chains of deoxyribonucleic acid (DNA), which collectively contain more than 3 billion letters that comprise the human genetic code. These letters (also called “bases” or “base pairs”) are in effect instructions for making proteins, the essential building blocks of life. Some of the DNA sequences that make up a genetic code may be faulty and can give rise to a variety of disorders. Genetic screening or actually altering an organism’s genetic code offers revolutionary new ways of diagnosing, curing, and even preventing the emergence of many disorders.

Gaining the ability to successfully treat genetically based disorders has been the work of many decades. People had long been aware that parental traits often reappeared in their offspring, but they could only speculate on the mechanism that made this happen. An important step forward came with experiments conducted during the latter half of the nineteenth century by Gregor Mendel. His systematic study of the propagation of peas revealed rules of inheritance through which traits were passed from generation to generation, although the biological processes that drove them were still unclear.

While Mendel was conducting his experiments, other scientists had been taking advantage of improvements in microscopy to obtain a better understanding of the constituents of plant and animal cells. First came the discovery of the cell nucleus, followed by the use of improved staining techniques to reveal the presence of chromosomes in cell nuclei. During the first decade of the twentieth century, Thomas Hunt Morgan found that these chromosomes were the site of the key agent of heredity, the gene. Morgan and his associates performed experiments with fruit flies that helped them to

unravel the process of trait transmission, but little was known then about its molecular basis. The puzzle began to be solved in the 1940s when DNA (deoxyribonucleic acid) was identified as the key constituent of genes. This set the stage for one of the most important scientific discoveries of the twentieth century. In 1953, James Watson and Francis Crick determined that the molecular structure of DNA consists of bases attached to pairs of sugar-phosphate backbones that form intertwined spirals, the now-famous double helix. This discovery laid the foundation for rapidly expanding insights into the functioning and reproduction of cells.

Another milestone was reached in the 1970s when researchers learned how to separate and isolate portions of DNA. This allowed the development of procedures for transferring genetic material from one organism to another. As has been the case with a great deal of contemporary scientific research, new technologies have created greatly expanded opportunities for advancing scientific knowledge. In the case of genetics, the development of polymerase chain reaction machines gave researchers the ability to obtain and analyze virtually unlimited amounts of DNA, while at the same time identifying mutations associated with particular diseases.

Continued advances in laboratory equipment and techniques made possible the discovery of the distinctive sequence of bases that characterized the DNA of a few individual genes. This gave rise to the possibility of determining the sequences for all of a particular organism's genes. By the mid-1980s, the 150,000 bases that made up the genome of a virus had been sequenced, but the possibility of doing the same thing for the more than 3 billion bases of the human genome seemed remote at best. But by the early 1990s, new technologies in the form of automated sequencers and mapping machines, along with faster and more powerful computers, were propelling advances in basic science. The eventual determination of the human genetic map had become a distinct possibility.

Discovering Genes and Patenting Them

Up to this point, the sequencing effort had been conducted by researchers working as part of the Human Genome Project, which had been launched in 1990 and co-ordinated by the U.S. Department of Energy and the National Institutes of Health. By the end of the decade, a private company, Celera Genomics, also was engaged in decoding the human genetic code. In early 2001, both enterprises separately published “rough drafts” of the human genome that were in general agreement with each other. The complete sequence was published in 2003, exactly 50 years after the discovery of the molecular structure of DNA.¹

Although Celera Genomics made a major contribution to human genetics, its involvement in genetic research has highlighted some of the issues raised by the coupling of scientific discoveries with commercial motivations. Even before the mapping of the human genome, the potential monetary value of genetically engineered organisms was underscored when in 1980, the U.S. Supreme Court in a 5:4 decision ruled that a human-made organism (in this case, a bacterium that could digest oil) was entitled to full patent protection.² The next stage appeared with the mapping of the human genome. Researchers were now able to hone in on specific genes and determine their function. Armed with this information, biotech firms successfully filed patent applications that gave them commercial control over the application of that gene. For example, when a biotech firm held a patent based on their discovery of a gene implicated in certain kinds of cancer, they then had an exclusive right to market laboratory tests, diagnostic devices, and therapeutic products based on that gene.

The rationale for allowing genes to be patented was the same as for the patenting of mechanical devices or new chemical compounds, that the possibility of obtaining a patent would serve as a powerful stimulus for innovative research. At the same time, however, critics pointed out some serious problems inherent in the patenting of genes. In addition to giving rise to monopolies, critics noted that the patenting of genes would likely retard scientific advance by inhibiting the free flow of information. Patent

documents could provide essential information, but to directly employ the gene usually required the payment of permission fees to the holder of the patent. Moreover, genetic research often required numerous steps and stages, each of which may have been controlled by a different patent, and fees were sometimes assessed for the use of the information covered by a patent. Even the process of simply finding out who owned what could entail substantial costs. Critics also pointed to the practice of “patent stacking,” whereby a single gene sequence was covered by separate patents covering key elements of the gene, such as expressed sequence tags and single nucleotide polymorphisms, along with the gene itself.

The patenting of genes was the source of considerable revenue. Commercial entities such as pharmaceutical firms were profiting handsomely from gene patents, but so were public and not-for-profit institutions such as universities and research organizations. Allied against these for-profit and nonprofit organizations were public-interest organizations and many components of the medical establishment, including the American Medical Association, which has a long history of opposing the patenting of medical and surgical procedures.

After a number of lower court rulings, and with billions of dollars at stake, the U.S. Supreme Court took on the patenting of genes in 2013.³ The case centered on Myriad Genetics, a Salt Lake City firm that held patents on two genes, BRCA1 and BRCA2, linked to ovarian and breast cancer. Their ownership of these patents allowed Myriad Genetics to claim royalties from any medical provider performing tests for the presence of these genes. In the case of *Association for Molecular Pathology, et al. v. Myriad Genetics, et al.*, the Court unanimously ruled that as “naturally occurring” entities, genes were “products of nature,” and as such were not subject to being patented.⁴

Bioengineering on the Farm

A less dramatic but no less controversial application of genetics has been the development and cultivation of genetically modified (GM) crops, also known as genetically modified organisms (GMOs). Genetic modification is nothing new, of course; humans have been using selective breeding for millennia in order to improve on naturally occurring plants and animals. But selective breeding can be a hit-and-miss affair that entails thousands of genes and may take many generations to achieve an intended result. Genetic engineering makes it possible to regularize and accelerate the process by transferring a single gene or set of genes to obtain a desired characteristic.

In some quarters at least, genetic modification of food crops has become especially attractive as a way of dealing with present and future food shortages. Although there is no imminent crisis in the global production of grain, some parts of the world have been, and will continue to be, grain-deficit regions.⁵ In other parts of the world, increasing affluence is triggering a growing appetite for meat, which demands considerably more grain (and water) per capita than does a largely vegetarian diet. Finally, the effects of climate change can be debated, but they are not likely to be wholly benign as far as grain production is concerned.

Most genetic interventions do not increase crop yields by making individual plants more prolific. Rather, the costs of cultivation may be lowered through new means of controlling weeds, pests, and diseases. It is now a common practice to sow fields with crop varieties that have been genetically modified to have increased resistance to herbicides so the application of weed killers will not affect the food crop. Use of these crops may have the added benefit of allowing the application of safer herbicides that need to be used less frequently. It is also possible to eliminate or reduce the use of pesticides through the cultivation of corn and cotton varieties that have been modified to produce a pesticide derived from *Bacillus thuringiensis*, a naturally occurring soil bacterium.⁶

Genetic modification can also be used to increase the nutritional value of foods. One notable example has been the development of strains of rice that

prevent certain kinds of blindness by supplying increased quantities of vitamin A. Another example of a useful genetic modification is the creation of crop varieties capable of tolerating long periods of drought. Somewhere over the horizon is the production of “edible vaccines”—food crops that prevent certain diseases when consumed. Genetically engineered crops may also be used to promote “conservation tillage,” a mode of energy-efficient cultivation that conserves the soil and the organisms in it by eliminating or sharply reducing the need for regular plowing. On the far horizon are possible technologies that promote more efficient photosynthesis, drought resistance, nitrogen fixation, and other qualities that have the potential to significantly increase food production.⁷

GM crops now constitute a substantial portion of the global food economy; in 2014, 18 million farmers around the world were cultivating GM food crops on 448 million acres of farmland.⁸ In some countries and for some crops, GM varieties dominate. In Brazil, the second largest user of GM crops and the world’s largest producer of soybeans, 91 percent of that crop has been GM.⁹ Argentina, India, and Canada are also major planters of GM crops, but the United States is by far the largest user of GM crops, with 169 million acres—about half of total cropland acreage—sown in 2013.¹⁰ At this point, only four types of GM crops are cultivated in significant numbers—soybeans, canola, cotton, and corn—but they dominate the market in the United States. In 2013, GM crops accounted for 93 percent of the soybeans, 82 percent of the cotton, and 85 percent of the corn.¹¹ With figures like these, it is apparent that the consumption of food based on GM crops is hard to avoid in the United States. At least 60 percent of processed foods found in American supermarkets contain one or more GM ingredients, usually corn, soy, or canola.¹²

Although GM crops are confined to only a few countries, their widespread use in the United States and a few other countries has generated substantial revenues. In 2014, the worldwide market value of GM seeds and associated technology fees amounted to \$15.7 billion. Of that sum, farmers in the industrialized countries spent \$11.3 billion, or 72 percent, while the remaining \$4.4 billion was spent in the developing countries.¹³ Most of these revenues have gone to the few firms that dominate a highly oligopolistic industry.¹⁴

Opposition to GM Crops

As previously noted, the United States accounts for more than half of the world's croplands sown with GM seeds. GM crops are far less common in many other places. Some European countries have put a moratorium on their use, and opposition to such crops can be found throughout the world. At the most fundamental level, critics of GM crops share a concern that changing the genetic makeup of plants is a dangerous venture into uncharted territories. Alterations to an organism's genome, which in nature may take millions of years, can now take place in a matter of days. And, according to critics, the introduction of laboratory creations into the natural world may have dangerous unintended consequences. Opponents of GM crops point to the possible presence of new allergens or toxins that could afflict many consumers of these foods. Concerns have also been voiced about the danger of cross-pollination (sometimes referred to as "outcrossing") of GM plants with naturally occurring plants, which could result in the emergence of "super weeds" with a resistance to commonly used herbicides. There have also been cases in which genetic material from corn used for animal feed has shown up in corn intended for human consumption.¹⁵



Top photo: Philippe Psaila/Science Source; Bottom photo: Gallo Images/Getty Images

The director of an agricultural R&D center (top) in Thailand inspects genetically modified crops, while others (bottom) point to their potential dangers.

Arguments against the use of GM crops can also be based on the economics of agricultural production. In the industrially developed world, the “farm problem,” at least until recently, has stemmed from too much production, not too little, resulting in low food prices and depressed incomes for farmers. Increasing production through the use of GM crops exacerbates the problem, and puts even more pressure on small farmers who are most vulnerable to falling prices. Overproduction is, of course, not a problem in most poor countries, where simply keeping up with population growth is a major challenge for agriculture. But even there, the use of GM crops raises some important issues. Seeds for GM crops are more expensive than naturally occurring varieties. Extensive cultivation of GM crops would likely benefit wealthy, large-scale farmers and intensify rural economic inequalities. Less problematic is the alleged development and sale of GM seeds with “terminator technology” that prevents them from propagating new seeds. Consequently, each new crop has to be sown with seeds purchased from the firm that markets them. In fact, “terminator technology” is not currently employed by seed producers. Moreover, crops are not usually propagated with seeds from the previous season’s crop; new crops are generally sown with commercially obtained seeds, both GM and otherwise.¹⁶

A more serious concern, only marginally related to the use of GM crops increase, is the extension of monoculture—the cultivation of only a few varieties of plants over a wide area. This practice poses the danger of massive crop failures because it eliminates the natural firewalls that prevent the spread of a pest or disease. To be sure, massive crop failures are a rarity in modern farming, but the main thing that prevents their occurrence is the extensive use of insecticides and other pesticides, which create problems of their own.

In regard to the real and imagined dangers of GM crops, extreme fears are probably not justified. Recent research has not demonstrated that GM crops pose clear-cut dangers, but, as with all novel and potentially far-reaching technologies, a large dose of caution is certainly in order. At the very least, continued research into possible negative consequences is essential. In the words of one plant pathologist, “We need to devote the research to risks now, rather than deal with repercussions later.”¹⁷

GM crops exemplify the limitations of technological fixes. At present and for the near future, existing agricultural technologies are sufficient for

feeding the world's population. The tragic existence of millions of malnourished people is not the result of inadequate food production, but of warfare, unfair trade practices, misguided governmental policies, and the maldistribution of income and productive resources. Genetically based agricultural technologies have the potential to improve food production and nutritional standards, but they shouldn't be viewed as a substitute for needed economic and political reforms.

Genetic Mapping and Screening

While recently developed technologies are used to alter the genetic makeup of plants and other organisms, some technologies are being used to get a better understanding of natural genetic endowments and their consequences. Most notable is the use of pre- and postnatal screening to discover potential abnormalities in infants. It is hard to take issue with technologies that prevent early deaths and crippling diseases, but as will be noted next, even these benefits can have a dark side. Also problematic is the genetic screening of adults that does not have a curative intent.

Perhaps the least objectionable use of genetic mapping is in the realm of law enforcement. Identifying the perpetrators of crimes, always a major concern for police forces, has been significantly augmented through DNA testing. As has now become familiar to viewers of televised crime, both real and fictional, a DNA sample obtained from a suspect can be matched with DNA evidence taken from a crime scene to determine guilt or innocence. Sometimes it is not even essential to have a suspect's DNA sample; a close match with a relative's DNA may provide an important insight into the identity of an at-large murderer or rapist.

Tests of this sort require a prior record of an individual's genome or at least a portion of it. In recent years, many police forces have been accumulating DNA records for large numbers of people. In many jurisdictions, anyone arrested is required to submit a DNA sample, usually obtained through a simple mouth swab. Even though a suspect may be exonerated, his or her genome will remain on file, most likely in a centralized data bank maintained by the FBI. On the other side of the coin, some individuals convicted of various crimes have been exonerated when subsequent DNA tests indicated that they were in fact innocent; from the first use of DNA evidence in 1988 to the end of 2015, 363 convictions had been overturned, and 20 residents of death row were shown to be innocent.¹⁸

Whether or not the mandatory submission of a DNA sample can be successfully challenged by invoking the U.S. Constitution's prohibition of "unreasonable search and seizure" is still being debated. Meanwhile, the

collection of DNA samples by firms in the private sector has become a source of concern to civil libertarians, although it is not yet widespread. As might be expected, physicians and other medical practitioners have taken the lead; having a patient's genetic information can make an invaluable contribution to diagnosis and treatment. At the same time, however, the growing use of electronic medical records increases the danger that these records, many of which contain sensitive information, could be accessed by individuals with malicious intent.¹⁹ More benign but still problematic is the legal right of employers and insurance companies to require individuals to authorize the release of their medical records, which may contain information about genetically based disorders. The Genetic Information Nondiscrimination Act, passed by the U.S. Congress in 2008, forbids insurers from denying health insurance or charging higher premiums because an individual's genetic profile indicates a higher risk of certain health problems. This stricture does not, however, apply to life or disability insurance.²⁰ Moreover, the U.S. Equal Opportunity Commission has ruled that employers may not use genetic information when making decisions about hiring, promotions, layoffs, and other aspects of employment. At the same time, however, an employer may make a conditional job offer to a prospective employee and then require him or her to authorize the release of his or her health records as a condition of employment. Clearly, the emergence of DNA testing has created a number of issues and problems in balancing improved medical care with the protection of individual privacy, a conundrum that will reappear when we consider in a later chapter how advances in electronics also pose potential threats to personal privacy.

Cloning, Present and Future

The patenting of genes, the growing of GM food crops, and the threats to privacy posed by digitized genetic records are prominent examples of the legal and ethical issues raised by recently developed biological technologies, but they are hardly the only ones. Another prominent source of controversy has been the practice of cloning organisms. A clone is an organism that has been derived from another organism through asexual reproduction. Because all of the clone's genetic material originated with the "parent" organism, it is a genetic duplicate. During the 1950s, biologists successfully cloned frogs, but for many years, it was thought that the cloning of higher organisms was impossible or at least unlikely.

Complacency over cloning was shattered in 1997 when a team of researchers at the Roslin Institute in Scotland announced that they had successfully cloned a female sheep during the previous year.²¹ The genetic material of the sheep known as "Dolly" originated in the nucleus of a cell that had been part of the mammary tissue of an adult sheep, one of many nuclei that had been transplanted into the enucleated eggs of sheep of a different breed. Since these nuclei carried full complements of chromosomes (unlike sperm and eggs, which each contain only half the genetic material of ordinary cells), the eggs did not require fertilization. Instead, an electric shock was applied, which allowed some of the eggs to begin the process of cell division that results in an embryo. Thirteen out of 277 of these eggs were implanted into the uteruses of sheep who served as surrogate mothers. Of these, 12 miscarried, but Dolly was carried to term and came into the world on July 5, 1996.

The ultimate goal of the Roslin team was to genetically modify the cells of sheep udders so that they would produce commercially valuable drugs. The cells would then be cloned, allowing the reproduction of sheep that produced the drug along with their milk. It was anticipated that cloned sheep eventually could also be used for conducting research into genetically borne diseases. These, of course, are not the only possible applications of cloning. Sheep are not fundamentally different from other mammals, humans

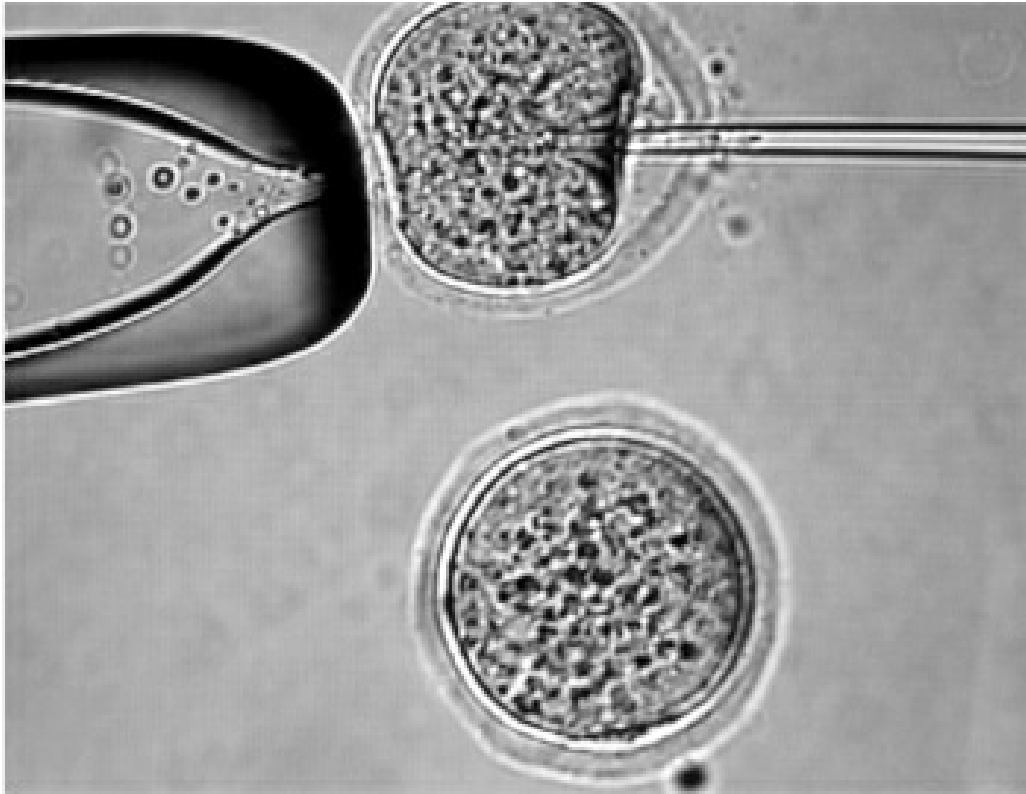
included, and there is no scientific reason that the procedures used to produce Dolly could not also be applied to the cloning of people.

The prospect of human cloning has raised a host of ethical questions. Would it be prudent to circumvent the normal process of reproduction, which ensures the healthy genetic diversity of a population? Will members of a particular segment of the population be especially inclined to clone themselves, and are they necessarily the kind of people who should be perpetuated? Will people with particular abilities allow themselves to be cloned for a fee so that prospective parents will be able to have a child with inborn talents? Will people with damaged organs clone offspring so that they are guaranteed future organ replacements that pose no danger of rejection? Might it be possible to eventually clone individuals from the cells of dead people? Right now, this is a far-fetched prospect, but so was the cloning of mammals a few years ago. Some might argue that such an outcome would be desirable, as it would preserve the genetic endowments of geniuses in the realms of science, music, the visual arts, and other exalted human endeavors. But at the same time, of course, it could also allow a ruthless dictator to attain a kind of immortality.



Maurice McDonald/AP Images

Dolly with Ian Wilmut, the leader of the team that cloned her.



James King-Holmes/Science Source

The initiation of cloning: A needle inserts the nucleus of an adult cell into an enucleated mouse egg.

Concerns over human cloning have led several governments to ban any efforts in this direction, and the U.S. government has barred the use of federal funds for human cloning research. Even so, cloning is a technology that will be difficult or even impossible to contain. Clandestine human cloning could take place anywhere, and eventually it might even be encouraged by governments beguiled by the prospect of creating a cohort of “super citizens.” In any event, neither tacit nor direct government support is essential for human cloning. There are many individuals wealthy enough to underwrite such a venture, and their ranks include persons whose outsized egos are likely to make their physical duplication an attractive proposition.

It is important to note, however, that governments or individuals will be disappointed if they expect that cloning will create identical copies of the original organism. Even “identical” twins, who are natural clones, are not really identical. There are many cases, for example, of one twin being left-

handed while the other is right-handed. Animals cloned in laboratories often differ considerably in both appearance and behavior from the animal from which they were cloned.²² These differences stem from biological processes that are still not well understood, along with environmental influences that begin in the womb and continue to shape an organism throughout its life. Without getting into the age-old debate about the relative importance of “nature versus nurture,” it simply can be stated that genetic endowments are not all-powerful, and that an organism’s environment is a major influence on its appearance and behavior. According to the rapidly developing field of *epigenetics*, an organism’s environment, in addition to being a major influence on its appearance and behavior, may also alter its genetic makeup.²³

Stem Cells and Future Therapies

At this point, the cloning of humans is only a hypothetical issue. Of much greater current salience is a promising but controversial medical technology, treating serious diseases through the use of embryonic stem cells. These cells appear during the early phase of embryo formation and have the quality of “pluripotency,” which means that they have the capability to become any of the 220 kinds of cells that constitute the human body, everything from bone cells to neurons. Stem cells in bone marrow are now being successfully used to treat leukemia, but the real promise of stem-cell therapies lies in the future. With further research it is hoped that stem cells can be used to regenerate organs that have been damaged by Parkinson’s disease, Alzheimer’s disease, and many other ailments.

Although promising, therapies using stem cells lie at least a decade in the future. The source of stem cells is still a source of controversy; current stem-cell research and application is based on stem cells obtained from embryos that have been created through in-vitro fertilization but have not been implanted into a uterus for further development. Alternatively, it may be possible to extract stem cells from embryos that received the genetic material of a patient to be treated with these cells. In either case, the use of embryos has galvanized opposition to stem-cell research. For individuals and groups who hold that life begins at conception and that an embryo is a human being, the destruction of an embryo through the extraction of stem cells is akin to murder.

Adhering to this point of view, President George W. Bush in 2001 prohibited the federal funding of stem-cell research unless it used existing stem-cell lines derived from embryos that were the product of in-vitro fertilization and where the sperm and egg donors had provided informed consent. Originally thought to constitute approximately 60 stem-cell lines, only about 15 of them proved suitable for research purposes.²⁴ Other restrictions on embryonic stem-cell research created difficulties for researchers. According to the government’s rules, research using stem cells had to be kept entirely separate from other kinds of research receiving federal

funding; even the shared use of a refrigerator was forbidden.

In 2009, these restrictions were lifted by the Obama administration, a move upheld in a number of court cases. Meanwhile, embryonic stem-cell research continues to be controversial. Polls indicate that a majority of Americans are in favor of it, but support or opposition tends to break along political and cultural divisions; Republicans and frequent church attenders were more likely to oppose embryonic stem-cell research, while Democrats and less frequent churchgoers tended to favor it.²⁵

Although most supporters of this research do not believe that an embryo constitutes a human life, its use as a source of stem cells still triggers a number of issues and problems. Currently, the embryos used for stem-cell research are the surplus products of in-vitro fertilization that are destined to be discarded when they are no longer needed. However, the supply of these embryos will likely not be sufficient if stem-cell research results in therapies that have large numbers of potential beneficiaries. This would give rise to two alternative means of dealing with supply limitations, both of which may be distasteful to many. On the one hand, the products of in-vitro fertilization would continue to be the sole source of stem cells, but because the number of embryos is necessarily limited, their stem cells would go to the highest bidder, the winners of a kind of lottery, or would be allocated in a manner reminiscent of the early days of kidney dialysis. On the other hand, an emerging technology is being used to reprogram specialized adult cells so they will act as embryonic stem cells. Known as “induced pluripotent stem cells,” these cells are currently used for drug development, but as with stem cells in general, their application to specific disorders remains an ongoing effort.²⁶

The Perils of Genetic Intervention

Stem-cell research, mammal cloning, GM foods, and the sequencing of the human genome have given rise to a host of ethical concerns that touch upon some of the most basic issues of human existence. On a somewhat less abstract level, governments are faced with the task of creating appropriate public policies to encourage the development of beneficial technologies while preventing the emergence of harmful ones, or at least mitigating their worst consequences. In hammering out these policies, it will be important to guard against an excessive enthusiasm for seeking in the human genome the answer to all of our medical, psychological, and social problems.²⁷

At the level of the individual, there is no doubt that many diseases have a genetic component, but genetic defects are not always clear-cut; a gene that malfunctions under one set of environmental, nutritional, or other external conditions may be perfectly adequate in different circumstances.²⁸ It cannot even be said with complete confidence that the presence of a seemingly harmful gene is an unmixed hazard; genetic “imperfections” provide the raw material of genetic variability upon which natural selection operates.²⁹ Also, a search-and-destroy campaign waged against “defective” genes is likely to be a quixotic affair, for it may not always be possible to identify them. Each of us carries between 5 and 10 defective genes that have no consequence for us individually but which could at some future time become a problem for our progeny.³⁰

Finally, and most importantly, an overemphasis on the role of genes in determining physical and behavioral qualities could lead to a revival of the now discredited eugenics movement. Initiated in the late nineteenth century by Charles Darwin’s cousin, Francis Galton, the eugenics movement had many adherents, including leading scientists, politicians, and intellectuals.³¹ Its basic postulate was that biological inheritance was the major source of human differentiation; if some people had superior strength, intelligence, and even morality, it was because their ancestors exhibited these qualities and passed them down to their descendants. Although its focus was on the qualities of individuals, eugenics easily lent itself to racist notions of human

differentiation. According to the majority of eugenicists, the white race occupied the pinnacle of human development and all others were arrayed at lower places of the human hierarchy. The sexes, too, could be divided according to their general abilities, with women on average presumed to have lower intellectual capabilities than men, although they were deemed to be superior in the “lesser” qualities of empathy and nurturance.

Eugenics aimed at being far more than a scientifically based way to account for human variation; it was also a call to action. According to eugenicists, human progress depended upon the perpetuation of individuals with superior genetic endowments and the limitation or even elimination of those with inferior qualities. According to the program envisaged by “positive eugenics,” individuals whose physical, mental, and moral qualities marked them as “superior” were encouraged to have children who would inherit and perpetuate these qualities. This, however, was a difficult task. Much easier was the promotion of “negative eugenics,” which aimed at preventing the transmission of “undesirable” qualities from one generation to another. In its mildest form, negative eugenics motivated the promotion of birth control for low-income groups. It was also associated with more draconian measures, most notably the sterilization of “defectives.” In the United States, more than 60,000 compulsory sterilizations of “defectives” were performed between 1907 and 1963.³² The most horrific examples of negative eugenics took place in Nazi Germany, where 350,000 sterilizations were performed in the name of improving the German *Volk* and millions of men, women, and children were killed because they were adjudged to be members of “inferior races.”³³

These ghastly actions undermined much of the support for negative eugenics, but support for positive eugenics continued well into the 1960s. Although it was shorn of its racist underpinnings, eugenics was still predicated on a concern that humanity was threatened by the deterioration of its genetic foundation. Genetic endowments were taken to be the major source of human variation, and as one eminent geneticist put it in the early 1960s, “Human welfare, both with individuals and with society, is predicated on the health of the genetic endowment of human populations.... [An] appalling amount of human misery is due to defective heredity.”³⁴



Wisconsin Historical Society, WHS-2003

An early twentieth-century demonstration of support for eugenics. The demonstrators did not necessarily agree with the statements on the signs they were holding; they were hired to participate in the demonstration.

Eugenics in the Twenty-First Century

Eugenics has ceased to be a social movement aimed at human betterment, but concerns about the genetic endowments of individuals are very much with us. The elimination of genetically borne defects is no longer a government policy. Instead, it is now an individual, personal matter, as physicians and parents-to-be make extensive use of a variety of tests to determine the presence of genetically linked disorders such as Tay-Sachs and Down syndrome. Through genetic counseling, prospective parents are helped to decide if a fetus with inborn defects should be aborted or carried to term.³⁵ For prospective parents using in-vitro fertilization, this decision is somewhat less painful because it is now possible to test a single extracted cell from an embryo consisting of only eight cells. Even so, the decision to terminate life at any stage of development is a difficult one. Yet for all of the potential anguish they may cause, these choices will likely become more widespread as researchers find genetic links to a growing number of disorders.

Although more medical problems may come to be associated with particular genetic malfunctions in the years to come, their influence should not be exaggerated. For one thing, a decade of research conducted after the initial sequencing of the human genome has shown that early expectations of tying certain diseases to particular gene abnormalities turned out to be far too optimistic. There is no question that genetic abnormalities can be implicated in many diseases, but how the two are connected is turning out to be far more complicated than had been anticipated in 1990.³⁶ As we have seen earlier, making the transition from science to technology is often a long and difficult process. It is also important to understand that genes never determine physical and behavioral development by themselves. Genes function within individual organisms, and these organisms are always affected by their environments. As David S. Moore has noted, “It is a mistake to think that genes are necessarily the first link in the causal chains of biological events. From the moment of conception, environmental factors and genetic factors are in an ongoing ‘dialogue’ with one another about building a person. Each of these sets of factors brings its own necessary information to this conversation.”³⁷

Focusing upon genetic endowments to the exclusion of everything else is

a simplistic form of determinism that harks back to excesses of the eugenics movement. At the same time, it is more than likely that advances in biological and genetic research will serve as the basis for a plethora of potential medical applications. Taken to the extreme, expanding knowledge about genetics holds out the promise—or the threat—of what the eminent biologist Edward O. Wilson has called “volitional evolution,” that is, directing human heredity to favor some traits while extinguishing others.³⁸

The possibility of purposefully altering the course of human evolution has recently been boosted through the development of a new technology known as *Crispr-Cas9*, which allows an organism’s genome to be easily and inexpensively modified.³⁹ Should *Crispr-Cas9* and other twenty-first century genetic technologies live up to their potentials, we will be presented with “the most profound intellectual and ethical choices that humanity has ever faced.”⁴⁰ We have yet to get to that point, but continued progress in understanding the structures and operation of the human genome will offer new ways of addressing a host of physical and psychological maladies. It will take a great deal of collective wisdom and foresight embodied in new ethical principles to decide which should be pursued and which should be rejected.

QUESTIONS FOR DISCUSSION

1. Where do you stand in the debate over using fetal tissue as a source of stem cells? Are embryos human beings? Even if they are, might it be justified to extract stem cells from them in order to cure an individual of a debilitating disease?
2. GM foods are sometimes derided as “Frankenfoods.” Is this a fair way to characterize them? Do you have any qualms about consuming GM foods? Why?
3. Most specialists are of the opinion that there are no technical barriers to human cloning. Although no legitimate agency is likely to financially support human reproductive cloning, it could be funded by an individual seeking to perpetuate himself or herself. Should such a practice be forbidden with stiff penalties attached? If so, how would such a ban be enforced?
4. Gene-based therapies can now be used to successfully treat cystic fibrosis and a few other diseases, and more applications of this technology may be expected in the future. If they become available, should there be encouragement (financial and otherwise) for all gene therapies? Should they be used to treat “deficiencies” like premature baldness or short stature? Who should be empowered to decide if these therapies should be developed and applied?
5. The field of epigenetics has challenged the utility of the long-standing “nature versus nurture” debate. In its place, accumulating scientific evidence is demonstrating the effects of environmental factors on an organism’s genetic makeup. Are there any implications of this approach to heredity for both the individual and society?
6. What does Edward O. Wilson mean by “volitional evolution”? Is it just a synonym for eugenics? Is it something that should be pursued?

PART FOUR

Technology and the Transformation of Work

Few elements of human life have been as powerfully affected by technological change as the ways in which we spend our working lives. As is noted in Chapter 9, humans survived for most of their existence through gathering and hunting. This mode of life was radically overturned by the adoption of agriculture, and then much later by industrialization. The introduction of new technologies has been a prominent feature in all of these transitions, but as argued in this chapter and contrary to commonsense beliefs, technological advance did not always make working life easier; in fact, sometimes the contrary has been true.

Although modern technologies have provided us with a plethora of goods and services with less physical effort, they have also brought with them the fear of widespread unemployment. Chapter 10 takes up this long-standing issue, indicating when this fear is appropriate and when it is misplaced. Without downplaying the real pain caused by job losses due to technological change, this chapter provides some reasons to be optimistic about the future levels of employment, while at the same time noting the effects of technological change on the distribution of income and wealth.

Chapter 11 moves the discussion from the *quantity* of available work to the *quality* of working life. Industrialization radically changed the nature of work. New technologies altered many aspects of life on the job, as did the theories and practices of management that were developed at this time. Today, it is often remarked that we are living in a “postindustrial” economy

and society, but the distribution of skill and authority in the workplace is still a contentious issue, and will likely remain so, even as some occupations flourish while others disappear.

CHAPTER NINE

| Work in Nonindustrial Societies

For most people, the majority of their waking hours is spent doing some sort of work. Be it as an assembly line worker, a sales clerk, or a psychiatrist, we gain our livelihood and a good measure of our individual identity from the work that we do. Technological change has been a major influence on the way we go about our work. Today, few of us are directly engaged in the actual production of things. Nor do we find it necessary to work from sunup to sundown in order to secure our livelihood. All in all, technological change appears to have lightened our workload substantially. Yet, by now, it should be apparent that the consequences of technological change are not always simple and straightforward. The development of technology over time has not always resulted in diminished workloads; in fact, the opposite has sometimes been the case. In this chapter, we will examine the relationship between work and technology before the onset of industrialization. The facts and concepts developed here will provide perspectives that should be helpful when we consider subsequent changes in work and technology.

Working with the Earliest Tools

The history of work is virtually synonymous with the history of the human species. To trace the influence of technology on work, we need to begin with our likely ancestors, the Australopithecines, who were shaping and using stone tools at least 2.6 million years ago. Paleoanthropologists are not in agreement as to which group of primates are entitled to be put in our genus, *Homo*, but there is no doubt that making and using tools was one of their distinguishing characteristics.¹ Although early stone tools have a crude appearance, this does not mean that the productive technologies early humans employed were primitive. From the outset, it is important to draw a distinction between the apparent crudity of the product and the skill that went into making it. Technologies in “primitive” societies are simple because only a few tasks are involved in the productive process, and a single person usually performs all of them.² In these societies, the division of labor is limited; a worker does everything required to produce something, and the work process is not fragmented into separate tasks allocated to different individuals.³ There may be some degree of specialization; a few jobs may be the exclusive work of women or men, or a worker may specialize in the production of a particular good, although again the task is his or hers from start to finish.⁴ But most workers in “primitive” societies do not specialize in a single task, so they are not likely to be virtuosos in a particular area. They are, as the old adage has it, jacks of all trades and masters of none.

This lack of specialized skills does not mean, however, that workers in “primitive” societies are lacking in technical ability. Although the overall work process is simple, the individual workers may be highly dexterous and ingenious as they go about their work. Take, for example, the production of stone tools. What could be more primitive than Stone Age technology? But in point of fact, the production of stone tools is a considerable achievement. In the first place, the idea of making an implement by chipping a stone is hardly obvious. Although sea otters commonly use a stone for breaking clam shells, modifying a stone so that it can serve as a better tool is unknown in the animal world. Second, the fabrication of stone tools is a task that calls for

considerable skill and practice. The effective chipping of a stone tool requires the preparation of a properly sited striking platform on the stone to be chipped, and the delivery of the striking blows at the proper angle. In some cases, the stone is chipped by the use of a pressure chipping tool, such as a piece of antler, which forces a flake off as pressure is applied to it. Whatever the method employed, the production of stone tools is not a simple process; most of us would experience some difficulty in duplicating the work of early humans and protohumans.⁵ At the same time, new generations of toolmakers did not have to develop these techniques by themselves. The regularity of the tools' shape and design suggests that the techniques of toolmaking were transmitted from person to person. An educational process was an integral part of Stone Age technologies.

The use of stone implements by prehumans and early humans was a crucial factor in the development of a species of animal that would forever be characterized by its ability to make and use tools. This ability was not simply the result of biological evolution; it was at the same time a cause of it. The process through which early hominids evolved into humans began with the assumption of upright posture and the anatomical changes that made the hand capable of performing an increasing variety of tasks. One of the most important of these was the production and use of tools. In turn, tool use stimulated brain development and gave an advantage to those individuals whose mental capabilities allowed them to be the most proficient makers and users of tools.

In sum, manual dexterity, tool use, and brain development evolved together in a mutually reinforcing manner.⁶ By the Upper Paleolithic era, this combination of evolved hands and brains had given rise to an impressive variety of equipment: pins, awls, needles with eyes, spoons, saws, axes, pestles for grinding, scoops, and shovels.⁷ Some early hunters discovered that they could double the distance that a spear could be thrown through the use of a throwing stick (also known as an *atlatl*), long before Archimedes (c. 287–212 B.C.) explained the principle of leverage.

Work and Leisure in Technologically Primitive Societies

Significant as the first tools were for human development, the control over the environment that they offered was modest indeed. It is easy to visualize a life that, in the classic formulation of the seventeenth-century philosopher Thomas Hobbes, was “nasty, brutish, solitary, and short.” A “primitive” technology seems to be associated with a precarious and insecure existence, one in which the daily struggle for mere subsistence occupied all of a person’s time and energy. But once again, we fail to give technologically unsophisticated people the respect they deserve. Research on the actual lives of these people indicates that Hobbes may have been wrong, and that a life of unremitting toil is not a necessary consequence of a low level of technological development.

Societies that sustain themselves through hunting and gathering are rare today. Still, there are a few parts of the world where agriculture and industry have not taken over and the ways of earning a living likely resemble the ones employed by our prehistoric ancestors. One such place is the Kalahari Desert of southern Africa, the home of the !Kung Bushmen. It is a harsh, difficult environment, one that would seem the natural locale for the kind of life described by Hobbes. Since they possess only the simplest technologies, it might be expected that the life of the !Kung is one of unceasing hardship, and that the bare necessities of life are obtained only through continuous toil. Yet this is not the case. As the field research of Richard Lee has demonstrated, the !Kung do not have to work especially hard.⁸ By gathering protein-rich mongongo nuts and over 80 other species of food plants, and supplementing these with the meat of game animals, the !Kung provide themselves with a nutritionally adequate diet. The work of gathering and hunting is not particularly arduous. According to Lee, adults put in a six-hour workday on average, about two and a half days a week. Earning a living thus requires only a total of 12 to 19 hours of labor each week. These numbers do not include times spent on food preparation and traveling to hunting grounds and areas suitable for gathering, however.⁹ The remainder of the !Kung’s working

hours are taken up with such activities as visiting and entertaining friends and relatives, and engaging in dances that put the participants into a trance.

The modest work required to meet the needs of the !Kung has led one commentator to characterize the !Kung community as “the original affluent society.”¹⁰ Here, affluence is not the same thing as abundance, for the !Kung lack the material possessions common to more technologically advanced societies. A nomadic people, they have no permanent dwellings. Their clothing, as befits life in a warm climate, is minimal. They lack all but the most basic domestic utensils, and they have no way of conveying these except on their own backs.

Besides not producing many material goods, they have not produced many of their own kind. They have controlled their rate of reproduction and have avoided putting excessive pressure on their environment. The population density in their territory is only 41 persons per square mile. In contrast, agricultural societies have densities ranging from a few hundred to several thousand, while urban centers in industrial societies may pack tens of thousands of people into a square mile of space.

What the !Kung do have in great supply is leisure time. This leads to the seemingly paradoxical conclusion that technological progress may result not in the saving of labor but in its increase, or, as Marshall Sahlins puts it, “the amount of work per capita increases with the evolution of culture, and the amount of leisure per capita decreases.”¹¹ Why is this so? The answer lies in the equivocal connection between technological change and the requirements of work. A technologically dynamic economy generates labor-saving devices, but at the same time it produces a steady stream of new goods that are eagerly sought after. This means that labor-saving technologies are generally used to increase income, not to reduce the hours of work. As workers in a technologically advanced society, we often find ourselves on a treadmill, working long and hard to obtain the material goods that we may have little time to enjoy.



robertharding/Alamy

A !Kung San woman with a harvest of mongongo nuts.

The !Kung live lives of marked deprivation when measured against the material standards of most other societies. Their static economy and society have not produced the continually expanding and changing outflow of goods characteristic of technologically dynamic ones. Instead, they have maintained an equilibrium between their wants and their capacity to achieve them. Modest requirements and simple technologies have produced a way of living that lacks physical amenities, but leaves much more leisure time than can be found in our more “advanced” way of life.

Work and the Development of Agriculture

Although the !Kung way of life is a rarity today, it must be remembered that hunting and gathering was the dominant mode of existence over most of the history of humankind. This age-old pattern began to change about 12,000 years ago, when people first began to cultivate their food instead of foraging for it. After its likely beginning in the Tigris-Euphrates Valley of the Middle East, within a few thousand years, farming independently appeared in other parts of the world, most notably in Egypt's Nile Valley, the Yellow River Valley in China, the Indus Valley in India, and parts of Central and South America. These were epochal developments, for in many ways the development of agriculture marked the most fundamental change in human life and the way it is sustained through work.

Why, after tens of thousands of years of successful foraging, did humans take up farming, a transition that has been dubbed the "Neolithic Agricultural Revolution"? Much debate still surrounds this question.¹² The movement from hunting and gathering to agriculture occurred over a long period of time in many different parts of the world, making it hard to generalize about its causes. Further complicating the matter is the lack of clearly defined boundaries separating the old ways of life from the new. Some hunting and gathering groups engaged in what might be termed proto-agriculture by encouraging the growth of certain plants and semidomesticating animals. It also seems to be the case that in some regions hunting-and-gathering activities remained for hundreds if not thousands of years after the establishment of sedentary agriculture.¹³ On a more positive note, despite a lack of a consensus on all of the causes of the Neolithic Agricultural Revolution, most scholars agree that changes in population size, the climate, and the natural environment strongly affected many hunting-and-gathering societies and, at least in some cases, impelled a turn to deliberate plant cultivation.

Whatever its causes, the result was a new symbiosis between plants and people. Domesticated grains could not reproduce themselves as they had done before humans intervened. People had to assiduously cultivate these

descendents of wild grasses, and their lives increasingly depended on regular harvests of grain. Technological progress thus resulted in a greater regularity of work patterns. Also, people had to work harder and more consistently because there were more of them. Agriculture allowed considerably higher population densities than those found in hunting-and-gathering societies, but at the cost of a greater workload for each individual.

Farming Techniques and Patterns of Work

The interconnections between the development of agricultural technologies, population expansion, and increases in the amount of work performed can be seen through an examination of successive stages of agricultural technology. One of the earliest forms of farming, known as slash-and-burn (or swidden) cultivation, is based on cutting down indigenous vegetation and then burning it on the spot. This not only clears the land, but it also puts nutrients into the soil. A variety of crops are then planted on the cleared land. After harvesting, the plot is abandoned for a number of years, which allows the land to replenish itself before the cultivators return to begin the process once again. Slash-and-burn cultivation stands in an intermediary position between foraging and more intensive forms of farming, and it likely antedated the more settled forms of agriculture that were practiced in the aforementioned river valleys of India, China, the Middle East, and Central and South America.¹⁴

Although slash-and-burn cultivation alters the environment more than foraging does, on the whole it makes fewer demands on the land than other forms of farming. The soil is given ample time to recover, typically five years or more, and every effort is made to nurture the tree seedlings that will regenerate the forest. The natural variety of plant life is preserved, thus avoiding the radical simplification of the environment characteristic of settled forms of farming.¹⁵ At the same time, slash-and-burn agriculture supports population densities greater than those found in hunting-and-gathering societies—up to 150 people per square mile—but with little increase in work effort. Slash-and-burn agriculture requires that an annual average of 500 to 1,000 person-hours of labor be expended on all phases of crop production.¹⁶ This comes to a little more than nine and a half to 19 hours of work per week, figures that compare quite favorably with the work schedules of the !Kung. In some societies, such as the Bemba of Zimbabwe, even less work is required. Only three to four hours of work are performed each day even during the busiest agricultural seasons, and averaged over a year, only one to two hours per day are required.¹⁷

Slash-and-burn agriculture requires less effort than more “advanced” forms of farming, but its drawback is that it cannot support large populations. One study of three Mexican farm communities that employed different mixes of slash-and-burn and sedentary farming technologies showed that almost 14 times as many families could be supported on the same acreage when irrigated farming was used instead of slash-and-burn methods.¹⁸ This, in fact, may be the primary reason for the development of settled, intensive agriculture. People began to practice this form of cultivation (perhaps while continuing to employ slash-and-burn techniques on other plots of land) in order to supply food to a growing population when no new land was available for cultivation. Settled forms of agriculture allowed more people to be fed because farmwork was not dependent on the availability of vast tracts of infrequently cultivated land. The same farm plot could feed much larger numbers of people whose labor was in turn required by the much greater demands of sedentary farming. In extreme cases, such as that of early twentieth-century China, with labor-intensive agricultural technologies the land could support enormous numbers of people—6,000 per square mile in some places.¹⁹



Danita Delimont/Getty Images

Slash-and-burn agriculture near Daraina, Madagascar.

The paradox underlying the development of agricultural technologies until recently is that as the land becomes more productive, people have to work much harder, for the increased productivity of the land is the result of an increase in the number of workers and the amount of work that they do. Settled forms of agriculture require labor not just for the direct tasks of soil preparation, planting, and harvesting. If the land cannot be left fallow for long periods of time, it is imperative that farmers take active roles in maintaining the fertility of the soil; this requires gathering, storing, and applying organic wastes that range from animal droppings to the mud scraped from the bottom of ponds. Stubborn weeds and grasses must be removed at regular intervals. Unless rainfall is totally adequate, irrigation networks have to be built and maintained. Animals that provide power and manure must be cared for. Storage buildings have to be constructed. Farm implements need to be built and kept in repair. Plants require protection from insects, even if this means picking them off by hand, one at a time.

The adoption of settled agriculture thus signifies a steep increase in the amount of work that has to be performed. Irrigated agriculture in particular requires sharp increases in the amount of work performed. Surveys of farms

in India show that with the introduction of irrigation much more labor is required while the crops are growing; work is no longer largely confined to plowing, planting, and harvesting.²⁰ Twice as much labor may be required per unit of irrigated cropland than in the case of dry farming.²¹ All in all, as sedentary agriculture develops, the amount of work required goes up sharply. In Southeast Asia, for example, an agricultural economy based on the transplantation of rice seedlings into irrigated fields requires an annual average of nearly 300 person-days of work. This situation changes only when industrial products such as farm machines and chemical fertilizers are introduced into the farm sector. This began to happen in Europe and North America a century and a half ago, and in many parts of the world it is yet to occur. In these places, the biblical injunction that “in the sweat of thy face shalt thou eat bread”²² is a harsh reality.

The Ironies of Progress

At this point, one may question the benefits of an “advanced” technology. The three productive systems just examined represent successive stages in economic development, but it is by no means certain that they represent across-the-board progress, especially when the amount of time that has to be devoted to labor is considered. One cannot even say with certainty that they represent progressive increases in one critical component of technology, the amount of skill exercised by individuals. The skills employed by foragers seem no less sophisticated than those employed by sedentary farmers. At the same time, however, the total skills found within the society as a whole may be greater in the latter case because the permanent communities that accompany sedentary agriculture allow specialization and a more extensive division of labor.

These comparisons of foraging, slash-and-burn, and sedentary agriculture give a strong indication that technological advance does not necessarily result in the saving of human labor. We are accustomed to thinking that new technologies result in the diminution of human drudgery, but the example of the epochal shift from hunting and gathering and slash-and-burn agriculture to settled crop cultivation shows that this need not be the case. We are left with the sobering realization that the development of agriculture, one of the greatest technological advances in human history, resulted in dramatic increases in the duration, pace, and extent of human labor.

Urbanization, Specialization, and Economic Relationships

Not all of the consequences of sedentary agriculture were so grim. Settled farming was paralleled by the development of towns and cities, which were often characterized by monumental architecture and other artistic advances. Dense permanent settlements also gave rise to specialized religious practitioners, as well as more complex modes of civil and military organization. Occupational specialization flourished, allowing craftsmen to turn out higher-quality work and produce entirely new kinds of goods. Agrarian societies also made possible the development of roads and other elements of infrastructure that facilitated the work of merchants and artisans, giving a further stimulus to occupational specialization.²³

In some cases, division of labor extended beyond workers specializing in a particular product; the work process was itself broken up. The Greek historian Xenophon (c. 430–354 B.C.) noted how, on occasion, shoe manufacture was subdivided: “One man earns a living by only stitching shoes, another by cutting them out, another by sewing the uppers together, while there is another who performs none of these operations but only assembles the parts.”²⁴ A similar pattern can be observed in Rome during the days of the Republic, when the metalworking industry contained such occupational specialties as pattern makers, smelters, turners, metal chasers, and gilders.²⁵

The change in economic relationships necessitated by specialization was even more important than the products themselves. Specialized producers need to exchange their goods and services with others. This is commonly done through some kind of market. Production for a market instead of for the direct use of family and community members implies a different kind of relationship with others. For most of human existence, work was performed as part of an extensive set of mutual obligations shared by members of the same group. But when work is done in order to make goods for sale in a market, it ceases to be embedded in particular social relationships. Instead, it

is done as a freestanding activity, governed by self-interest rather than a sense of obligation to members of one's group. The spirit of this kind of work was captured by a famous passage in Adam Smith's eighteenth-century classic, *The Wealth of Nations*: "It is not from the benevolence of the butcher, the brewer, or the baker, that we expect our dinner, but from their regard to their own interest. We address ourselves, not to their humanity, but to their self-love, and never talk to them of our necessities, but of their advantages."²⁶ A market-based exchange is one in which both parties participate in a transaction through which each expects to gain. When the transaction is completed, that is the end of the relationship. A car salesman may engage in some friendly conversation about your spouse and kids, but what he is really interested in is your money, just as your interest is getting a good price on the car. The relationship ends when he pockets your money and you drive off with the car.

An exchange system such as this, cold-blooded as it may be, has vast consequences for the way work is done. When, as often was the case in the past, work is firmly rooted in a larger set of social relationships, the way that work is organized will not be governed solely by the technical requirements of the job.²⁷ More will be at stake than efficiency, innovation, and the general development of production. It may be far more important to see to it that all members of the family or community are employed, or that jobs are parceled out not according to the abilities of the workers, but rather in accordance with their social position. For example, in India, only members of the lowest castes engage in the tanning of leather, for this is considered an "unclean" occupation and therefore improper for a high-caste individual.

Although urbanization results in more occupational specialization and some disentangling of economic and social spheres, this separation may not be fully realized. Particular occupations may be the special province of specific social groups. In the African city of Timbuktu, until recently, butchers, barbers, slipper-makers, masons, tailors, and smiths were all hereditary tradesmen, and in the case of the smiths, almost all marriages were between members of families involved in the same occupation.²⁸ These alignments may be firmly buttressed by religious beliefs and practices that prevent the free movement of individuals into specific occupations. In Timbuktu, it was widely believed that if someone other than a member of the

Arna tribe tried to sew up a leather slipper, supernatural forces would cause the needle to jab his hand. In similar fashion, it was believed that one who was not a member of a mason family would suffer a fatal fall if he were so unwise as to attempt to build his own house.²⁹ In societies such as this, the division of labor and the market system have not completely taken over. Although the economy is fairly complex, economic relationships are still kept within the context of the established social order.



David Cumming/Getty Images

The caste of this leather worker in India is a major determinant of his occupation.

Guild Organization and Technological Change

Families and tribes are not the only social groupings that regulate economic activity in traditional societies. In some traditional societies, such as medieval Europe, organizations known as guilds were of considerable importance. Guilds are groupings of people engaged in the same kind of occupation, be it manufacturing, trade, the provision of a service, or even begging and thievery.³⁰ One of the primary purposes of guilds is to restrict the practice of a particular craft to members of the guild, who also control recruitment into the guild. Close relationships between guild members are further reinforced by regular festivals and ceremonial functions, such as observance of the feast day of the guild's patron saint. These are not the only sources of solidarity; guilds also have a hierarchy of political offices that set rules, adjudicate disputes among members, and generally regulate the work activities of the members.

Guild organization had significant consequences for the pattern of technological change and for the work activities of guild members. On the one hand, the guild system facilitated the transfer of skills. Entry into a guild began with a long period of apprenticeship, which has been characterized as "the most widespread arrangement for transferring technical knowledge outside the family devised by human societies."³¹ Apprentices spent much of their time on menial tasks, but they also had an extended opportunity to gain essential knowledge about their craft. Much of that knowledge involved the acquisition of tacit skills that could be acquired only through observing a master craftsman and by engaging in hands-on practice.³² The relationship between master and apprentice was closely constrained; the apprentice agreed to work for his master and not leave or get married without the master's permission. In return, the master imparted craft skills and provided the apprentice with room, board, and clothing. Violation of these stipulations by either side could result in the payment of a cash penalty to the aggrieved party.³³

While guild organization and practice helped to preserve and transfer

skills, they also were a source of technological retardation. Although long apprenticeships facilitated skill acquisition, they also produced a kind of “trained incapacity” that locked guild members into set ways of doing things that inhibited innovation. Also, since the practice of a trade required membership in the appropriate guild, recruitment regulations and stipulated training programs set limits on who could practice a trade. In some instances, these regulations resulted in the exclusion of individuals who were not already members of a guildsman’s extended family,³⁴ although this was not a universal feature of guild organization.³⁵

Many other guild regulations and procedures worked against technological change. In order to maintain their monopoly positions and keep prices high, guilds set exacting standards for workmanship and attempted to restrict output by individual members. Limits were placed on the number of apprentices and other workers that could be employed in a guild member’s shop, while deviations from normal work practices, such as working under artificial light, were prohibited. In general, technological innovations were discouraged, for the prime concern of the guild was the maintenance of the existing way of life.



Granger, NYC — All rights reserved.

This fifteenth-century cabinetmaker practiced his trade as a member of a guild. His wife is also at work as she spins thread with a distaff as the child labors by her side.

The inhibitions created by guild organization meant that economic and

technological progress often required the establishment of enterprises in areas remote from guild control. This occurred in the Roman Empire, where craft workshops were established on great estates in the outlying provinces, far from the cities and guild regulation. Here could be found such technological and economic novelties as an establishment near Arles that boasted eight water mills, as well as glass and textile factories in eastern Gaul where work was done by wage laborers rather than independent craftsmen.³⁶ It probably is no coincidence that the rise of modern industry first occurred in England, where guild restrictions were weaker than they were in the rest of Europe.

Slavery and the Inhibition of Technological Development

The most extreme means of tying occupation to social status is through the operation of an institution that is unfortunately all too common in human societies: slavery. Slavery was a major source of labor in the empires of the ancient world; it would not be an exaggeration to say that slave labor was the foundation for a large portion of economic life. Slavery persisted in early medieval Europe, although its spread was inhibited by the belief that Christians should not wage wars against fellow Christians for the purpose of enslaving them. By the thirteenth century, the church forbade the buying and selling of Christian slaves, but no such restriction applied to people of other faiths, especially Muslims. Scattered vestiges of slavery could be found in eighteenth-century Europe, but by that time, the major center of slave labor was the New World, where enslaved Africans supplied much of the labor for the plantation economies of the Caribbean, the American South, and parts of South America.

The institution of slavery had a number of unfortunate consequences for work, worker motivation, and the development of workplace technologies. Slave labor was inefficient when compared to most forms of free labor because work had to be closely supervised with coercion as the main source of motivation. Slaves were charged with the performance of simple if arduous tasks, but little was expected of them in the way of initiative, innovation, or attention to detail. Slaves produced great amounts of wealth for their owners, but the institution of slavery powerfully inhibited the development of a skilled labor force, an essential component of long-term economic advance.

It is sometimes asserted that slavery also inhibited the development and use of labor-saving technologies since slave owners paid very little for the labor supplied by their slaves, usually not much more than the cost of their subsistence. This is not altogether convincing; after all, slave owners could have increased their incomes by adopting technologies that enhanced the productivity of their slaves while still paying very little for their upkeep.

More likely, slavery inhibited technological advance indirectly by engendering negative attitudes about work and its place in one's life.

The Greeks and Romans of the classical age often manifested a strong respect for work when it was part of a self-sufficient lifestyle. But work was despised when it was done for another—be he a master or simply a customer—because it signified that the worker was locked into a relationship of servitude that prevented him from being a free citizen, whose proper activities were directed toward political life and the pursuit of pure knowledge.³⁷ This attitude is exemplified by the assertion of the Greek philosopher Aristotle that “no man can practice virtue when he is living the life of a mechanic.”³⁸ When slavery became widespread, as in the days of the Roman Empire, this attitude toward work hardened. Since more and more of it was being done by slaves, manual work was seen as an inherently degrading activity not fit for a free man.

This attitude also characterized the American South before the Civil War. Although most white Southerners did not own slaves, they inhabited a culture in which manual work could easily be associated with slave labor. Due in part to the low status of manual work, the South had a weaker tradition of engineering and other technological endeavors. This was reflected in a much slower pace of industrialization than occurred in the North, and ultimately was one of the key reasons for the South's defeat in the Civil War.

The Measurement of Time and Changed Working Patterns

There are two ways to consider the relationship between work and time: in terms of the amount of time that is expended on work, and in the way that it is scheduled. Technological change altered both of these.

As we have seen, in technologically simple societies where subsistence comes through foraging or slash-and-burn agriculture, relatively little time is expended on work. With the introduction of settled farming and the beginning of urbanization, the hours of work lengthened. Still, the sharp separation between work and other activities that we take for granted today was not nearly as pronounced. The workweek was punctuated with social events, religious observances, community social activities, and other excuses for the avoidance of work.

For the farmer, certain times of the year, such as sowing and harvesting, required long hours of work, but during other times of the year, some leisure time could be enjoyed. Although a craftsman might spend long hours at his place of business, not all of his time was taken up with productive activities. Many hours were spent socializing with neighbors and customers. A good deal of time was spent on haggling over prices with prospective customers, an activity often done more for the sheer pleasure of bargaining than for any real economic purpose. Concern about time did not pervade workers' consciousness. There was little of the frenetic desire to "get ahead" that is so typical of many inhabitants of the modern world. Jacques Le Goff's description of the Middle Ages can be taken as typical of the general attitude: "On the whole, labor time was still the time of an economy dominated by agrarian rhythms, free of haste, careless of exactitude, unconcerned by productivity—and of a society created in the image of the economy, sober and modest, without enormous appetites, undemanding, and incapable of quantitative efforts."³⁹

Above all, the idea of keeping to a fixed work schedule rarely took hold. As Gideon Sjoberg describes work patterns in a preindustrial city, "Merchants and handicraft workers generally do not adhere to any fixed

schedule. Shopkeepers open and close their shops as they see fit. They may open one morning at nine, the next at ten, and so on. The lunch hour is likely to be longer on some days than others. Ambulatory merchants, likewise, are apt to keep rather irregular schedules.”⁴⁰

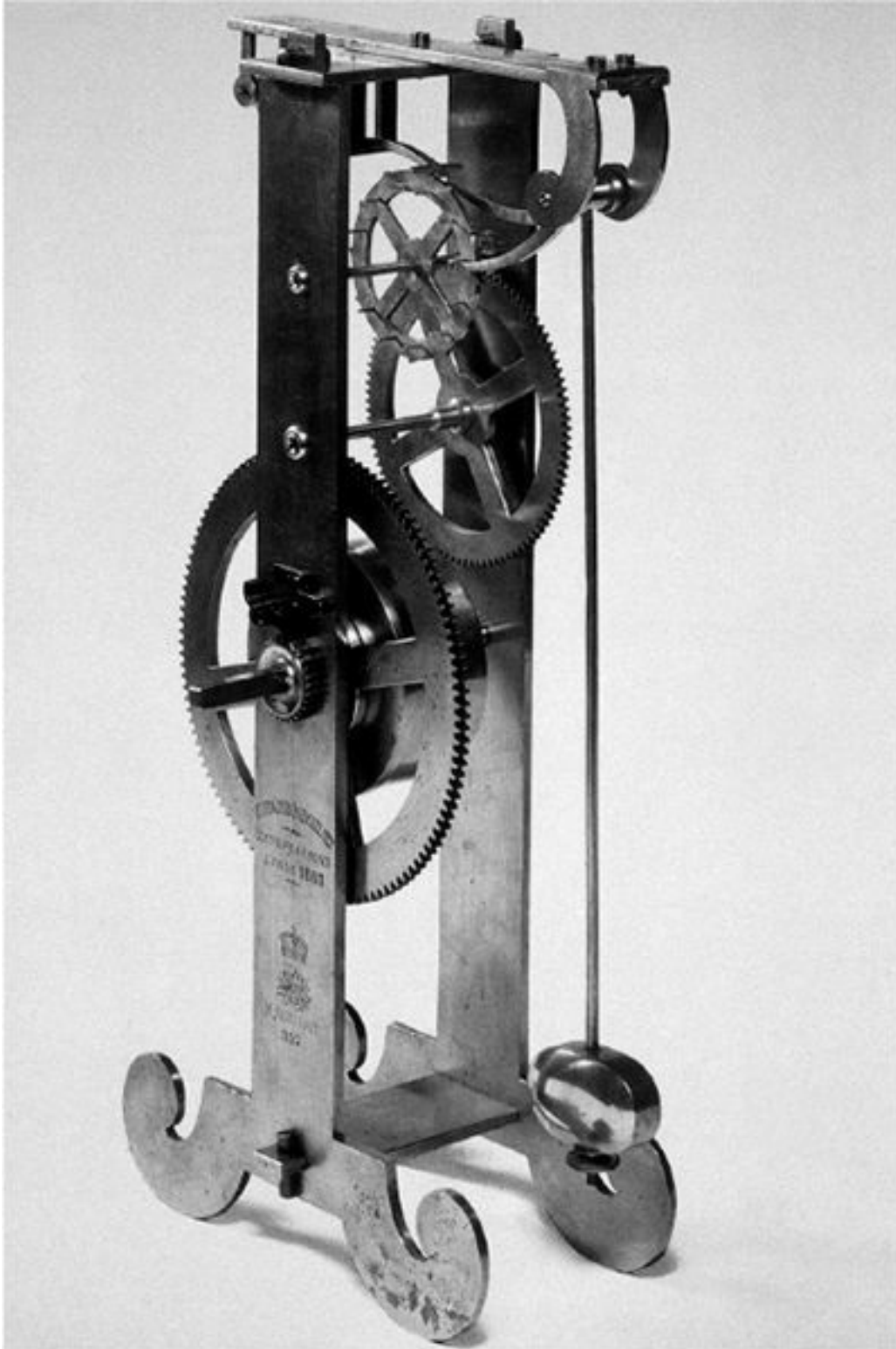
These attitudes toward time and work seem to indicate a set of values different from the ones we take for granted today. Work was not pursued with the kind of single-mindedness that is so evident today. Nor was the time devoted to work considered a scarce commodity to be carefully utilized in order to bring the maximum economic return. These conceptions of work developed slowly and only in conjunction with major changes in the way people viewed themselves and their surroundings. In the Western world, a major impetus to these changes may have been religious. The rise of Protestantism, especially in its Calvinist form, gave a new centrality to work, for it made work into a quasi-religious “calling.” According to Calvinist doctrine only those predestined to salvation could hope to enter heaven, and material success was taken as a sign of being one of the chosen few. Equally important, this “calling” was manifested not just by a willingness to work hard to gain material success but also by a systematic and methodical approach to work.⁴¹ This spirit was clearly congenial to the regulation of work activities according to the dictates of a precise schedule.

The Clock

Important as these changed attitudes might have been, “modern” attitudes toward work, especially the way it was organized and scheduled, were also influenced by a key invention that allowed the precise scheduling of work activities: the clock. To be sure, methods of telling time had existed throughout the ancient world. Sundials, candles with marked segments, and vessels that discharged water at a regular rate were all employed in antiquity. But each had drawbacks: sundials were useless at night and on cloudy days, candles could blow out, and water clocks froze in the wintertime. Equally important, most work activities in the ancient world required little in the way of precise timing and scheduling. These requirements arose only in conjunction with a new kind of social organization: the medieval monastery.⁴² By the standards of their day, these monasteries were very large enterprises, many of them containing hundreds of monks and other workers. Their cooperative efforts required precise scheduling, as did their patterns of religious observance, which required regular times for prayers, masses, and other religious observances. This was most pronounced in the monasteries following the Rule of St. Benedict, which divided days and nights into intervals of 12 hours each and required prayers to be said at sunrise, at the third hour of daylight, at noon, at the ninth hour of daylight, and at sunset.⁴³

The first clocks were built in the thirteenth century, their construction motivated by a growing awareness of the value of accurate timekeeping.⁴⁴ The scheduling of activities through the use of special timepieces had brought economic benefits to the monasteries and secular enterprises, and over time, the idea of orderly routines and schedules had become an integral part of city life in late medieval Europe. There is the example of Philip VI of France giving to the city of Amiens in the fourteenth century a charter that allowed the issuance of an ordinance “concerning the time when the workers of the said city and its suburbs should go each morning to work, when they should eat and when to return to work after eating; and also, in the evening, when they should quit work for the day; and that by the issuance of said ordinance, they might ring a bell which has been installed in the Belfry of said city,

which differs from the other bells.”⁴⁵ It was in these urban centers during the early fourteenth century that the mechanical clock began to exert its influence. The ringing of the town bell could be specifically tied to the needs of emerging occupations, as when the governor of the county of Artois granted to the government of the city of the same name the right to construct a special belfry because of the “cloth trade and other trades which require several workers each day to go and come to work at certain hours.”⁴⁶



Granger, NYC — All rights reserved.

Based on a discovery by Galileo, this clock mechanism uses a

pendulum to regulate its motion.

In addition to laying the foundation for a more regularized pattern of work, the clock embodied all of the key characteristics of a machine. It used an external source of energy (a spring or a falling weight), unlike traditional tools and devices that required human or animal muscle power. The even distribution of this energy required some sort of regulator, as typified by the pendulum discovered by Galileo and first applied to timepieces by Christian Huygens in Holland. The clock's operation was automatic, requiring little human intervention. Finally, the clock put out a standard "product"—hours, minutes, and seconds.⁴⁷

In producing this standard product, the clock had made time into a kind of substance. Without getting into deep philosophical waters, we can assert that time as we tend to think of it does not exist; when we think or speak about time, what we are actually dealing with are *measures* of time: seconds, hours, decades, or centuries. These units of time are then taken to have real substance and are treated as valuable commodities. Hence, we use phrases like "saving time," "wasting time," "spending time," and "buying time." Note, too, the assertion that "time is money."

The conversion of time into a commodity reinforces the rational spirit that was briefly described in Chapter 1. It stimulates the conscious choice of specific means for the attainment of given ends and provides a basis for judging the worth of a particular activity relative to others. Individuals in a society obsessed with time find it difficult to go about their work in an unplanned and irregular fashion.

The precise scheduling of work received further emphasis as new mechanical technologies began to make their appearance. Spinning jennies, power looms, flour mills, and refractory furnaces, as well as the waterwheels and steam engines that ran them, called for a mechanically paced way of working that was profoundly different from the old ways of doing things. The process that began with medieval monasteries and thirteenth-century clocks moved inexorably toward the conversion of most work into routinized procedures governed by artificial time schedules. In Chapter 11, we will look at these historical developments and attempt to bring them up to date. But before analyzing the effects of technological development on the quality of work today, we will examine an issue even more fundamental: the prospect

that technological advance might leave many people with no work to do.

QUESTIONS FOR DISCUSSION

1. After reading about the work habits of the !Kung, does trading places with one of them begin to seem attractive? How would a member of !Kung society feel about such a swap? All in all, who would be better off?
2. Which of the following two statements do you find more satisfactory? (1) “The development of agricultural technologies was beneficial to mankind because it allowed more people to be supported.” (2) “The development of agricultural technologies was harmful to mankind because it required people to work harder.”
3. The development of a market economy stimulated technological and economic development, but at the expense of a rather cold-blooded approach to human relationships. Is this a fair trade-off? Under what circumstances can marketplace exchanges coexist with emotionally satisfying interpersonal relationships?
4. Are there any modern occupations that retain characteristics of guild organization? Why have these persisted?
5. In many ancient societies, most notably Greece and Rome, major advances in philosophy, mathematics, engineering, and architecture were wrought by an elite class who owed their leisured existence to the labors of slaves. Do their accomplishments justify the institution of slavery in those times?
6. How often do you look at a clock, watch, or phone during the day? Is there anything unnatural about being governed by clocks? What would happen to modern society if all the timepieces stopped, never to run again?

CHAPTER TEN

Technology and Jobs: More of One and Less of the Other?

Mention technological change to some workers, and a cold chill is likely to go down their backs. Lurking behind many an innovation is the threat of a job lost. This is not an irrational fear. Throughout history, and especially in the modern era, many production technologies have been explicitly motivated by the desire to increase productivity. Since productivity is usually measured in terms of output per worker, the consequences of productivity increases seem clear: the reduction or elimination of labor. For example, if worker productivity increases at a rate of 2 percent a year—less than the post-World War II average in the United States—the size of the economy will double in about 35 years. On the other hand, productivity growth can be cast in negative terms by noting that today's output of goods and services would require only half the number of workers 35 years from now.

While productivity gains have made our material lives much richer, they have also raised the specter of mass unemployment. If a relatively few workers can perform all the necessary labor, large numbers of people will end up with no jobs and no work to do. At least that is the fear. Fortunately, the situation is more complicated. Technology's effects on employment are substantial, but they can also be contradictory. In this chapter, we will trace the complex connections between technological change and unemployment by looking at the historical record, and by considering where the productivity improvements wrought by technological change seem to be leading us. In

addition, the chapter will briefly consider how technological change has affected the distribution of income, and will note some of the consequences of globalization, a process that has accompanied technological advance that also influences employment and worker remuneration.

The Technological Threat in Historical Perspective

A cursory examination of technological change reveals many examples of jobs lost because of technological advance. In 1920, the American railroads employed 113,000 locomotive engineers and 91,000 firemen. In 2002, these railroads carried a much greater volume of freight but needed only 40,000 engineers and no firemen to do so.¹ During the early 1980s, studio musicians saw recording jobs erode by more than a third as a result of the growing use of musical synthesizers.² From 1972 to 1977, 21 percent more telephone calls were made throughout the Bell System, yet the number of operators fell by 32 percent.³ Over a five-year period beginning in 2002, steel production increased by almost 5 percent, yet employment fell 10 percent. During the same period, corn production went up by 30 percent while farm payrolls dropped by about the same percentage.⁴

Striking as these developments have been, they are not unique to our times. Beginning in the late eighteenth century, the power loom forced many handloom weavers out of their traditional craft, and those who stayed on did so only because they were willing to accept miserably low wages.⁵ Many similar examples could be extracted from the history of the Industrial Revolution. The introduction of machinery threatened the livelihood of large numbers of workers and produced a considerable amount of social unrest. Attempts to introduce the spinning jenny into the English woolen trade during the late eighteenth century resulted in numerous riots. By the early nineteenth century, worker resistance to new machinery was widespread in several regions of England, culminating, as we saw in Chapter 2, in the machine-smashing Luddite outbreaks.



Heritage Image Partnership Ltd/Alamy

Before the development of automatic exchanges, the telephone industry employed thousands of switchboard operators, most of them women.

Opposition to new technologies because of their consequences for employment has not been confined to the workers whose jobs were threatened. The fear of the effects of new technology on employment has on occasion moved public officials to take drastic actions. In 1638, the British government banned the use of “engines for working of tape, lace, ribbon, and such, wherein one man doth more amongst them than seven English men can doe.”⁶ A more extreme (although perhaps apocryphal) example comes from the Polish city of Danzig, where in 1661, the municipal authorities destroyed a mechanical ribbon loom and drowned its inventor, for fear that the new device would put handweavers out of work.⁷ Consignment to a watery oblivion was also advocated for a mechanical cotton picker by the Jackson, Mississippi, *Daily News* in the late 1930s: “It should be driven right out of the cotton fields and sunk into the Mississippi River, together with its plans and specifications. Nothing could be more devastating to labor conditions in the South than a cotton-picking machine.”⁸

A Case for Optimism

Examples, however numerous, do not conclusively prove that technological advance is incompatible with high levels of employment. Although there can be no dispute that particular technological changes have resulted in job losses and attendant personal tragedies, this does not tell the whole story. The effects of technological change are complex, and it is easy to fix upon one particular result and ignore others. Rather than dwell exclusively on the fate of particular industries and occupations, it is essential to consider the larger picture.

When considering the effects of technological change on the overall level of employment, one thing must always be kept in mind: even if all available technologies were used to their utmost, there would still be plenty of work to do. In many parts of the world today, including many “developed” countries, there are still large numbers of people who lack the basic necessities and amenities of life. More and better food needs to be produced and distributed, more houses built, more clothing manufactured. People need to be educated, healed, and entertained. Even with high levels of affluence, needs and wants do not decrease. When it comes to the consumption of goods and services, it is likely that high levels of consumption do not diminish the desire for still higher levels of consumption; appetite may grow with eating. Although it may not be a particularly noble trait, the desire to acquire more and more is present in most human beings. As a result, progressively higher levels of economic development may generate the need for continued high (or perhaps higher) levels of production.

As economists have noted, scenarios of widespread unemployment induced by technological change are predicated on what has been called the “lump of labor fallacy,” which postulates that there is only so much work on hand for a given work force. But as we have just seen, there is no intrinsic reason that work cannot expand as more people enter the work force or lose the jobs that they had held. At the same time, however, it has to be recognized that the realization of potential job opportunities will depend on having a labor force with the requisite skills (or the ability to develop them)

and a political and economic system able and willing to pay for the work that needs to be done.

The seemingly endless expansion of needs and desires can be seen clearly in the field of medicine. As we have seen in Chapter 7, despite stupendous achievements in medical technology, we find that the monetary and human resources being devoted to health care have increased rather than diminished. Indeed, the rising cost of health care, which now takes more than 17 percent of the gross national income of the United States, has become a major social and political issue. New medical technologies have generated new possibilities and new hopes. Instead of accepting sickness and death as the inevitable working of fate or God's will, we expect that cures will be found and that medical personnel will be available to administer them. It should therefore come as no surprise to find that employment projections indicate that the demand for health care workers has increased year after year and in all likelihood will continue to do so in the future.⁹ As this example indicates, technological advances will not lead to job losses if the demand for products and services increases at the same pace as increases in productivity. It is also important to bear in mind that the level of demand is affected by the price of a particular product or service. If productivity increases bring down the cost, more people can afford it, thereby increasing the size of the market for that product. This, in turn, may motivate an employer to take on more workers so that the increased demand can be met. Much of the history of mass production conforms to this pattern, as exemplified by the automobile industry and the interrelated increases in productivity, employment, production, and purchases that began when Henry Ford began to produce large numbers of Model T cars during the second decade of the twentieth century.

In other cases, lower prices may not result in significantly higher levels of demand, because people will buy only so much of a particular product irrespective of its price. (In the jargon of economists, such a product is "price inelastic.") Even so, since consumers pay a lower price for this product, they have more money left over to spend on other things. This increases the effective demand for other products and enhances employment prospects in the industries that make them. To be sure, many economists believe that there may be times when aggregate demand will be insufficient because consumers

prefer to save the extra money rather than spend it on new purchases. According to many economic historians, this phenomenon of “underconsumption” may in fact have been the underlying cause of the Great Depression of the 1930s. Under such circumstances, governments may have to stimulate demand by increasing their own expenditures, even if this means running budgetary deficits.¹⁰

As a final point, it is also important to remember that technological change often generates problems that require a great deal of work be done. Animal and plant habitats need to be restored, bodies of water require purification, and victims of accidents and pollution need medical care. Many nuclear power plants are nearing the end of their useful lives, and safely decommissioning them will entail years of labor by thousands of workers. In general, the cost of environmental cleanups is hardly trivial; as was noted in Chapter 6, the United States will have to spend billions of dollars each year for many years just to deal with hazardous wastes and old refuse dumps. The funds spent on environmental cleanup and protection can be the basis of many jobs.



Getty Images News/Getty Images

Although environmental damage is always unfortunate, it can provide a substantial number of jobs.

How Technology Creates Jobs

Fixing upon particular examples of jobs lost to technological advance can lead to a kind of tunnel vision. While some technologies destroy existing human jobs, others produce jobs that had not existed earlier. No one worked as a locomotive engineer before the coming of the railroad, and there was no need for X-ray technicians before the twentieth century. In fact, most of the occupations held today did not even exist one hundred years ago. This trend can be expected to continue. Occupations such as genetic engineer, global positioning system technician, website designer, and social media strategist could hardly be imagined a generation ago, but they will become increasingly significant as the technologies that gave rise to them are developed and deployed.

While the historical record shows that new technologies can give rise to whole new industries, it is often difficult to determine in advance the occupational consequences of a new invention. When the transistor was invented, it was at first thought that its primary application would be simple substitution: the replacement of vacuum tubes in amplifiers.¹¹ Because of its small size and low power requirements, the transistor's first practical application was to make hearing aids more compact and efficient. Today, transistors and other solid-state devices are the foundation of industries unknown a few decades ago—personal computers, smartphones, e-book readers, and MP3 players, to name but a few.

General technological advance has created a host of new products and the jobs necessary to make them. And in this regard, too, actual events have run well ahead of many predictions. In 1963, one economist warned that American households were saturated with domestic appliances, resulting in a stagnant market for manufactured goods; the only significant new product was the electric can opener.¹² Today, if he is still alive, the man who made this prediction is likely to live in a house equipped with a smartphone, big-screen HD television, food processor, microwave oven, Blu-ray player, personal computer, and Wi-Fi router. He might even have embraced the economic and environmental benefits of solar energy by having solar panels

installed on his roof. These products, all of them virtually nonexistent as consumer items five decades ago, have generated many new jobs in manufacturing, marketing, and servicing.

The Indirect Effects of New Technologies on Employment

In the past, a single new technology could be responsible for a large proportion of the new jobs that came into existence. Today's economy is much more complex, so no one technology is likely to have the same impact. It is unlikely that any recent technological innovation will equal the greatest job generator of the twentieth century: the automobile. Although direct employment in the automobile industry has steadily declined in recent years, the approximately 250 million cars and light trucks on America's roads provide employment for legions of mechanics, sales personnel, and insurance agents, as well as many workers whose jobs are indirectly tied to the automotive culture and are employed in everything from oil refineries to fast-food restaurants.

None of the new industries that have emerged as a consequence of recent technological change is likely to match this record. The jet airliner, as emblematic of our present transportation system as the automobile, has not led to the direct creation of many jobs; relatively few people are employed by America's airlines and passenger aircraft manufacturers. The computer, often hailed as the most significant invention of our age, has not added a great number of manufacturing and service jobs, and many of the former have been relocated to low-wage countries. The same can be said of the television industry, and just about any of the industries that owe their origin to recent technological changes.

At first glance, it looks as though the pessimists have got it right: technological development in established industries destroys jobs, and the occupations created by new technologies do little to offset the losses. But these conclusions follow if one looks at only the specific industries without considering indirect effects on employment.

Consider the airline industry again. It is true that despite the industry's dramatic growth in recent decades, employment has gone up only slightly. But at the same time, air travel has stimulated a number of other sectors. Travel and tourism, powerfully stimulated by the growth of the airline

industry, are now major sectors of the world economy, accounting for 9.2 percent of global GDP, 4.8 percent of world exports, and 9.2 percent of global investment according to one reckoning.¹³ The growth of jet-age travel and tourism has brought with it a great many job opportunities in hotels, restaurants, travel agencies, tourist attractions, and the like. Television has also had a considerable, if unmeasurable, impact on economic growth by stimulating a demand for new products and services that are presented on programs and commercials. In similar fashion, the spread of computers into our economy has been essential to the development of new industries, video games and social media being the most obvious. All in all, some jobs have been lost as computers increased productivity in clerical, manufacturing, and other occupations, but at the same time new jobs are being created as computers have stimulated the growth of new or existing industries.

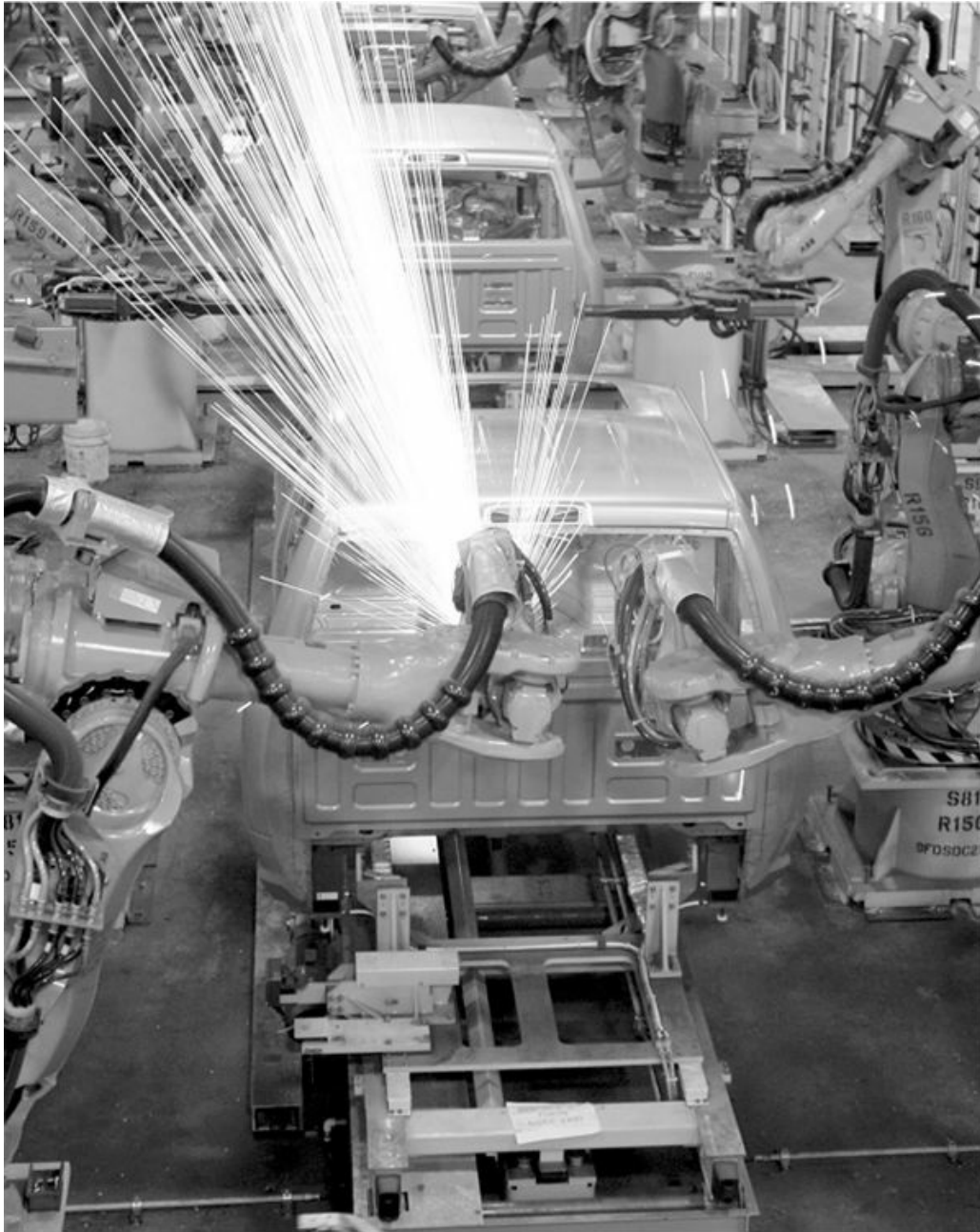
The Machines Aren't Ready to Take Over

When people visualize technological change in the workplace, they often conjure up an image of legions of robots doing what people used to do. There is no denying that robots have been making an impact on factory production. By the end of 2014, about 1.5 million robots were employed in the world's factories, and their numbers were rapidly expanding.¹⁴ Moreover, robots are only the final step in a more general process of automating production. Computer-aided design (CAD) systems make it possible to draw a design on-screen, change its size and shape, call up stored shapes, and rotate the design to see how it looks from different perspectives. The design can then be tested through the use of computerized procedures. When the design work is completed, the new product can be built by a computer-aided manufacturing (CAM) system, in which computerized instructions run the robots and other machinery that fabricate and assemble the parts that have been designed with the help of computers. Computerized systems can also be used to organize the manufacturing process by scheduling production, directing the movement of parts, and generally keeping everything under control.

Industrial computers are also the basis of flexible manufacturing systems that alter the basic rules of mass production. Instead of using special-purpose machines that do only one thing, it is possible to use general-purpose machines that can be quickly reprogrammed to do a variety of things. For example, automobile manufacturers can now rapidly reprogram assembly-line robots to do different welding operations, depending on what is coming down the line, all of which happens in response to a bar code affixed to a rail running below the vehicle.¹⁵ Flexibility of this sort is especially important for the manufacture of products that are made in small quantities or undergo rapid changes in specifications.

At present, these technologies have appeared piecemeal in most industrial settings; they are "islands of automation" on the shop floor. Over time, it is hoped, they will become part of an integrated system that governs the total manufacturing process from initial design to the testing of the completed product. When this occurs, a great deal of production will take place with

very little direct human intervention.



Carlos Osorio/AP Images

Robot welders at work on an automotive assembly line.

As exciting as these developments are, the advance of industrial automation will be a slow process. Automated manufacturing systems are

very expensive, with each workstation costing up to a million dollars. More important, many technical problems remain unsolved. There are still many difficulties surrounding the transport of materials from one station to another without human intervention. Robots are particularly difficult to adapt to assembly operations, and a lot of hand labor, much of it done in low-wage countries, is still used for assembly operations. Robots and other elements of automated production technology have been eliminating some jobs, but there are limits to how far this process can go. Manufacturing systems that rely on automated production technologies also operate on the thin edge of disaster. If a robot or other computer-controlled process fails, production comes to a complete halt and everything stacks up behind the obstacle until human workers sort out the problem.¹⁶ Even worse, a small programming error can cause thousands of dollars of damage to machines and material in a few seconds. The challenges of programming, controlling, and maintaining computer-controlled industrial processes have put a high premium on skilled workers, who remain in short supply while other manufacturing workers remain on the unemployment rolls month after month.¹⁷ Technical issues will continue to put an upper limit on the extent to which robots can replace human workers. An even greater obstacle to expanding the use of robots is the structure of twenty-first-century economies, as we shall now see.

Technology, Jobs, and the Changing Structure of the Economy

Although fully automated industrial processes have been only partially realized, there is no denying that they have made substantial inroads into manufacturing employment. Robots, computerized controls, and CAD-CAM systems have reduced the need for human labor in many industries, a process that will continue in the years to come. But alarming as this prospect may appear, it is nothing new. Over the past century, many of the jobs performed by manufacturing workers have been lost to mechanization, yet total employment has undergone a massive increase. This has occurred because the bulk of job creation, especially in recent decades, has not been in the production of things but in the supply of services, segments of the economy including, but not limited to, education, medicine, entertainment, law enforcement, wholesale and retail sales, and transportation. In 1950, 18.1 million workers were employed in manufacturing, construction, and raw materials extraction, while 26 million worked in the service sector, both public and private. By late 2015, with many millions of additional job holders, these figures were 19,817 million and 122,179 million, respectively.¹⁸

In the 1950s, manufacturing, construction, and raw materials extraction were pillars of the economy. These occupations are still important, but they have steadily declined as sources of employment. The number of these jobs has not dropped in absolute terms, but they have fallen sharply relative to service occupations. In 2015, manufacturing, construction, and resource extraction had only 1.7 million additional jobs, a small increment when compared with the massive growth in the number of service jobs.¹⁹ Even these figures may underestimate the extent to which services have been numerically dominant in modern economies. Many jobs in the manufacturing sector are actually service occupations. Independent consulting engineers provide a service, and are put in this category for statistical purposes, but if they perform similar duties as members of the engineering staff of a manufacturing enterprise, they appear as manufacturing employees. The

number of workers performing service-type functions in the manufacturing sector is large and growing, another indication of the changing nature of work.

Many occupations fall into the service category, and not all of the jobs in this sector of the economy are equally desirable. Trash collectors perform a service, just as neurosurgeons do. What many of these varied services have in common, however, is that they incorporate a personal element. This in fact is what makes them desired by consumers who have a surfeit of manufactured goods. For many people, the most sophisticated machine is no substitute for human contact. This desire will likely retard the replacement of human service providers by even the most sophisticated technologies. Computer-based expert systems can do an excellent job of diagnosing certain illnesses and even performing some surgical operations,²⁰ but they fall short in providing a significant element in recovery from many illnesses—a patient's confidence in the services provided by a skilled medical practitioner.

The desire for services shows no signs of abating, and this sector will generate many future jobs. Still, relying on services to drive the economy and provide jobs seems to violate common sense. The basis of human survival is food, clothing, shelter, and the implements necessary to sustain life. How can the majority of the work force be employed in occupations that directly contribute nothing to production? In fact, much economic progress can be interpreted as an ongoing reduction of the number of workers employed in producing the necessities of life. Two hundred years ago, more than half of the population of Europe earned their livelihood by growing food, just as is the case in many poor countries today. With the rise of industrialization and the provision of such things as irrigation pumps, mechanized farm implements, and chemical pesticides and fertilizers, the labor requirements of agriculture steadily dropped; today, less than 5 percent of the work force in most industrial countries is engaged in farming. The same thing could happen in manufacturing in the years to come.

The displacement of agriculture by industry was closely tied to the rapid progress of technology during the nineteenth and twentieth centuries. In the case of the service sector, however, modern technologies are often of lesser importance. This is a major reason for the slow growth in productivity that has been characteristic of the American economy in recent years. While

manufacturing employees have made much use of machines that embody increasingly sophisticated technologies, many service occupations have been only lightly touched by them. An attorney's office will make heavy use of information technology and a hardware store will use computers to track sales and inventory, but the main work of these enterprises entails face-to-face communication of the sort that only humans can provide.

Perhaps the clearest example of the labor-absorbing quality of services can be found in education. Despite efforts to use audiovisual aids, computer-based massive open online courses (MOOCs), and machine-scored exams, most teaching is conducted much as it was in the time of Socrates: through lectures and discussions, both of which require some degree of personal contact. Since much of the appeal of a service has to do with the human contact it provides, the more "productive" a service job is, the less satisfying it may be for the consumer. A teacher could greatly increase his or her productivity by lecturing to a class of 500 rather than 25, but most students would find so "productive" a class much less enjoyable, and the lack of personal attention would probably result in lowered levels of learning for many of them. It is also significant that one of the most successful online educational programs, the Khan Academy, is most effective when students have the opportunity to interact on a face-to-face basis with human teachers who go over students' homework, monitor their progress, and help them with any difficulties they may have encountered.²¹



Hulton Archive/Getty Images; Xinhua/Eyevine/Redux

Electronic trading has reduced traffic considerably at the New York Stock Exchange, as can be seen in these photographs, one taken in 1962, the other in 2012.

To be sure, a good many services have experienced sizable productivity

gains through the introduction of labor-saving technologies. The classic example of this can be found in the telephone industry. If telephone calls were still manually switched as they were in the 1920s, today's level of telephone traffic would require no fewer than 50 million operators. Although the impact may not be as profound, it is likely that many of today's services will also experience technologically induced productivity gains and corresponding drops in employment. Email, word processing, automated banking, and the like have undoubtedly caused job losses, and will continue to do so. But does this mean that unemployment will necessarily increase? Here, again, the example of the telephone industry may be relevant. Some actual, and millions of potential, jobs were lost due to the introduction of automatic telephone switching, but total employment in the telephone industry continued to rise because increased levels of demand stimulated the industry's expansion. Equally important, the expansion of telephone communications has acted as a powerful stimulant to the economy as a whole, leading to the creation of many jobs that would not otherwise exist. The job-creating qualities of a new technology are usually hard to predict in advance, but they are there all the same.

Technology and the Distribution of Income

At this point, it can be fairly argued that the creation of new jobs through technological change is not the whole story; also in question is the nature of the jobs created, and in particular, how well they pay. In this regard, the record of recent years has been mixed. On the one hand, technological change has resulted in the emergence of many new, high-paying occupations and business opportunities. On the other hand, technological change has been implicated in diminished economic opportunities and an overall reduction in wages for significant portions of the labor force.

Technology and Income Inequality

The growth of income and wealth inequality has been one of the most profound economic and social changes over the past four decades. To cite one indication of growing inequality, in 1975, the top 20 percent of American households accounted for 40.7 percent of the income received in the United States. By 2011, their share had climbed to 52 percent. Even more extreme has been the relative gain of households in the upper 1 percent, from around 10 percent of the nation's total income in the 1970s to more than 20 percent in 2012.²²

For many writers, the wide income gap reflects the basic structure of twenty-first-century economies, where technical skill or the lack of it are the prime determinants of wages and salaries. This common belief is summarized in a publication of the International Monetary Fund: "Technological progress ... increases the premium on skills and tends to substitute away low-skill inputs. Technological progress thus increases the relative demand for higher skills, thereby exacerbating inequality in income."²³ According to one reckoning, from 2000 to 2009, the number of manufacturing employees with only a high school diploma declined by 38.7 percent, while the number of employees with college and postgraduate degrees increased by 2.4 percent and 44.4 percent, respectively.²⁴

The growing importance of educational credentials has surely diminished incomes for certain groups of workers. For workers with only a high school education or less, automated production technologies have eliminated many jobs that a generation ago paid decent wages while requiring few skills. Undoubtedly, many workers have lost well-paying jobs because their limited skills made them vulnerable to being replaced by robots. For the economy as a whole, the loss of these jobs has not resulted in widespread unemployment, because these losses have been offset by large employment increases in the service sector. At the same time, however, service-sector jobs on average do not pay as well as manufacturing jobs, although there is wide variation in both.²⁵

At the other end of the income scale, great fortunes have been made by the creators of search engines, social media sites, and widely used computer programs, while more modest fortunes are being earned by men and women

with expertise in cybersecurity. A lot of money also has been amassed as an indirect result of technological change. For example, advances in communications technology make it possible for a musician or athlete to gain a worldwide following. This increases the stakes for competitors in a “winner-take-all” contest. A singer or soccer player may be only slightly better than his or her peers, but if he or she is considered “the best,” their fans will number in the tens of millions, which in turn will be reflected in their salaries.²⁶

Other students of economic and technological change have argued that some well-rewarded skills are not technical, but are essential to make optimal use of advanced technologies because realizing the potential of digital technologies often requires a fundamental restructuring of a firm’s organizational structure and operations. As Erik Brynjolfsson and Andrew McAfee summarize, “The most productive firms reinvented and reorganized decision rights, incentive systems, information flows, hiring systems, and other aspects of organizational capital in order to get the most from the technology.”²⁷ As a result, some high earners are not just the technically proficient members of the labor force but also include well-educated men and women with a broad range of aptitudes and skills.

Technology, Employment, and a Changing Work Force

It should be evident that technological change has not been kind to workers with only a high school education or less.²⁸ It can also make life very difficult for older workers, especially those with limited skills. Unemployed workers over 50 usually require more time to find new jobs, and when they do, remuneration is likely to be lower than what they had received in their previous job.²⁹ Many simply give up and drop out of the labor force (and no longer are counted as being unemployed). The fact that technological change may have increased economic opportunities overall is no comfort to a veteran autoworker who was displaced from a well-paying job by a robot welder. Although qualified workers will be needed to program and repair robots, such jobs are not likely to go to the former autoworker. They may go to his or her son or daughter, but for a mature worker with obsolete skills, the future is bleak unless training programs and some form of income supplement can help him or her through a difficult period of transition. For the nation as a whole, the job losses suffered by older workers will likely be a growing problem as the population of the United States collectively ages; whereas there were 63 million men and women aged 55 or older in 2002; by 2025, there are projected to be 103 million of them.³⁰

The situation is not altogether dire if older workers receive the training needed to assume new jobs. Although older workers are sometimes stereotyped as being difficult to re-train, several studies have shown that this need not be so.³¹ The biggest impediment to equipping older workers with new skills may not inhere in the workers themselves, but rather stems from the erroneous belief that old dogs can't learn new tricks.

Recent decades have been the scene of breathtaking technological advances, but they have also been marked by economic globalization, altered family structures, reductions in government benefits for poor people, tax policies that have favored upper-income groups, increased immigration, stagnant minimum wages, and the erosion of union power, to name only the most prominent changes over the last few decades. Technological changes have surely contributed to both job losses and widening income economic inequalities, but all of the factors noted immediately above have been highly relevant. When assessing the importance of technological change in

promoting inequality, it is worth noting that all industrialized nations have also been the scene of significant advances in technology, but few of them have exhibited income and wealth inequalities as large as those of the United States.³²

One would have to go back to the 1920s to find the same degree of income inequality in the United States as exists today. Substantial wage and salary differentials are likely to persist if employment trends continue. According to the U.S. Bureau of Labor Statistics, between 2014 and 2024 some of the largest additions to the U.S. work force will come from the ranks of personal care aides, food preparation and serving workers, retail salespersons, and janitors and cleaners.³³ These are for the most part poorly remunerated jobs that require little in the way of formal education. Does this mean that the men and women holding these jobs will be condemned to low levels of remuneration throughout their working lives? Wages and salaries supposedly are based on employees' contributions to the organizations they work for, but they also reflect factors external to individual workers such as minimum-wage laws, tax policies, and the extent to which federal, state, and local governments support or oppose unionization. Technology will continue to powerfully affect the distribution of income, but it need not be the only influence. There is always the possibility that government policies can be used to move income distribution in the direction of greater equality.

Technology, Globalization, and Jobs

The loss of jobs as a result of technological change is an old story. A more recent source of job losses has been economic globalization—in particular, the offshoring of manufacturing jobs to low-wage countries. Much of this has been the work of multinational corporations (MNCs). The availability of low-wage labor in the poor countries of the world is often cited as the primary reason for moving jobs abroad, but it is not the only one; MNCs may have operations in other countries because they want to be close to important markets, insulate themselves from currency fluctuations, reduce transportation costs, and avoid tariffs and other trade barriers. Access to cheap labor is undoubtedly an important motivation for transplanting jobs to a poor country, but the advantages of a low-paid work force may be offset by other costs. A successful offshore operation requires adequate communication and transportation infrastructures, trainable workers, and at least minimally effective and honest governments. If cheap labor were all that mattered, all of the world's manufacturing would be done in sub-Saharan Africa and other places with large pools of unskilled workers.

Although technological change and the offshoring of jobs are separate phenomena, they are closely related. Technological change in the form of shipping containers and intermodal transport systems has dramatically lowered the cost of transporting manufactured items from low-wage countries to consumers abroad.³⁴ A typical case of intermodal transportation begins with a manufacturing plant loading its products into shipping containers, which then travel by truck to a port where the containers are loaded onto a ship that may take the products halfway around the world. The containers are then put on railroad flat cars bound for a distribution point, where they are offloaded onto trucks that take them to their final destination. Through this process, the costs of loading, unloading, and reloading crates and boxes are eliminated, and losses due to the effects of weather, damage, and pilferage are greatly reduced.

While improved technologies have lowered the time and expense of the transportation of physical goods, the rapid advance of digital technologies has

made it possible to transfer information at close to the speed of light— company memos, contracts, technical diagrams, legal briefs, market reports, and anything else that can be digitized. This has made it possible to offshore some activities requiring expert knowledge, such as interpreting lab tests, as well as some requiring minimal skills, such as processing bill payments and staffing call centers. As of now, however, job losses due to moving white-collar work to low-wage countries have been less evident than the loss of manufacturing jobs to these countries. Many information-related occupations will likely remain in the industrially developed world because they require a fair amount of face-to-face interaction and relationships based on trust.³⁵ And even when some elements of the job can be reduced to digitized communications, as has been noted previously, it will still be necessary to employ creative, well-educated workers to initiate, guide, oversee, and evaluate the kinds of changes that are essential to the realization of the potential advantages of digital technologies.



WorldFoto/Alamy

An abandoned steel mill in Pennsylvania gives silent witness to the consequences of economic globalization.

In sum, economic globalization has brought benefits by lowering the price of goods, facilitating the diffusion of modern technologies, and in general opening up the world to new ideas and ways of doing things. But it has had its unfortunate consequences as well. Throughout the developed world, empty steel mills, abandoned factories, and depopulated communities bear witness to industries and jobs lost to foreign competition. As with technological change with which it is closely connected, economic globalization has created winners and losers. Manufacturing workers have been particularly hard hit as their jobs have been outsourced to countries with cheaper labor or other inducements. As we have seen, there is no inherent reason that technological advance should lead to long-term unemployment, and the same can be said of economic globalization. Both create new opportunities, but adjustments will not come spontaneously. As will be noted in the next section, matching job skills to these opportunities will require the implementation of appropriate policies in the private and public sectors.

Rebounding from Job Losses

A general optimism regarding the consequences of technological change for employment should not obscure the fact that adjustments will not be smooth and automatic. There will always be a need for purposive action if technological change is not to result in a great number of individual tragedies alongside a general economic advance.

In fact, there have been few effective programs to mitigate the inevitable destruction of some jobs by technological advance. When the necessary adjustments have been made, they have been done on an ad hoc basis. A few unionized workers have been able to nullify the job-destroying effects of technological advance by striking advantageous bargains with their employers. For example, locomotive firemen were left with little to do when the diesel-electric replaced the steam locomotive, but they were able to negotiate contracts that preserved their jobs for many years. Make-work schemes, however, do not address the real problem of technologically induced job loss. Most people seem to have a real need to work, and to do work that has some intrinsic meaning. At the same time, as has been noted, technological change has not eliminated the need for work. The problem, then, lies in putting the two together by preparing workers whose jobs have been eliminated by technological change to take on jobs for which a real need exists. In an era of rapid technological change there is a fundamental need for retraining programs that help displaced workers develop new skills and prepare them for new jobs.

Unfortunately, current training programs in the United States have not been up to the task. Although federal, state, and local governments have a number of job training programs in place, they are still restricted in scope and scale. In part, this is due to the chronic underfunding of such programs, resulting in their inability to meet demand for them. But even with adequate funding, formal training programs can do only so much. The most effective training programs focus on skills learned on the job. In general, however, the private sector has failed to take a leading role in improving workers' skills because employers fear that their workers will use their newly acquired skills

to obtain better-paying positions elsewhere. The reluctance of employers to pay for retraining also results from tax policies. Some states offer a tax credit in return for incurring some training costs, and the federal government awards tax credits for the training of targeted individuals such as veterans, but tax credits and deductions are more generous for investments in physical capital than they are for human capital. At the same time, many workers fail to take advantage of the retraining programs that do exist because these programs do not take into account workers' skills and competencies. Many of the jobs eliminated by technological advance have been held by unskilled workers with limited education. A basic remedial program may thus be an essential component of a successful retraining program. And, sad to say, many young people are entering the labor force with serious deficiencies in essential reading and mathematics skills. Workers operating at these low levels are especially likely to be victimized by technological change, and it will be a major challenge to help them develop the skills that allow them to adjust to a technologically dynamic economy.

As has just been noted, one of the best places to learn new skills is by working on a real job. For many workers, however, a new job is likely to pay less than the job that was lost to technological change (or globalization, for that matter). Under these circumstances, it would make sense for a government-sponsored insurance program to supplement the new wage up to a certain level. Such a program would likely motivate a worker to take an available job rather than hold out for a higher-paying one that might never materialize. It would also lower resistance to job-related technological change. So far, no country has adopted such a program on a permanent basis, but it is worthy of serious consideration in this era of stagnant wages due in part to technological change.³⁶

Benefits, but Disruption Too

All in all, the fear that technological advance will lead to widespread unemployment seems unwarranted. Technological change does eliminate specific *jobs*, but it does not eliminate *work*. While some occupations are rendered redundant by new products and processes, others are being created. To be sure, this is cold comfort to mature workers who have been replaced by new machines. They may find work in America's expanding service sector or even in businesses that have been created by recent technological advances, but in all likelihood they will suffer a cut in pay. Even those who land good jobs may do so at the cost of considerable geographic, social, and psychological dislocation. Technological change often results in the rise of some geographical regions and the decline of others. Beginning more than a century ago, the rise of the automobile industry stimulated the rapid expansion of the Detroit area. In recent decades, the development of the semiconductor industry produced substantial growth in northern California's Silicon Valley. Taking advantage of new job opportunities may require pulling up stakes and moving to an unfamiliar part of the country, leaving friends, family, and community behind.

There is no getting around the fact that technological change can be a painful, disruptive process. Occupations and jobs rise and fall, and with them the fortunes of many individual people. There are spectacular winners and pathetic losers. Special efforts must be made if the latter are not to be ruined by the advance of technology. Technological change may destroy a career in which one has invested his or her whole life. It would be irresponsible and cruel to turn a blind eye to the needs of workers displaced by technological advance.

At the same time, it would be foolish to attempt to limit the development and spread of new technologies for fear of massive job losses. Far from being the product of technological advance, unemployment is much more likely to occur during periods of technological stagnation. One British labor historian has estimated that during the late seventeenth century, half the population of England were paupers because there was not enough work for them to do.³⁷

This situation began to change only when a series of technological changes helped to produce the Industrial Revolution. After two centuries of technological advance, significant numbers of people are still dogged by poverty and unemployment, but there is no denying that things are much better than they once were. Certainly our situation stands in stark contrast to the more technologically backward parts of the world, where vast unemployment and the poverty that accompanies it are the order of the day.

This, however, is not the end of the matter. Although technological advance has expanded employment opportunities for millions of people, it can still be argued that it has led to the degradation of the work they do. People may have jobs, but they are dreary, alienating, and unrewarding. In the next chapter, we will try to determine if this is really the case.

QUESTIONS FOR DISCUSSION

1. List a few jobs that have been rendered obsolete by technological change. Are some of these jobs so unpleasant that they are better done by machines? On the whole, have more “good” jobs or “bad” jobs been eliminated by technological advance?
2. What new products and services have been created by technological advance during the past 20 years or so? To what extent are they “essential” parts of contemporary life?
3. Is there anything problematic about an economy that centers on the production of services instead of the production of goods? Is a country with such an economy in an inherently dangerous position when it confronts international economic, political, and military competition?
4. In what ways is economic globalization similar to technological change in regard to job losses? Does it make sense to try to block either technological change or economic globalization in order to preserve jobs?
5. Should federal and local governments come to the aid of workers who have lost their jobs because of globalization and technological change? Is this a legitimate role of government? If so, what sort of policies and programs might be formulated to meet workers’ needs?

CHAPTER ELEVEN

| Technological Change and Life on the Job

The word *manufacture* literally means the production of something by hand, and for most of human history, it was just that. Goods were produced in small numbers by individual craftsmen who relied on little more than their own skills and a few tools. This situation began to change markedly in the middle of the eighteenth century as industrialization began to transform the way that things were made. To be sure, this was a revolution that was a long time in the making; people did not pick up their newspapers one day in 1750 and read “Industrial Revolution Breaks Out in England!” Many of the changes that produced an industrial society were small and slow to develop. Others were more dramatic, but even these required numerous incremental changes before they were effective. But taken together, these changes utterly transformed the way things were made, and with them the way people worked. This process continues today, with technological advance constantly changing the nature of work. In this chapter, we will consider the historical relationships between work and industrialization, as well as where they seem to be headed today.

Industrial Production

An economy based on industrial production has a number of special characteristics. In the first place, it requires large amounts of energy. Before industrialization, almost all of the energy used came from organic sources: human and animal muscle power and the burning of wood and other plant products. Civilization rested on the physical labor of peasant farmers and artisans (and in many places, slaves), whose efforts produced the surplus that supported the activities of small numbers of artists, priests, soldiers, and government officials. The use of new sources of energy allowed vast increases in production while at the same time lightening some of the physical burdens of work.

The first new energy source for the emerging industrial economy was water power. Waterwheels date back to antiquity, and were widely employed during the Middle Ages; over 5,000 of them could be found in England according to the eleventh-century Domesday Book. But these were simple devices that produced little power. With the mechanization of key industries such as spinning, weaving, and flour milling, larger, more elaborate wheels began to be used in great numbers. Of particular importance was the development in the nineteenth century of water turbines, which were far more powerful than the waterwheels that had been used for centuries. To an increasing degree these sources of power were built according to systematic, empirically derived principles, making them significantly more efficient.¹ Today, far from being obsolete in an age of fossil fuels, turbines in hydroelectric power plants supply electrical power to many parts of the world.²

Moving water continued to be important industrial power sources well into the nineteenth century, at which time steam engines slowly began to supplant waterwheels and turbines. Originally built to pump water out of mines, during the late eighteenth century, the steam engine was brought to a higher level of efficiency by James Watt's invention of the separate condenser. Of equal importance, Watt devised new linkages and gearing systems so that the up-and-down motion of a piston could be translated into

rotary motion, which was essential for the powering of many types of industrial machinery.

During the Industrial Revolution, steam and water animated a great number of new machines. Among the most important of these were machine tools that could produce large numbers of identical parts. The possibilities of this system were first indicated in the early nineteenth century when the Franco-British engineer Marc Brunel teamed up with Henry Maudslay, a pioneer designer and builder of machine tools, to produce large numbers of pulley blocks for the British Navy. After they installed 44 machines at the Portsmouth (England) Navy Yard, their staff of 10 workers was able to produce 160,000 blocks a year, a larger output than the one that had been achieved by 110 men using traditional techniques.³

The installation of power-driven machinery was complemented by the establishment of a new setting for productive work: the factory. Instead of the craftsman's shop with its half dozen or so workers, the dominant manufacturing enterprise was the large factory in which hundreds and even thousands of people performed the tasks that large-scale production required. As industrialization took hold, the size of manufacturing establishments grew rapidly. In 1870, one of the largest industrial enterprises in the United States, the McCormick reaper plant in Chicago, employed no more than 500 workers. Thirty years later, more than one thousand factories had between 500 and 1,000 workers, and over 400 had more than 1,000.⁴ Three steel plants and a locomotive works each had more than 8,000 workers.

With the spread of the factory system, most manufacturing workers no longer worked as self-employed artisans. They now worked for a business firm, and were dependent on it for the tools they used, the facilities they worked in, and of course the money they took home. Independent workers ceased to be the foundation of the economy. The typical worker was now a hired member of a firm, a wage-earner rather than an independent producer. Industrialization had created a society of employees.

The supervision and coordination of large numbers of employees, in turn, required entirely new methods of organization. Not only were far more people working in a single enterprise, they were also socially and psychologically separate from their employers and detached from their other social roles and responsibilities. As a result, the face-to-face contact and

personal attachments found in the craftsmen's shop gave way to bureaucratized managerial methods. Hierarchical command structures, written rules, strict job definitions, the precise scheduling of work, and rigid procedures became typical ways of organizing production.

Machine-Paced Labor

The spread of industrial technologies helped to make work a more regular and precisely scheduled process. New power technologies were of particular importance in making work follow strict temporal rhythms. Industrial processes that made use of steam engines and waterwheels were obviously unsuited to irregularly paced methods of working. Since they were expensive pieces of capital equipment, these power sources and the machines they ran had to be operated constantly if they were to be used efficiently; sitting idle they produced no income. This meant that not only were the times of work more precisely scheduled, but work had to be performed at all hours. Shift work and labor at unsociable hours made their appearance, a situation that stood in marked contrast to the life of the craftsman working under guild regulations that usually prohibited working at night or under any form of artificial illumination.

Many of the new industries that emerged in the nineteenth century gave further impetus to precisely scheduled, clock-regulated work patterns. This was especially evident in the operation of one of the era's key industries, the railroad. The size of this new enterprise, the multiplicity of tasks required, and above all the need for adhering to precise schedules made the railroad a key example of the temporal regularization of work. The emphasis on scheduling and the efficient use of time also had an effect on the larger economy and society. As Henry David Thoreau said of the railroads of his era:⁵

They come and go with such regularity and precision, and their whistles can be heard so far, that farmers set their clocks by them, and thus one well-regulated institution regulates a whole country. Have not men improved somewhat in punctuality since the railroad was invented? Do they not talk and think faster in the depot than they did in the stage office?

During the railroad's earliest years, railwaymen were required to carry "good watches and correct them daily."⁶ From that time onward, the conductor's pocket watch, accurate to a few seconds a day, became emblematic of his occupation. On a larger scale, the demands of railroads led

to the establishment in 1883 of Standard Time and the division of the United States into four time zones. No longer would each community observe a unique time that was based on a noontime determined by the highest point of the sun's passage. A new technological system had produced the artificial method of marking time that we take so much for granted today.

The railroad was not the only industry that required high standards of temporal regularity in the workplace. In factories of every sort, workers had to accommodate themselves to the demands of the machinery, and in many cases the machines were harsh taskmasters. And not only was the pace more frenetic and unvarying, the work itself was often highly unsatisfying. For many of the new industrial occupations, the required work often called for only the most rudimentary skills. Many machines were designed so that the skill required inhered in the machine and not in the worker who tended it. Although the traditional labors of artisans and farmers also had their periods of drudgery and monotony, the factories that sprang up in the nineteenth and twentieth centuries seemed to usher in a new era of deadening labor—repetitious, narrowly specialized, radically simplified, and paced by the machine.⁷



© Historic Photo Archive.net

A locomotive engineer and a conductor make sure that their watches are in agreement.

The employment of large numbers of workers, each performing specialized tasks that had to be closely scheduled and coordinated in accordance with the needs of machinery, necessarily resulted in the loss of worker autonomy. Even Friedrich Engels, Karl Marx's collaborator and a strong advocate of the rights of working people, was convinced that industrial technologies resulted in a regime that was "more despotic than the small capitalist who employs workers ever has been." Engels stressed that industrial technology required strict managerial authority:⁸

If man, by dint of his knowledge and inventive genius has subdued the forces of nature, the latter avenge themselves upon him by subjecting him, in so far as he employs them, to a veritable despotism independent of all social organization. Wanting to abolish authority in large-scale industry is tantamount to wanting to abolish industry itself, to destroy the power loom in order to return to the spinning wheel.



SCOTT S. HAMRICK/Newscom/Tribune News Service/FREDERICKSBURG/PA/USA

A rapid working tempo makes it possible for this poultry-processing plant to ship 200 tons of dressed chickens every day.

Industrial technology thus stands indicted as the destroyer of long-established ways of working that had allowed workers to enjoy at least some measure of independence. Machinery and the accompanying factory system increased production, but only at the cost of a cold, regimented on-the-job existence. Many would consider it a poor bargain. But the story is not yet complete; before we blame the advance of technology for the degradation of work, we must consider how these technologies came into being and whose interests they served.

Is Technology to Blame?

Industrialization resulted in rapid and sustained economic growth and a massive increase in consumer goods. But at the same time, for many people, it meant a thoroughly unpleasant work environment. Were industrial technologies in themselves the cause of the long working hours, monotonous routines, and the general degradation of labor often found in industrial economies? Here, we again meet a fundamental question about the nature of technology: Does technology determine a basic human process such as work, or is technology itself shaped by economic and social relationships?

The history of industrial technologies seems to indicate that similar technologies can support a variety of working arrangements. The use of steam power did not always require massive factories under centralized direction. In the Coventry ribbon industry, weaving was done on power looms situated in blocks of independent workshops that were arranged so that they could make use of a single steam engine.⁹ By the mid-nineteenth century, these cottage factories contained over 1,000 power looms, as many as could be found in the conventional factories throughout the city.¹⁰

The Coventry ribbon-weaving industry is not an isolated example. In Sheffield and Birmingham, cities at the very heart of England's Industrial Revolution, local artisans could rent work spaces supplied with transmission belts connected to a centralized steam engine; "Power to Let" was a sign commonly seen in Birmingham during this period.¹¹ Fundamental mechanical innovations of the early nineteenth century, such as the Jacquard loom (which introduced the use of punch cards for the guidance of an industrial operation), were used not in large factories but in small workshops that were often part of the workman's home.

By themselves, these examples do not prove much. As we have seen, a fundamental feature of technological advance is that innovations begin to be used on a small scale and are steadily expanded as experience is gained with them. Still, the late nineteenth- and early twentieth-century deployment of machines in factories of ever-increasing size was not simply the result of increasing technological sophistication; putting workers into large factories

may also have been motivated by a need to control and discipline them.

Employers had long contended with strong-willed, independent workers under a variety of working arrangements. Before the Industrial Revolution, one such arrangement was the domestic (or “putting out”) system of manufacture. An employer supplied workers with tools and raw materials that were to be used in the workers’ own homes. The employer then picked up the finished product several weeks later. This system gave the workers a good deal of autonomy and flexibility—too much, as far as many employers were concerned. The lack of direct supervision often resulted in shoddy products and a slow pace of production. Even worse, some workers bilked their employers by selling the raw materials, using an inferior substitute, and pocketing the difference.

Given these managerial problems, it is easy to see the appeal that the factory had for many employers. Within the walls of the factory, the workers were required to put in regular hours while the pace of their work was controlled by foremen who closely supervised their activities. Although perhaps overstated, one scholar’s summation captures an essential reason for the development of the factory:¹²

It was purely for purposes of discipline, so that workers could be effectively controlled under the supervision of foremen. Under one roof, or within a narrow compass, they could be started to work at sunrise and kept going until sunset, barring periods for rest and refreshment. They could be kept working six days a week. And under the penalty of loss of all employment they could be kept going almost throughout the year.

The development of the factory made close managerial control possible. Even so, the closest management by itself cannot ensure regular work efforts. Unless one supervisor can be assigned to each worker, the latter will always find ways to escape scrutiny and evade work if so inclined. In extreme cases, disgruntled workers can even resort to sabotage, a word that derives from the throwing of wooden shoes—sabots—into the machinery. In a setting where workers are employees and have no direct stake in the success of their enterprise, such inclinations are likely to be widespread. In working environments like these, machinery takes on an importance that goes beyond the improvement of productive processes. Machine-based technologies can ensure that work is steadily performed and that it is performed in accordance

with the requirements of the management. As one critic of management-inspired industrial technologies put it:¹³

Machinery offers to management the opportunity to do by wholly mechanical means that which it had previously attempted to do by organizational and disciplinary means. The fact that many machines may be paced and controlled according to centralized decisions, and that these controls may thus be in the hands of management, removed from the site of production to the office—these technical possibilities are of just as great interest to management as the fact that the machine multiplies the productivity of labor.

Machines can be complex and hard to manage, but people are even more difficult. Many employers eagerly sought machine technologies as a way of counteracting the vagaries of human motivation and performance. Machines provided a model of reliable performance, as well as a way of coaxing it out of their workers. The factory system that began to emerge in the late eighteenth century was not exclusively the consequence of the technologies employed; at least as important as the operational requirements of machine-based technologies were the desires and intentions of management.

Industrial Technology and the Division of Labor

A major characteristic of an industrial society is an extensive division of labor. Instead of a single craftsman performing all of the tasks involved in making a product, production is broken into small segments, each one performed by a different worker. This reduces production costs, as it is not necessary to pay top wages to a highly skilled worker to do everything; some of the work can be done by a person with lesser skills at lower wages.

Production based on division of labor requires managerial control, but equally important, it makes such control easier to exert. As long as tasks are kept simple so that workers can be readily hired and fired, there will be little need to depend on workers with all-around skills. This can benefit management because the special abilities of skilled workers generate an independent spirit and a fair amount of economic leverage, as John Delorean's description of the behavior of skilled toolmakers in the automobile industry illustrates:¹⁴

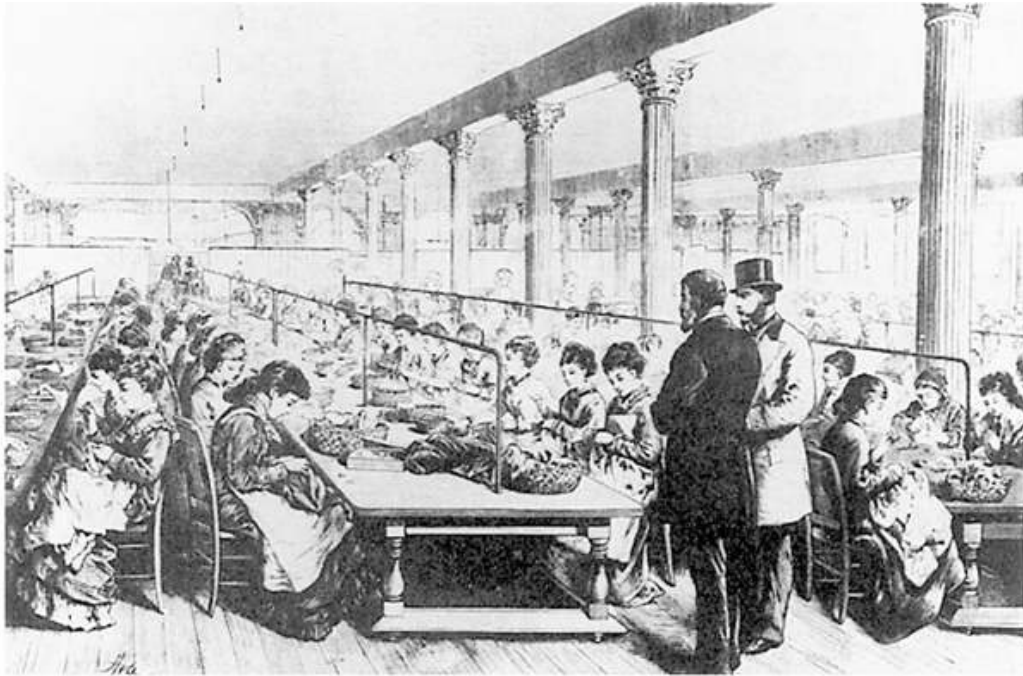
These fine old tool makers worked hard and were very proud of their craft. They kept their big tool boxes right underneath their work benches. If you looked at them the wrong way or dealt with them in any manner other than a man-to-man, professional fashion, they would simply reach under their work benches without saying a word, throw their tools into the big box, lock it up and leave. That was it. Each guy figured, "What the hell. I don't have to take this from anybody. I'm a pro. I know this business and I am not depending on you or anyone else."

The ultimate marriage of machine technology and the division of labor is the assembly line. Instead of using a variety of skills and working at their own pace, workers perform specialized and repetitious tasks that are dictated by the tempo of the moving line. The development of this system of production is attributed to Henry Ford, and rightfully so.¹⁵ After taking his inspiration from the meatpacking industry (which, of course, used a "disassembly" line), Ford and his associates realized productive gains that had scarcely been imagined in the past. Before Ford's introduction of the moving line in 1913, automobiles were produced in small batches by workers

with a multiplicity of skills. The work was undoubtedly more satisfying, but the product was high in price and necessarily limited to the rich. The assembly line allowed dramatic price cuts for two reasons: it drastically reduced the time needed for manufacture, and it allowed the substitution of low-wage, unskilled labor for the high-priced labor of all-around craftsmen. Ford's description of work in his factory captures the essence of this new form of manufacture.¹⁶

One man is now able to do somewhat more than four did only a comparatively few years ago. That line established the efficiency of the method and we now use it everywhere. The assembling of the motor, formerly done by one man, is now divided into eighty-four operations—those men do the work that three times their number formerly did.... In the chassis assembling [room] are forty-five separate operations or stations. The first men fasten four mudguard brackets to the chassis frame; the motor arrives on the tenth operation and so on in detail. Some men do only one or two small operations, others do more. The man who places a part does not fasten it—the part may not be fully in place until after several operations later. The man who puts in a bolt does not put on the nut; the man who puts on the nut does not tighten it.

The extreme division of labor found on the assembly line was paralleled by an unrelenting tempo of work and the absence of any control over it by the workers. Until efforts at “job enrichment” began to change the nature of automobile production,¹⁷ manufacturing methods followed the Ford pattern closely. With the typical automobile assembly line churning out 50 to 60 vehicles per hour, each worker had but a few seconds to complete an operation such as mounting a shock absorber or installing a windshield. When problems arose, the worker had to make the best of a bad situation, even if it meant installing something improperly. Under these circumstances, work can be little more than a rather unpleasant way of earning a living. Extracting any sense of personal fulfillment from the work performed is just about impossible.¹⁸



Everett Collection/Superstock; Granger, NYC—All rights reserved.

Machinery was not always a prerequisite for factory production. Note the similarity in the general layout of two clothing factories, one operating before the invention of the sewing machine, the other afterward.

Scientific Management Once Again

In addition to controlling the pace of work through the use of the assembly line, managers also attempted to regulate work by using elaborate systems that removed all vestiges of worker control over work processes. The most significant of these was Frederick Taylor's Scientific Management, which was briefly discussed in Chapter 2. The important thing to reiterate here is that Scientific Management stipulated the precise scheduling and organizing of work activities, and that these procedures were never to be left to the workers' discretion. As Taylor explained his system,¹⁹



Philip Gendreau/Corbis

Generator assembly at a Ford plant in the 1930s.

Perhaps the most prominent single element in modern scientific management is the task idea. The work of every workman is fully planned out by the management at least one day in advance, and each man receives in most cases complete written instructions, describing in detail the task which he is to accomplish, as well as the means to be used in doing the work.... This task specifies not only what is to be done, but how it is to be done and the exact time

allowed for doing it.

The development of these instructions was the work of a small group of technical specialists who were not directly involved with the work being performed, for, as Taylor stipulated, “All possible brain work should be removed from the shop and centered in the planning or laying-out department.”²⁰ Efficient work required unfettered control by specially trained managers, who were to be repositories of all knowledge regarding the work being done: “The managers assume ... the burden of gathering together all of the traditional knowledge which in the past has been possessed by the workmen and then of classifying, tabulating, and reducing this knowledge to rules, laws, and formulae.”²¹

Many would see Taylorism as a perversion of scientific means of inquiry and a travesty of engineering practice. But repellent as it may seem to us today, the spirit of Scientific Management still lives in technologically advanced societies. The explosion of knowledge that is the driving force of our sophisticated economy can fragment the population into groups of specialized experts. This may be a natural outcome of the growth of knowledge, but it takes on a pernicious quality when specialized knowledge is the exclusive possession of one group of people who attempt to use it as a means of dominating others. Under these circumstances science and technology do not simply supply detached knowledge that is used for universal human betterment. They are used to strengthen the position of a dominant group by removing the control over work processes from the hands of those doing the actual work.

Industrial Work and Recent Technological Developments

Many social critics have decried the human consequences of technologies and managerial strategies that take the skill out of human labor. Others have taken a different tack, arguing that an industrial system that “de-skills” workers is doomed to failure. A great deal of contemporary industrial work, according to this perspective, requires substantial amounts of independence if it is to be done effectively. A modern factory and its constituent departments cannot be expected to hum along indefinitely like a well-oiled machine, nor can all of the jobs be precisely defined and completely subject to control from above. Breakdowns, disruptions, and normal deterioration are inevitable, and they all require prompt attention and often a fair amount of innovative ability on the part of the workers.²²

Even routine tasks often require knowledge of special quirks in the machines and work processes. This knowledge can be gained only through intimate acquaintance with the work itself; engineers cannot plan everything in advance.²³ There are many occasions when shop-floor workers understand things better than their bosses, and their involvement in production processes may be essential to a firm’s success. This point was strongly articulated by a General Electric executive when he noted, “All of the good ideas—all of them—come from hourly workers.”²⁴ Workers who have been reduced to mindless operatives may not even be able to keep the machinery going when the inevitable problems emerge. Accordingly, effective managers realize that the destruction of worker skills through mechanization and rigid centralized controls is self-defeating, for an ignorant and hostile work force means production losses as well as high costs for maintenance and direct supervision.²⁵

A precisely programmed production process that makes use of specialized machinery while sharply separating the tasks of those who plan and those who work is possible only when the product is a standardized one. This system generated a great outpouring of mass-produced goods, but it may not be appropriate to today’s economy and society. With improvements in the

overall standard of living, consumers are less willing to buy exactly the same things that their neighbors do. Instead, they have an appetite for goods and services with distinctive qualities. These cannot be produced by traditional manufacturing processes. As former Secretary of Labor Robert Reich has argued, rigid production technologies were appropriate only when business enterprises were “engaged in high-volume, standardized production, entailing a large number of repetitive tasks with clearly defined goals, in which almost all contingencies could be identified and covered.”²⁶ In contrast, the production of nonstandardized items requires much more flexibility, making it difficult to replace human skills with machines and machinelike processes. At the same time, the continual modification and customization of products and procedures require the ongoing efforts of a variety of workers—designers, toolmakers, computer programmers, systems analysts, setup personnel, maintenance and repair staff, construction workers, and machinists, as well as personnel involved in marketing, distribution, sales, and service. All of these occupations require a fair degree of skill and on-the-job autonomy.

The production of standard products for a mass market creates a fertile ground for the extreme division of labor and the de-skilling of work that was typical of many businesses during the nineteenth century and a good part of the twentieth. But when consumers continually demand new, nonstandard products, existing ways of producing things no longer make sense from an economic standpoint. Firms that cling to the old routines not only oppress their work force, they run the risk of eventual bankruptcy.

Technological Change and White-Collar Work

At this point, it can be fairly argued that a concentration on industrial work is misplaced. As was noted in the previous chapter, the number of workers in manufacturing enterprises has steadily declined in relative terms, and these workers are now a small segment of the labor force. Work on the assembly line, often considered the epitome of industrial work, in reality occupies only a tiny fraction of workers in the manufacturing sector. Due to fundamental changes in the economy, the typical worker in the United States no longer toils on some factory floor.

As the number of manufacturing jobs relative to the total labor force has declined, more and more people are now found in white-collar occupations. More workers are engaged in what the U.S. Bureau of Labor Statistics classifies as “office and administrative support occupations” than any other type of work, comprising about 16 percent of the nation’s labor force.²⁷ Today, the typical workplace is not the factory but the office. Some analysts have seen this as an indication that the general occupational level has improved. Moreover, it has been argued that technological change has in many cases increased skill requirements and allowed clerical workers to take on broader responsibilities, an assertion that will be taken up in the last part of this chapter.

Although some technologies have the potential to empower workers, others are used to monitor them continuously. These technologies are especially appealing to managers like the one who stated, “I’m a great one for believing that people will really do what’s *inspected* and not what’s *expected*.”²⁸ They now have at their disposal many ways to monitor their employees. As Ellen Alderman and Caroline Kennedy have noted: “Keystroke monitoring (where the computer counts the number of keystrokes per minute), telephone accounting monitoring (where the number of phone calls per hour and the length of each call are recorded), as well as service observation (where supervisors listen in on calls), and keeping track of unplugged time (measuring time spent away from the computer) are all

becoming commonplace.”²⁹ To these can be added the counting of mouse clicks and the monitoring of email messages, sometimes with programs that detect potentially incriminating words like *boss* and *union*.³⁰ Even executive and higher-level employees are not immune; laptop computers, cell phones, and voice mail all can keep employees tethered to an “electronic leash” that can make work a 24-7 obligation.



Exactostock-1527/SuperStock

Although farms and factories still produce most of our essential goods, the office is the typical workplace of twenty-first-century employees in the developed world.

Industries and organizations, as well as the workers who are employed by

them, vary immensely, making it impossible to come to a summary judgment of the consequences of technological change for white-collar work. Twenty-first-century technologies offer expanded opportunities for monitoring workers, but they also have the potential to empower these workers by making available vast troves of information that used to be available only to upper-echelon managers. It is also important to keep in mind that ascribed characteristics of workers, such as their gender and ethnicity, can affect the way in which technological changes have altered their jobs. There is some evidence that early examples of office automation were more beneficial to male rather than to female workers. In the insurance industry, for example, high-level positions in the management of electronic data processing systems became almost exclusively male preserves, while routine clerical work became an increasingly female occupation. A similar pattern was observed in the Internal Revenue Service, where computerization reduced the number of middle-level jobs, thereby blocking advancement opportunities for a largely female clerical staff.³¹ These examples indicate that when a labor market is already segmented along gender or ethnic lines, new technologies can reflect or even reinforce existing divisions. One group may benefit from new ways of doing things, while another group may find themselves in the same, or possibly worse, circumstances.³²

Telework

The differential effects of new workplace technologies can also be seen in the way computer and communications technologies have been used for work performed away from conventional workplaces. Known as *telecommuting* or *telework*, this mode of labor has grown in recent years. In 2012, more than 3.2 million American workers or 2.6 percent of all workers were classified as teleworkers according to a strict definition that encompassed employees who did at least half of their work at home. A more inclusive definition that included everyone who did at least some work at home, along with workers who do not have a fixed place of employment—plumbers, truck drivers, landscapers, and the like—put 30 percent of employees in this category.³³ Another approach was taken by the Gallup polling organization, which defined a teleworker as someone who used a computer at home as part of his or her job. In this case, the number of teleworkers was quite a bit higher at 37 percent, but on average, employees who worked at home did so for only two days a month. Only 9 percent of employees worked as telecommuters for at least half of the working week.³⁴

Although it is based on modern technologies such as email, texting, teleconferencing, cloud computing and data storage, telework represents a return to a mode of work that prevailed before industrialization, suburbanization, and new transportation technologies combined to separate the workplace from the home. As we have seen, domestic production prior to industrialization was riddled with problems of motivation and discipline that were ultimately overcome by the development of the centralized factory and its regimen of close supervision. Modern communication technologies have allowed some reversal of this long-term trend. Through telework, workers can avoid expensive, stressful commutes and have more on-the-job flexibility.

In the past, homes adjoined the workshops of skilled craftsmen, but a home worksite also could be a place where miserably paid workers put in long hours in cramped cottages and fetid tenements. This dismal history caused an initial opposition to modern telework by organized labor. Labor

unions also opposed work done in the home because dispersed and easily replaced workers are difficult to recruit and organize.

Union opposition to telework has softened in recent years with the realization that telework can be beneficial for many workers. Abundant possibilities for exploitation exist when workers are isolated in their individual homes, are dependent on their employers for their livelihoods, and can be easily replaced, but not all work in the “electronic cottage” conforms to this model. Electronic homework need not be confined to such things as routine word-processing tasks. Jobs requiring a high degree of skill and expertise can also be done in the home. It may even be possible for many specialized services to be supplied by homeworkers who are not employees of a firm but work on a contract basis, perhaps as a member of an autonomous teleworkers’ association. At the same time, regular employees who work far from their firm’s central office may not have to be electronically supervised as long as they have a personal stake in the success of the firm. This is more likely to happen when employees occupy upper-level positions within an organization. For these workers, new technologies can make their work more autonomous, convenient, and fulfilling.



Courtesy Michael Miller

One of the advantages of telecommuting is being able to combine work and family responsibilities.

Although telework can bring a number of benefits, workers should understand that a prolonged period of absence from a central workplace, even

if it does not result in diminished output, may put these workers at a disadvantage when it comes to pay raises, promotions, and assignment to new projects. Teleworkers may be cut off from vital information, have difficulties forming job-related relationships with other workers, and may be excluded from essential job-related networks. As Joel Mokyrr has noted of conventional working relationships, “Proximity in a plant or office created personal familiarity and thus conditions of trust and believability. There is always a role of body language, intonation, and general demeanor in human communications.”³⁵ In sum, electronic communications technologies can be used for many work-related purposes, but there remains a need for at least occasional “face time” at a workplace.

The “Gig Economy”

An intriguing change in the organization of work has been the recent rise of the “sharing” or “gig” economy (so called because workers are employed as independent contractors to perform specified tasks). As briefly noted in Chapter 2, this has been exemplified by Uber, a firm whose drivers use their own vehicles and connect with customers through smartphones. Workers defined as contractors rather than employees can also work for firms providing personal services, computer programs, and grocery deliveries, to name a few.

Although the expansion of the gig economy has been made possible by digital technologies, the basic idea is an old one. As we saw in the previous chapter, before the rise of the factory system, many employers did not directly hire workers; rather, they supplied tools and raw materials to workers who produced cloth and other goods in their homes. The workers were then paid after the finished goods had been collected by the employer.

Even though the model is an old one, the development of the modern-day gig economy has generated some new issues about the worker–employer relationship. Whether a worker is an employee or a contractor will determine the applicability of laws governing wages, hours, and working conditions. This in turn will hinge on such issues as the extent of control exercised by the employer, the permanency of the worker–employer relationship, and whether the work being performed is an integral part of the employer’s business.³⁶

Other examples of the gig economy are the forging of direct connections between customers with suppliers of goods and services, thereby dispensing with an employer altogether. One of the best known of these is Airbnb, which allows owners of houses and apartments to temporarily rent all or part of their homes to short-term visitors. Once again, digital technologies facilitate making connections between buyers and sellers. At the same time, computer- and smartphone-based social media may also be important for the establishment of a modicum of trust between strangers because these media contain some information about each person.

Some observers see today’s gig economy as the harbinger of dramatic

changes in the nature of twenty-first-century employment. As evidence, they point to 30.2 million independent workers in the U.S. economy, an increase of 12 percent from 2010 to 2015.³⁷ On the other hand, skeptics note that the overwhelming majority of workers continue to be employees of business, governmental, and nonprofit organizations, and that the number of self-employed workers has actually fallen slightly over the past decade.³⁸ All in all, it can be reasonably stated that the gig economy will expand in the years to come, but the rapidity and extent of that expansion is still in doubt.

Smart Technologies and Dumb Jobs?

Optimistic students of technological change are fond of pointing out that as computerized processes continue to emerge, a growing segment of the labor force will be found in jobs that require high degrees of skill. Instead of monotonously tightening nuts and bolts or engaging in routine clerical operations, large numbers of workers will be engaged in tasks that cannot be performed by computers. Frank Levy and Richard Murnane have called attention to the many kinds of work activities that cannot be reduced to computer-friendly routines, the abilities and processes that they have dubbed “expert thinking” and “complex communication.”³⁹ And, as we saw in the previous chapter, even where computers have taken hold, a large number of employees will be required to continually modify organizational structures and operations to make optimal use of computer-based technologies. From these perspectives, occupational skill levels are going up, and the proportion of unskilled factory operatives and office clerks is declining in twenty-first-century enterprises.

It is undeniable that these trends can be found throughout the economy, but to less optimistic observers, predictions of the radical upgrading of workers’ tasks are at best premature. Plenty of jobs still require only the most minimal levels of skill and training. The task of monitoring industrial processes can be just as dull as the most routine assembly operation, and in any event, many of these functions can be performed by sensors connected to computers. Even maintenance and repair jobs may represent only a slight improvement in required skill levels. Technological advances can lower maintenance requirements, and when repairs need to be done, they can often be accomplished by simply disconnecting a faulty module and replacing it with a new one. The task of diagnosis, which often requires the greatest amount of the repair person’s skills, has itself been simplified through the development of special test circuits and computer-based “expert systems.” The need for repair skills will always be present, and it is unlikely that technological developments will allow the elimination of repair personnel. Still, any dilution of the repair person’s skill will have significant

consequences for the overall skill levels of the labor force, for these workers comprise the largest single group of skilled workers.⁴⁰

Moreover, even if the optimists are largely correct, their predictions only hold for industries that make extensive use of advanced technologies. High-tech factories and offices may require higher levels of employee skills, but these are not the workplaces of large numbers of workers today or in the near future. Nor will new high-technology industries generate great numbers of new jobs. To be sure, some high-tech occupations have grown rapidly in recent years and are projected to do so in the future. According to the U.S. Bureau of Labor Statistics, from 2010 to 2020 employment in “Computer and Mathematical Occupations” is expected to grow by 22 percent, for a net addition of 778,300 jobs.⁴¹ This represents a healthy rate of growth, but it is more than matched by the 1,443,000 projected new jobs for “Healthcare Support Occupations” (about half of which are expected to be home health care aides), the 1,861,900 additional jobs in the retail trade, and 1,029,500 more jobs in “Food Preparation and Serving Related Occupations” during the same period.⁴² In fact, of the 10 occupations with the largest numerical employment increases projected from 2010 to 2020, only two—registered nurses and postsecondary teachers—require much in the way of advanced training. The remainder—occupations like personal care aide, truck driver, and customer service representative—hardly represent the high-tech future.⁴³ Advanced technologies have given rise to a number of occupations that have grown at a rapid rate from a low base; however, in absolute terms, most of the job growth in the near future will take place in occupations that have been around for a long time.

Although technological advance does not seem to be the source of large, across-the-board increases in workers’ skills, it doesn’t seem to be producing the opposite effect either. While the skill requirements in some occupations have decreased, they have increased in others, and it is likely that all of these changes have offset one another, leaving no net change one way or the other.⁴⁴ It may also be the case that there has been some degree of polarization as skill requirements have increased in some jobs and occupations and decreased for others.⁴⁵ For example, automobile manufacture has changed substantially as a result of the introduction of computer-controlled equipment. This, in turn, has led to changes in the skills

exercised by the factory workforce; while skilled workers have experienced upgraded skill levels, the opposite has been the case for production workers.⁴⁶ This bifurcation was not the inevitable outcome of technological change, however. The distinction between skilled and unskilled workers has always been a prominent feature in the automobile industry, and in the absence of changes in organizational structure and culture, the introduction of new production technologies reinforced this division by giving skilled workers most of the responsibilities for the operation, maintenance, and repair of technologically sophisticated equipment while leaving ordinary production workers with jobs that continued to require little in the way of skill.

This is hardly an atypical pattern. As several researchers have noted, organizational patterns strongly influence the skills used by workers.⁴⁷ One aspect of organizational structure that may strongly affect workers' skill levels is the distribution of power. When there is a sharp division between those who manage and those who work, and when managers view their workers as hostile and unreliable, workers will be treated as replaceable parts. Their skill level will be low, and they will be controlled by centralized supervision and machine-paced work processes.⁴⁸ By contrast, when a more democratic and egalitarian order prevails, technologies that require the initiative and commitment of workers are more likely to be selected, and workers will be given a chance to develop their skills and take their places as valued members of the organization.

New technologies can be developed to increase levels of skill, or they can be used to diminish them. As with all matters regarding technology, choices have to be made. These choices emerge in an environment where the intentions and relative power of employees, managers, and the owners of enterprises are usually at least as important as emerging technological capabilities in determining the course of technological change and its consequences for a firm's workers.

QUESTIONS FOR DISCUSSION

1. Do you agree that many early industrial technologies were used as ways of controlling labor? What sort of historical research could be done in order to test this proposition?
2. Do employers have a legitimate right to electronically monitor their employees? Would you object to monitoring by your employer? Should federal or state governments pass laws that limit electronic employee monitoring? If so, what would be reasonable limits to this practice?
3. Can you see any indications that consumers are showing a preference for nonstandardized products? How will changed consumer preferences affect workplace technologies?
4. According to some predictions, a growing number of jobs will be held by “teleworkers”—employees who work at home while using computers to receive, process, and transmit information. What sort of jobs could be done in this way? Would you like to work as a teleworker? Why?
5. What are some of the key skills used by practitioners of an occupation you are interested in? Which of these skills might be replaced by technological advances in the near future? Would a diminished need for these skills make this occupation more or less attractive to you?
6. As noted in this and the previous chapter, the optimal use of computers in many work settings will require employees who are able to restructure organizational structures and procedures. To be more specific, what sort of things might need to be done? How would you go about preparing for a job that requires skills of this sort?

PART FIVE

Communication

The ability to express and understand complex thoughts is one of the most fundamental characteristics of the human race. For most of human existence, this was done primarily through the spoken word. The invention of writing greatly expanded the reach and permanency of communication, but for hundreds of years, reading and writing were confined to tiny segments of the population. As we will see in Chapter 12, the invention and diffusion of printed works marked a revolutionary stage in human communication by making written works accessible to much larger numbers of people and at the same time contributing to profound social, political, cultural, and psychological changes.

For the next four centuries, communication technologies remained static, as people waited weeks and even months for the arrival of a letter. But in the middle of the nineteenth century, a dramatic transformation occurred. The next chapter presents the transformative media technologies that began as the telegraph brought virtually instantaneous communication to every part of the world where wires had been strung. This was only the beginning of the next revolutionary phase, as radio and then television vastly expanded the range and content of human communication. Their history will take up a substantial part of Chapter 13.

Still, the revolution in human communications was far from over. While the consequences of radio and television are still being debated, recent years have seen the emergence and rapid diffusion of a host of new media

technologies, carrying with them the potential for massive changes equal to those wrought by printing, the telegraph, radio, and television. In Chapter 14, we will consider two of them, the internet and mobile communication devices. Today, many people view these media as being virtually synonymous with technology in general. As such they occupy a special place in our everyday lives, which now incorporate heavy reliance on the internet and the frequent use of social media. As with the technologies that have come before them, the creation and use of social media and other new ways of communicating highlight the complex issues presented by new communication technologies.

CHAPTER TWELVE

Printing

When I needed a permanent means of recording and subsequently disseminating my ideas about how some major features of technology are connected to social structures and processes, I naturally thought about writing a book. If I were not so verbose, I could have written a magazine article. There are, of course, other ways of retaining and transmitting information and ideas. They can be stored in a person's memory and then communicated through the spoken word; indeed, that was the way things were done for most of human history, and are still done in nonliterate societies. If present trends continue, at some point in the future, books, newspapers, and magazines may be largely supplanted by websites and e-books. But until very recently, nothing has equaled words printed on paper as a rapid, cheap, and portable means of storing and transmitting information. Moreover, the importance of printing goes well beyond the storage and communication of information. The social effects of printing have been immense, making printing one of the most significant technological innovations of all time.

The development of a written language is one of the hallmarks of civilization. While a spoken language is a basic element of all human societies, not all of them developed a written language. Of the approximately 5,000 to 8,000 languages that are spoken today, only a very small percentage appear in written form, and in many cases, these written languages have been recent inventions, stimulated by missionaries or other contacts with the outside world. One interesting example of an effort to create a written language appeared in the 1820s, when a Cherokee Indian named Sequoyah

single-handedly constructed a written language so that his people could more effectively resist the encroachments of white settlers. A written language was an essential technology, for as Sequoyah observed, “Much that red men know, they forget; they have no way to preserve it. White men make what they know fast on paper like catching a wild animal and taming it.”¹ After much laborious effort, Sequoyah succeeded in constructing a system of writing that could be mastered in a few weeks. Unfortunately for Sequoyah’s people, the new written language by itself could not stem the advance of the white man into Cherokee territory.

The writing systems of the great languages of the world were also constructed to serve practical purposes. In ancient Egypt, Babylonia, and China, writing was used to keep financial accounts and to facilitate communication between government officials. Writing also served a spiritual purpose in many cases, for it allowed the recording and diffusion of concepts that were central to the local religion. Since church and state were tightly interwoven in these ancient states, writing met the needs of the political elite in their dual role as priests and secular officials. As with many technologies, writing owed its development to the needs of one group of people and was used to maintain and extend their influence over others.² For example, the priests of Egypt during the days of the pharaohs were able to refer to written calendars that allowed them to predict the cyclical flooding of the Nile, thereby demonstrating their supposed indispensability.

The Printing Revolution

Other than the maintenance of a social and political hierarchy, the effects of writing were minimal when the written language was understood only by a small segment of the population. Few of the common people had the time and inclination to become literate, and even if they were able to read, the great cost of producing written documents kept these works out of their reach. Written materials had to be laboriously drafted and copied by hand.

Documents central to a civilization, such as the Bible of medieval Christianity, were scarce and inaccessible because monks and other scribes had to labor for many months to produce a single volume. Few individuals and institutions could amass even modest libraries; two of the largest book repositories in England, the abbey libraries of Canterbury and Bury, each held 2,000 books, while the library of Cambridge University had only 300.³

In the absence of widespread literacy, the ability to memorize was developed to a level scarcely imaginable today. People made use of elaborate mnemonic devices in order to recall important facts and concepts. This facility made it possible to preserve laws, ceremonies, and stories in the minds of individuals. It was not unusual to find people who could recite sacred texts and heroic sagas that might today occupy hundreds of pages of printed text.

All of this began to change dramatically with the introduction of printing with movable type. As with many other technological innovations, printing originated in East Asia. In the fourth century A.D., the Chinese copied stone inscriptions through the use of paper rubbings. By the seventh century, Chinese printers were using carved wooden blocks to produce books on agriculture and medicine. Chinese accomplishments using this method were prodigious; during a 12-year period that began in 971, printers in the city of Chengdu published a 5,048-volume compilation of Buddhist scriptures that required the carving of 130,000 blocks. A significant advance came in the middle of the eleventh century when a man named Bi Sheng invented a system of printing that used individual pieces of clay type set in a wax matrix. Two hundred years later, another Chinese inventor, Wang Zhen,

created a rotating type frame that allowed the typesetter to easily pick out the required pieces. The Chinese also experimented with metal type, although it was their Korean neighbors who achieved success in this endeavor during the fourteenth century.⁴

Printing developed more slowly in Europe. In the early fifteenth century, playing cards and pictures of saints were printed from wooden blocks. It is likely that by 1440 woodblock printing was also used for the production of small books containing a few lines of text.⁵ This method was not suitable for printing lengthy books, as the type for each page had to be laboriously carved from a single piece of wood. At about this time, some printers also made prints from copper plates that had words and images engraved into them.⁶ As with woodblock printing, engraving was a very labor-intensive process that did little to lower the cost of the written word. What made printing a much more efficient process was forming each page from individual pieces of type that could be used over and over again. As we have just seen, this had already been done in China, but the basic idea had to be reinvented in Europe, stimulated perhaps by some knowledge of what the Chinese had been doing.⁷

Although there are other European claimants to this invention, Johann Gutenberg (ca. 1400–1468) is usually given credit for devising a workable system of printing with separate pieces of type. In order to put the idea into practice, Gutenberg also had to develop a number of new techniques, such as a method to uniformly cast pieces of type. This was done by punching the letter into a copper matrix and then using the resulting mold for casting the actual pieces of type. Setting these individual pieces of type in a straight line also presented a problem. Gutenberg solved it by designing a mold that kept each piece of type within acceptable tolerances, and by equipping them with a ridge on one side and a corresponding groove on the other. In this way, pieces of type could interlock with one another when they were set in a frame.⁸



The Development of Printing, plate 5 from 'Nova Reperta' (New Discoveries) engraved by Philip Galle (1537–1612) c.1600 (engraving)/Straet, Jan van der (Giovanni Stradano) (1523–1605) (after)/STAPLETON COLLECTION/Private Collection/Bridgeman Images

Mass-produced communication: a sixteenth-century print shop.

Important as the invention of movable type was, the printing of books in large quantities required more than simply composing a page from individual letters. As is always the case with major technological changes, a whole system of interrelated elements had to be developed. Obviously, some sort of a press was required; here the ancient winepress provided a useful model. New kinds of ink, compounded from lampblack and linseed oil, were also necessary. The production of durable type required considerable experimentation with different alloys; a mixture of tin, lead, and antimony proved to be the winning combination. And to realize the economies offered by printing, costly parchment was replaced by paper, a Chinese invention that had passed through the Islamic world and began to be produced in Europe early in the fourteenth century.

In a world that produced its goods through individual craftsmanship, the first books printed from movable type were harbingers of the age of mass production. While the hand-copied and illuminated books of the past were works of art available to only a few, printed books, tracts, and pamphlets

were standardized products that reached a large and growing audience. According to one estimate, more than 10 million copies of 40,000 different titles were produced during the 50 years following Gutenberg's invention. Had they been copied by hand, the task would have taken a thousand years.⁹ During the century that followed, as many as 200 million books were printed in Europe.¹⁰

Printing and the Expansion of Knowledge

Printing and the consequent expansion of the number of books in circulation did much to transform European society. By systematizing knowledge and making it readily available, printing helped to promote the rational modes of thought that characterize a modern society. As happened five centuries later with the rise of the internet, information flowed much more readily, with everything from treatises on accounting to printed musical scores receiving widespread distribution. With so much information circulating, it was no longer necessary to simply accept the judgment of a few authorities, and a more critical spirit emerged. Printing also allowed the widespread distribution of maps and accounts of global exploration. As a result, new geographical discoveries could be widely publicized, and errors and inconsistencies could be made evident through the cross-checking of existing maps and printed descriptions.¹¹ The clearer definition of space made possible by printed maps gave a great impetus to voyages of discovery that opened the world to European civilization and vice versa. Better maps made journeys less hazardous, and the ongoing definition of the world's spatial contours motivated explorers and colonists to fill in the remaining blank spaces on the maps.¹²

While explorers were making fundamental geographical discoveries, others were gaining new insights into how the world worked. The great advances in scientific knowledge that began to emerge in the fifteenth and sixteenth centuries were pushed forward by printing. As with the progress of geographical exploration, the advancement of science was to a substantial degree the result of the spread of information through print media. Science requires accurate data, but before the age of printing, information was scattered, quirky, and often highly inaccurate. To be sure, much of the information disseminated by printing was bogus, but because information reached a much greater audience, it was subject to informed criticism, making for greater accuracy. In short, printing allowed the establishment of an intellectual feedback system that helped to drive out errors.¹³

More was involved than the transmission of factual information. Human

knowledge was significantly advanced by a greater exposure to different theories, perceptions, and interpretations. As Elizabeth Eisenstein has summarized the process:¹⁴

Much as maps from different regions and epochs were brought into contact in the course of preparing editions of atlases, so too were technical texts brought together in certain physicians' and astronomers' libraries. Contradictions became more visible, divergent traditions more difficult to reconcile.... Not only was confidence in old theories weakened, but an enriched reading matter also encouraged the development of new intellectual combinations and permutations.... Once old texts came together within the same study, diverse systems of ideas and special disciplines could be combined. Increased output ... in short, created conditions that favored new combinations of old ideas at first and then, later on, the creation of entirely new systems of thought.

The spread of information through printing allowed major advances in scientific understanding. Everything from astronomical tables to accurate anatomical illustrations became grist for the scientific mill. Theories could be readily checked against a growing mass of information. Equally important, printing helped to change the nature of learning. Scientific investigators were freed from the drudgery of copying tables and texts. Also, as literacy spread and books were much more readily available, students of all ages did not need to spend vast amounts of time on rote memorization and the learning of elaborate mnemonic techniques. Freed from these tasks, advanced students and natural philosophers could devote their energies to "solving brain teasers, designing ingenious experiments and new instruments, or even chasing butterflies and collecting bugs if they wished."¹⁵ The pursuit of knowledge could take on a playful quality, and play can be a key ingredient in the development of scientific understanding.

Printing and the Rise of Protestantism

Just as printing helped to alter people's views of the physical and natural world, the new medium played a key role in transforming conceptions of the spiritual world. It is certainly no coincidence that the Protestant Reformation began less than two generations after Gutenberg's invention. Before then, unorthodox interpretations of prevailing Christian religious beliefs had sprung up from time to time, but they remained confined to particular locations. Although several instances of religious dissent may have occurred simultaneously, they were not linked together into an integrated attack on the authority of the centralized Church. The circulation of printed religious books and tracts created a more unified challenge to the dominant Catholic order and helped to turn a number of separate revolts into the Protestant Reformation.

Literacy and Protestantism reinforced each other; while Protestantism benefited from the expansion of the printed word, the religious beliefs of Protestant reformers did much to encourage printing. One of the central tenets of Protestantism was that individuals should study the Bible and interpret its message unencumbered by the guidance of priests, bishops, and popes. The production of printed Bibles carried the word of God directly to the faithful, while at the same time a great outpouring of religious tracts spread the words of religious reformers throughout Christendom. For good reason, Martin Luther praised printing as "God's highest and extremest act of grace, whereby the business of the Gospel is driven forward."¹⁶

Luther later lost his enthusiasm for popular Bible reading when it became apparent that the unguided reading of the Bible could result in "dangerous" beliefs that contradicted his own.¹⁷ But by then, individual reading of the Bible had become an integral part of Protestant life. Sixteenth-century English clergymen were told to "comfort, exhort, and admonish every man to read the Bible in Latin or English, as the very word of God and the spiritual food of man's soul, whereby they may better know their duties to God, to their sovereign lord the king, and their neighbor."¹⁸

The Catholic Church also used printed catechisms, tracts, and edicts as

weapons in its battles against the Protestant “heresy.” But the cultural order it attempted to maintain was fundamentally antagonistic to the use of printed sources and the spread of literacy. The Church was unwilling to allow laypeople to pursue Biblical scholarship, and it was deeply suspicious of popular Bible reading and interpretation. Catholicism was still rooted in the medieval past, and it was unprepared for the challenge presented by print technology.

If the Bible was to be made accessible to the Protestant faithful, it had to be printed in a language they understood, rather than in the Latin that had served as the universal language of the medieval clergy. While the Catholic Church strongly resisted the production of Bibles in modern European languages, Protestantism made it an imperative.¹⁹ In Protestant lands, the translation and printing of Bibles in vernacular languages spread the Gospel, but equally important, stimulated nationalism. A Europe that had been united under the cultural domination of the Catholic Church gave way to a patchwork of separate states, each with its own established church and a growing literature printed in the local language. Printing helped to destroy the unity of the medieval world, while within the borders of discrete national entities, a considerable amount of homogenization took place. Printing was of great importance in standardizing the languages of these nations. Dialects unsupported by a printed literature slowly faded away and were supplanted by a common form of French, German, or English.

Printing, Literacy, and Social Change

Motivated by the religious requirement of Bible reading, Protestants became literate to an extent not previously found in European civilization.

Throughout the Middle Ages, the great bulk of the population could not read. Even rich and powerful people were illiterate. Charlemagne, who reigned as king of the Franks from 768 to 814 and after 800 was the emperor of much of present-day Western Europe, was an intelligent and learned man, but he needed to have books and documents read aloud to him, and he relied on scribes to write down his words.

The only people who found literacy to be a necessity were members of the Christian clergy. (The connection between literacy and a religious vocation can be seen in the etymological relationship between the words “clerk” and “clergy.”) The ability to read was often taken as sufficient proof that a person was a member of the clergy, and therefore not subject to civil law. This could be a great advantage, for a person claiming “benefit of clergy” could escape corporal punishment or even execution if convicted of a crime. The 51st psalm of the Old Testament was known as the “neck verse,” because a person able to read it would be spared the gallows.²⁰ As might be expected, many illiterates tried to escape punishment by memorizing the psalm and then pretending to read it at the appropriate moment. This resulted in some farcical scenes in which a person attempted to demonstrate his literacy by “reading” from an upside-down Bible!

Protestantism, with its emphasis on Bible reading, created strong incentives for laypeople to learn to read. This skill could, of course, be useful in other endeavors. A person who could read and write was able to keep accurate records and accounts, learn about new ways of doing things, understand the law, enter into contracts, communicate with large numbers of people, and make use of banks. Thus, the often noted connection between Protestantism and rapid economic growth in early modern Europe was at least in part due to the superior levels of literacy in Protestant lands.²¹

As we have seen, the rise of Protestantism created a fertile environment for the development of the printing industry. At the same time, urbanization

and the spread of capitalism also made for a society that was more open to—actually hungry for—the new ideas that books could disseminate. On a more utilitarian level, the development of commerce and industry generated a need for written records and accounts. In later centuries, the desire for literacy was further stimulated by the growing concerns with social equality. In particular, the greater accessibility of education that culminated with the introduction of mass schooling in the nineteenth century produced a literate public and expanded the market for the printed word.²²

All of these historical forces produced an environment that was ripe for the large-scale production of printed works. Had they not been present, the invention of movable type would have been of much more limited significance. After all, printing had first emerged in East Asia, yet social conditions limited its influence in that region. Korean printers had independently invented movable type, but few books were printed by this means in Korea until the end of the nineteenth century. Korean scholars even invented a phonetic alphabet known as *Hangul* in the fifteenth century, which greatly facilitated the use of movable type. But Korea's traditional aristocracy clung to the use of Chinese characters for the written rendition of Korean words because their ability to understand the difficult-to-learn characters set them apart from the common folk. Although a mass readership literate in *Hangul* could have provided a large audience for printed works, no self-respecting writer was willing to use the “inferior” script. Consequently, printing with movable type had minimal effects on Korean society.²³

In Europe, social and cultural conditions created a strong demand for the products of print technology. At the same time, the technological advances that made the mass production of printed works possible did much to create these conditions. As with all major technological advances, the influence of printing is not a simple matter of technological determinism. Instead, we find a reciprocal, reinforcing relationship between technological change on the one hand and social change on the other. Moreover, printing with movable type did not effect a sudden revolution in Western society; even as late as the middle of the eighteenth century, 40 percent of English men and more than 60 percent of English women were illiterate.²⁴ Still, working in conjunction with the great changes that were sweeping over Western civilization, the development of print technology produced a transformation that has only

begun in many parts of the world today.

Psychological Effects of Printing

The effects of printing on religious, economic, and political life seem reasonably evident. A consideration of the consequences of reading for individual attitudes and ways of thinking, however, is a more speculative venture. The Protestant Reformation is an identifiable historical event, and its connections with printing seem clear. It is much more difficult to demonstrate that printing fundamentally changed basic ways of thinking, or that it altered how we understand our place in the world.

Still, we might reasonably speculate that printing resulted in a greater sense of one's separateness from the rest of society. Reading is usually a solitary activity. Novels, with their typical emphasis on one key figure, have been the central literary product of the past two centuries. It is therefore likely that a culture based on print is more individualistic than one that relies on collective means of communication, such as Sunday sermons or old-fashioned political oratory. It has even been suggested that the very concept of the "self" is foreign to people and cultures that have not been touched by literacy.²⁵

Some fascinating possibilities of this sort have been suggested by Marshall McLuhan, for whom media such as print or television have had consequences that far outweigh the overt messages that they carry.²⁶ According to McLuhan, printed books fundamentally changed civilization not because of the information they transmitted; the greatest consequences of printing lay in the different modes of thought and perception that it fostered. In McLuhan's analysis, each medium of communication engenders a distinctive way of looking at the world; as his famous aphorism has it, "the medium is the message." The reading of the printed word makes readers think in sequence, just as a sentence is sequentially read from left to right. Reading also produces an egocentric view of the world, for the reader's involvement with the printed word is solitary and private. For McLuhan, the intellectual and social consequences of print were immense, encompassing such diverse things as the Newtonian view of the universe, the employment of fixed prices for business transactions, and the "detribalization" of society.

It is impossible to summarize McLuhan's ideas in a few sentences. The intrepid reader is advised to turn to McLuhan's writings after first being warned that their author can be cryptic, elliptical, hyperbolic, and at times simply maddening. Nonetheless, some taste of his thinking can be obtained by looking at how McLuhan has interpreted changed painting styles as a reflection of printing, or what he has termed "The Gutenberg Galaxy." Reading, as McLuhan points out, inculcates a single "point of view," the fixed position of the reader.²⁷ In similar fashion, the visual arts that developed in the postprinting era began to depict scenes as they might be viewed from a single point in space. Given this central vantage point, the scene appears to have a three-dimensional quality due to the artist's employment of the principles of perspective. The employment of perspective is not a natural or necessary part of pictorial art. As any art student knows, to paint or draw something in perspective requires the application of special procedures and a good deal of practice. These artistic techniques were not employed in medieval painting, which was characterized by a visual flatness. Figures were not presented according to the rules of perspective, but rather in accordance with the importance of the subjects; in a typical Medieval painting, Jesus, an archbishop, and the faithful appear in the same plane, but they are not all of the same size; their size is commensurate with their importance in the spiritual hierarchy. Until the advent of printing there was no reason to depict subjects according to rules of perspective because printing and widespread reading had not conditioned people to see the world as it might appear from a single vantage point. As McLuhan has argued, the rules of perspective were developed and used only after printing produced an individualistic perception of the world.

Newspapers

For several centuries after the invention of movable type, the most important product of the printing press was the book. Beginning in the eighteenth century, a new kind of publication appeared that was to have equally revolutionary consequences for society. That publication was the newspaper. The transmission of written news has a long history, originating with the *Acta diurna* that was posted in the Roman Forum, and continuing with the printed broadsheets that circulated from late medieval times onward. The first regularly appearing newspapers emerged in the seventeenth century, and by the beginning of the next century, newspapers were established institutions in a number of European cities. Colonial America followed suit, with the appearance of *The Boston News-Letter* in 1704 marking the beginning of newspaper publishing in what was to be the United States.

These early newspapers were unimpressive, usually consisting of no more than four pages of hard-to-read type. Their circulation was also limited, being confined to the small number of people who were both literate and able to pay for a newspaper. This situation changed dramatically during the nineteenth century, when the newspaper became a mass-produced item, a product of Industrial Revolution technology.

One of the distinguishing characteristics of the Industrial Revolution was the use of new sources of energy, with steam power taking on a growing importance. The first steam-powered printing press was invented by Friedrich Koenig and Andreas Bauer in 1812, and was put to use by the *Times* of London in 1814. The use of steam power for this purpose necessitated a fundamental redesign of the printing process. Instead of manually pressing a sheet of paper against a flat bed containing the type, the job was done by a steam-powered rotating cylinder, while another cylinder did the inking. This process ran off 1,000 copies of the newspaper each hour, one-third the time that the handpress required.²⁸

Other refinements ensued. Printing on a continuously running roll of paper (instead of feeding single sheets of paper) greatly speeded up the process, as did the development of presses that printed on both sides of a

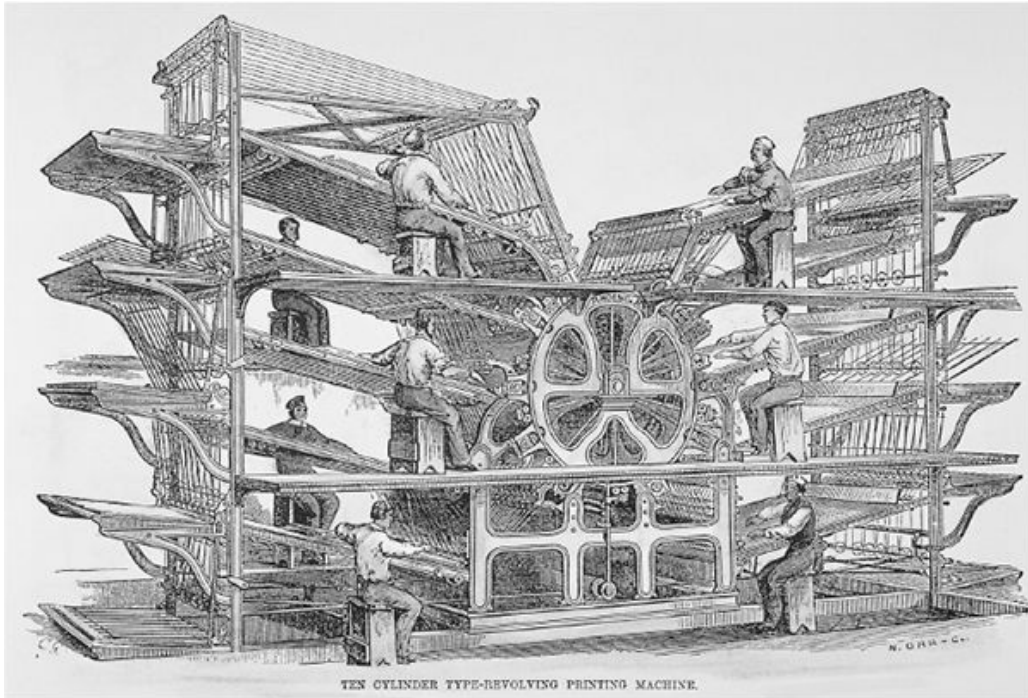
sheet and automatically cut individual pages. Improved inking processes contributed to the speed of production, while the use of wood pulp for paper also lowered production costs.

Improvements to the rotary press concept followed, most notably Richard Hoe's use of another rotating cylinder instead of a flat horizontal bed to hold the type. First employed in 1846, by the beginning of the Civil War improved variants of the rotary press could produce as many as 20,000 impressions per hour.²⁹ Printing was further accelerated by the invention of the stereotype plate, which allowed the easy production of duplicate plates for use on multiple presses. The stereotype plate was made by pressing a paper mat onto a frame of set type. After the mat was dried and shaped into a half of a cylinder, molten metal was forced into it, forming the actual printing plate. The other side of the rotating cylinder held type for another page. The first of these presses contained two cylinders, each with four plates, so an eight-page newspaper could be printed with each turn of the cylinders.³⁰ By 1890, improved rotary presses were capable of printing 48,000 twelve-page papers each hour.³¹

While the presses turned out newspapers with increasing rapidity, the need to set type by hand restricted the rate of production. A great deal of inventive energy therefore was expended on the development of automatic typesetting. Even Mark Twain was involved as a financial backer for such a venture; it unfortunately failed, dashing the great author's dreams of making a vast fortune.³² Success instead came to a German immigrant, Ottmar Mergenthaler, whose Linotype machine was the first effective typesetting device. First used in 1886, by the end of the century 3,000 of these machines were in use around the world.³³

The development of the mass-circulation newspaper was further stimulated by a host of nineteenth-century inventions that allowed the rapid gathering and dissemination of news. Railroads and steamships conveyed reporters to scenes of newsworthy events. The telegraph quickly relayed their stories back to the newsroom, and had the incidental effect of making stories less verbose because the senders of telegraphic messages were charged by the word.³⁴ The news-gathering power of the telegraph was enhanced by the laying of trans-Atlantic cables that greatly sped up communications between Europe and the United States. The telephone and, by the end of the century,

the radio further assisted reporters and the newspapers for which they worked.



Granger, NYC—All rights reserved.

A Hoe rotary printing press from the middle of the nineteenth century.

Circulation Wars and the Shaping of Public Opinion

As with other mass-production technologies, the improvements in newspaper printing dramatically lowered production costs. Before the 1830s, newspapers sold for 6 cents a copy, which in those days could buy a quarter pound of bacon or a pint of whiskey.³⁵ As production costs fell, the first American penny paper, the *New York Sun*, made its appearance in 1837. Aiming for a mass audience, the *Sun* offered sensational stories of dubious veracity, such as a report on the observance of life on the moon through the use of a powerful telescope located in South America. Other newspapers followed suit, and by the second half of the nineteenth century the cheap mass-circulation daily newspaper was a fixture in every city and town of Europe and North America. The expansion of newspaper readership occurred at a rapid rate. During the early decades of the nineteenth century, the *Times* had led all English newspapers with 10,000 readers,³⁶ while the largest New York newspapers usually printed editions of no more than 2,500.³⁷ By 1870, 2.6 million newspapers were printed each day in the United States, and by the end of the century, that figure had risen to 15 million.³⁸

Unfortunately, the spread of these newspapers was often stimulated by journalism of the worst sort. Newspapers built up circulation by running stories that stressed scandal, crime, and bizarre occurrences. The debasement of news reporting accompanied the increase in newspaper readership; the “yellow journalism” of that era, in the words of Edwin and Michael Emery, “turned the high drama of life into a cheap melodrama and led to stories being twisted into the form best suited for sales by the howling newsboy.”³⁹ Sensationalist newspapers had a long life. Until the internet drove the supermarket tabloids out of business, for many years shoppers in the checkout lane could be charmed by headlines like “My Steamy Nights with Brittany in UFO Love Nest.”

Both in the past and today, reportage of this sort demonstrated many newspapers’ low regard for the taste and intelligence of their readers. Beyond this, the mass-produced newspaper became a force in its own right, and its editorial policies did much to shape public opinion. This can be seen in the way the popular press helped to push America into a war with Spain in 1898.

To be sure, other forces were at work; having conquered the frontier of its own territory, the United States was seeking new triumphs of Manifest Destiny. Still, without the galvanization of public opinion by newspapers such as William Randolph Hearst's *New York Journal*, it is possible that the war could have been averted.

Hearst was engaged in a fierce struggle with Joseph Pulitzer's *New York World*, and inflamed coverage of a rebellion against Spanish rule in Cuba was a surefire way to sell papers. Through the use of sensational reporting, both papers enlarged their circulations to over a million each, a record at that time.⁴⁰ Reports of Spanish atrocities in putting down the rebellion, while having some foundation, were wildly exaggerated and given extensive coverage. Stories in the *World* left little to the imagination: "Blood on the roadsides, blood in the fields, blood on the doorsteps, blood, blood, blood!"⁴¹ Not to be outdone, Hearst's *New York Journal* played a prominent role in whipping up public enthusiasm for a war with Spain to "liberate" Cuba. When Hearst's artist-reporter in Cuba notified the boss that war was unlikely, Hearst reportedly sent him a telegram with the command "You provide the pictures, and I'll provide the war."

From the beginning of the revolt to America's going to war with Spain, hardly a day went by without a story about Cuba in one of the New York newspapers.⁴² And when the American battleship *Maine* blew up in Havana harbor, many newspapers were quick to attribute it to a Spanish mine. (To this day, the cause of the ship's sinking remains unknown, although it was likely due to internal causes.) Even though disputes with Spain over a variety of issues were almost fully resolved by this time, a significant portion of the popular press had whipped up a war hysteria that could not be extinguished. The brief war that ensued concluded with the United States assuming the role of an imperial power, with colonial holdings that stretched from the Philippines to Puerto Rico.

It would be an exaggeration to say that the Spanish–American War, or any other major historical event, was directly caused by the reportage of circulation-hungry newspapers. The remnants of Spain's American empire were an inviting target for turn-of-the-century America's expansionist ambitions. Under these circumstances, overheated news reporting reinforced opinions and ambitions that were already evident. Still, there can be no

denying that the journalistic policies of Hearst and Pulitzer made a peaceful resolution of disputes between the United States and Spain far more difficult.

It would be even farther from the truth to attribute such events as the Spanish–American War to technological advances in printing. To be sure, the mass-circulation dailies depended on improved methods of newspaper production, but much more was involved than such innovations as the steam-powered rotary press. The spread of education and literacy, spurred by the expansion of public schooling, created a large potential readership for these publications. The expansion of industry and commerce was accompanied by the emergence of a growing advertising industry that provided vast revenues for the newspapers. Urbanization and immigration produced large concentrations of population from which a mass readership could be drawn. Finally, a more democratic social order generated an environment in which the “common man” gained in political and economic importance; as the first of the mass media, newspapers were a natural outgrowth of mass society.

All of these trends reinforced one another. New printing technologies contributed to literacy and the rise of a mass readership, commercial expansion, and perhaps even the expansion of democracy. At the same time, the emergence of new printing technologies was stimulated by all of these economic, social, political, and cultural factors. As we have already seen, Gutenberg’s invention of movable type was accompanied by changes on many fronts. The same thing happened during the second half of the nineteenth century as a series of technological innovations made possible the publication of mass-circulation newspapers. In neither case did technological developments by themselves produce the epochal changes with which they are associated. The development of these technologies was part of a larger process of change. Yet at the same time, these technologies were major contributors to this process. From movable type to the steam-powered rotary press, the technology of printing exemplifies the complex, mutually reinforcing interactions between technological and social change.

Digitizing the News

A similar process can be seen today, as digital technologies now allow the transmission and reception of the printed word without the need for ink and paper. With the advance of digital technologies, readers can access vast amounts of material through the use of computers, smartphones, tablets, and electronic books. In recent years, e-books and tablets have become especially important sources of reading material. According to a survey conducted in 2015, 72 percent of adults had read a book during the past twelve months; of these, 27 percent had read at least one e-book.⁴³

So far, e-books have not threatened to replace printed books. The same cannot be said about newspapers and magazines. According to the Pew Research Center, concurrent with the rise of the internet, newspaper circulation fell at an accelerating rate from 2004 to 2010. It then fell at a slower rate and rebounded slightly in 2012, only to drop further in the years that followed.⁴⁴ More than a hundred newspapers went out of business altogether. Newspaper employment has reflected this downward trend, falling from 45,000 in 1978 to 36,700 in 2013.⁴⁵ Magazines have fared no better; circulation losses, especially for newsstand purchases, and declining revenues have for the most part paralleled the experience of the newspaper industry.⁴⁶

The overall decline of newspaper circulation has resulted in significant financial losses. Newspapers earn more of their revenues from advertising than they do from subscription payments and newsstand purchases, and lower circulation means lower advertising rates. Once again, the historical trend has been grim; revenue from print editions fell from \$44.9 billion in 2003 to \$16.4 billion in 2014.⁴⁷ Some of these losses have been offset by increased readership and income from digital editions. It would be helpful to note the size of the digital readership, but determining the number of readers of digital newspapers is difficult. Some readers peruse digital versions of print newspapers, but many more read a single article after searching the Web for specific information, or clicking on a link to an article that appeared in email, social media, or other sources.

Traditional newspapers now receive a quarter of their revenue from

digital editions.⁴⁸ This, however, does not so much reflect the growth of digital income as it does the decline of traditional sources of revenue. In any event, digital earnings have not compensated for the losses caused by the switch from paper to digital media. Some newspapers have attempted to increase revenue from digital editions by requiring a payment each time an article is accessed. Among the 98 U.S. newspapers with circulations over 50,000, the American Press Institute found that 77 of them use a digital subscription model. Some charge a flat fee for access, but much more common is a “metered” model, that allows a certain number of articles to be accessed (typically ten per month) before the payment of a fee is required. Whether or not these payment schemes will generate significant revenue is unclear at this point. An uncertain number of readers may be longtime subscribers willing to pay for the digital edition; crucial to the success of paid digital subscriptions will be convincing more people to sign up in years to come.⁴⁹

Although some readers access digital versions of established newspapers, Web-based news sources such as *BuzzFeed* and the *Huffington Post* have become important players in the news business. Moreover, many readers get their news via Facebook, Twitter, and other media platforms. These have become significant sources of news; 63 percent of both Facebook and Twitter users said they access news on their social network platforms, with Twitter being particularly important for breaking news at a ratio of nearly 2:1 over Facebook.⁵⁰ Altogether, 33 percent of the U.S. adult population get their news from Facebook, but only 2 percent use Twitter as their only source of news. As might be expected, there are age-group differences in attitudes toward social media as sources of news. While about half of users between the ages of 18 and 34 said that the sites were “the most important” or “an important” way they get news, only 34 percent of Facebook users and 31 percent of Twitter users over the age of 35 said these sites are among the most important sources of news.⁵¹

While social media has become an important means of accessing the news, even those who use it bring some skepticism to these sources. Perceived importance is not the same thing as trust. Only 15 percent of adults who use social media as a source of news say they have high levels of trust in the information they get from these sites.⁵²

Trustworthy or not, digital news sources have overtaken newspapers as sources of news and information. A recent Pew Research Center survey found that 36 percent of U.S. adults learned something about the 2016 election in the past week from a print newspaper.⁵³ This was lower than the portion that learned from radio (44 percent), digital sources (65 percent), or television (78 percent). This is a substantial change from only a decade ago, when newspapers outranked radio and the internet as the public's main source of news.⁵⁴ Another indication of the declining influence of newspapers came from the Pew Research Center survey, which found that a mere 5 percent of U.S. adults named print newspapers as their "most helpful" source for learning about the election, a percentage that trailed nearly every other media category (cable, local and national TV, radio, social media, and news websites) by wide margins.⁵⁵

Reading Digitally

The decline of printed newspapers may not be terribly troubling unless one is somehow connected to that industry. After all, the medium, be it a paper newspaper or a social media site, that conveys facts and ideas should not alter their substance. But remember Marshall McLuhan's dictum that "the medium is the message." We won't concern ourselves here with the possible psychological and cultural effects of digital media. Instead, we will focus on a narrower issue: the extent to which digital media is comprehended and retained when compared with conventional print media.

Due to the relatively recent arrival of digital reading materials, only a few empirical studies have been conducted on its consequences, while long-term studies are notably absent. Even so, some aspects of reading on-screen seem to be evident. For one thing, reading from a screen is likely to make concentration difficult. Embedded videos, pop-up advertisements, and links to other materials can be powerfully distracting. It also appears to be the case that on-screen readers are more likely to engage in multitasking than readers of paper materials.⁵⁶ The layout of on-screen materials can also pose some difficulties as layouts, colors, and typefaces may change suddenly, requiring continual adjustments on the part of the reader.⁵⁷

These attributes create obstacles to what has been called "deep reading."⁵⁸ Readers of on-screen materials tend to skim the text; as one researcher has noted, "When reading on screens, for example, people seem to reflexively skim the surface of texts in search of specific information, rather than dive in deeply in order to draw inferences, construct complex arguments, or make connections to their own experiences."⁵⁹ Research has also found that students, when reading digitally, tend to discard familiar print-based strategies for boosting comprehension.⁶⁰ In the words of another researcher, "Skimming had become the new reading: the more we read online, the more likely we were to move quickly, without stopping to ponder any one thought."⁶¹

In assessing the effects of on-screen reading, a lot depends on what is being measured. This is exemplified by one study that took a college-level

course and divided the students into two groups, one reading an assignment on a tablet, the other as printed matter. They were then given two tests, one a set of multiple-choice questions, the other a few short answers. When the scores of both groups were compared, there was no statistically significant difference in their mean scores. But according to the author of the study, when the range of score distributions was examined, the group who read the assignment on paper had greater frequencies of higher scores for both multiple-choice recall and the short answers that measured comprehension.⁶² Why this was so is unclear; quite a lot of future research is needed. Meanwhile, until we get a better sense of the advantages and disadvantages of reading on a screen, school districts, colleges, and other institutions would be wise to postpone massive purchases of tablets, e-readers, and other devices for the presentation of digital materials.

The rise of digital texts is only one component, and a small one at that, of the host of revolutionary changes that have been transforming media from the middle of the nineteenth century onward. These epochal changes are the topic of the next two chapters.



wavebreakmedia/Shutterstock

Many schools are now using tablets for a variety of educational activities, but their effectiveness is open to question.

QUESTIONS FOR DISCUSSION

1. Do statements that appear in print seem more true than those that are presented through some other medium? Why?
2. One of the major trends in the world today is the spread of literacy. In many parts of the world, only a small percentage of the population could read a generation ago; today, the majority of the population is literate. What sort of social, political, and economic effects will this produce? Will all of them be good?
3. Some social critics are of the opinion that the spread of electronic media is destroying literacy. Standardized test scores of reading and writing ability have in fact gone down in recent years. Are the new media the main cause? If so, is the slow destruction of the printed media by the electronic media necessarily a bad thing?
4. Lurid newspaper stories helped to fan a conflict between Spain and the United States that ultimately led to war. The Vietnam War, another overseas conflict involving the United States, met with a great deal of opposition, due in part to the continual presentation of that war on television. Marshall McLuhan would have thought this significant. Can you imagine why? Can you think of any fundamental differences between newspaper accounts of a war and those presented on television?
5. Do you think that digital technologies in the form of e-books, tablets, and smartphones will soon replace newspaper and magazines? Do conventional printed materials have a future? What, if any, advantages do they have over digital media?

CHAPTER THIRTEEN

The Electronic Media: From the Telegraph to Television

During the 450 years that followed the invention of movable type in the West, the printed word was the dominant form of mass communication. By the middle of the nineteenth century, words could be sent and received at unprecedented speeds through the newly invented telegraph. Although it was not identified as such when it was invented, the telegraph is a digital device, one that uses electrical pulses to transmit combinations of dots and dashes representing individual letters—the Morse Code. Few people send or receive telegrams today, but in its time the telegraph was as revolutionary as the internet is in ours. It lifted the isolation of remote communities, knit commercial enterprises together, greatly facilitated the operation of vast railroad networks, and brought news from all around the world.¹ Still, the telegraph had its limitations. Not only were trained operators required to encode and decode messages, large amounts of capital were needed to string up telegraph wires between communication points. Moreover, telegraphic communication was thwarted when the installation of wires was physically impossible or costs were prohibitive, as in the case of ships at sea or geographically remote places.

These limitations began to be overcome toward the end of the century as scientists and engineers in several countries learned how to send and receive signals through empty space. The first product of their efforts was radio. The experience gained with radio subsequently supplied the foundation for an

even more far-reaching medium: television. The social, cultural, political, and economic effects of these media have been at least as great as those of printing. We are still attempting to comprehend how radio and television have affected our lives, even as we now find ourselves facing the opportunities and challenges of digital media. The latter will be explored in the next chapter, but first we will survey the causes and consequences of advances in radio and television technology.

The Invention of Radio

It might be thought that the limitations of telegraphic communication created the motivation to develop a method of electrical communication that did not require wires. And it is certainly true that much of radio's development was "pulled" along by the demand for better methods of communication. But that came later; the first successful attempt at sending and receiving wireless communications had nothing to do with practical concerns. As we saw in Chapter 5, radio transmission and reception was first used by Heinrich Hertz as a way of empirically testing the theoretical formulations of James Clerk Maxwell. Hertz produced radio waves with an oscillator, a device that rapidly generated electrical pulses. To receive or "detect" the radio waves produced by these pulses, Hertz employed a piece of wire with small balls at each end, bent into a near circle. When this was placed in the vicinity of the oscillator, a spark jumped between the two balls in conjunction with the sparking of the oscillator. Through a series of experiments using these devices, he was able to confirm Maxwell's calculations that electrical waves traveled at the speed of light. Additionally, he showed that these waves propagated themselves in accordance with the laws of optics that had first been formulated for visible light.



Hulton-Deutsch/Corbis

Although Guglielmo Marconi did not invent radio, he played an important role in its commercial application. Here he is at age 27 with some early devices for transmitting and receiving wireless telegraphic messages.

Hertz's concerns were entirely in the realm of scientific inquiry, but others saw in his apparatus an embryonic technology that might realize the dream of wireless communication. Many experimenters tackled the numerous technical problems that kept radio from being a practical possibility. Although Guglielmo Marconi is often hailed as the inventor of radio, as with most significant inventions, there are many others whose contributions were equally important, such as Oliver Lodge, who developed the method of tuning a receiver so it could receive signals of a specific wavelength. At this point, radio was simply wireless telegraphy, useful only for sending and receiving dots and dashes. The transmission and reception of actual sounds was made possible through the use of continuous waves to carry a signal. This, in turn, had been made possible by Ronald Fessenden's incorporation of the heterodyne principle into radio technology. Heterodyne transmission and reception used two separate alternating currents, one generated by the transmitter and the other by the receiver. Oscillating waves transmitted at a certain frequency mixed with the receiver's lower frequency waves to

produce a wave that could be easily received.

Important as the heterodyne principle was, an even greater breakthrough came with the invention of better equipment for the transmission and reception of radio waves. These devices were based on the principle of using a small flow of current to govern a larger current. In this application the small current produced by a radio wave could be used to regulate the stronger current that drove the speaker of a radio. The first of these devices was the diode, invented in 1904 by John Ambrose Fleming, whom we met briefly in Chapter 4. It established the principle of controlling current electronically, but it had its limitations. A much more workable device was the triode, an invention of Lee de Forest. By using a separate electrode to control the current, the triode served as an excellent basis for a radio receiver, as well as for its amplifier.²

The Origins of Commercial Radio

While technical development proceeded at a good clip during these early years, few thought of radio as a means of providing entertainment and information for a large audience. Radio was seen simply as wireless telegraphy, and for many years its main use was for ship-to-shore communications. Radio was also used to transmit messages across oceans, thereby obviating the need for undersea cables, but high cost and unreliability plagued these efforts. Military forces also made extensive use of radio communications, and World War I stimulated a good deal of technical progress, especially in the development of mass-production techniques for the manufacture of radio components.

During the 1920s, interest in radio mounted as large numbers of amateur radio operators constructed their own equipment, sent out messages, and attempted to pick up the signals of others. Their chatter cluttered up the airwaves, and with a mischievous intent similar to that of today's hackers, a few even sent out bogus orders to naval vessels. But others had more serious aims. Throughout the United States, amateur radio operators, many of whom had developed their skills during World War I, began to broadcast news, weather bulletins, musical recordings, and even live musical performances. In a manner resembling the early days of the personal computer, enthusiastic amateurs made significant contributions to the new technology by constructing their own apparatus, finding new applications for radio communication, and in general exploring the potentials of the new medium.

At this time, business enterprises began to take notice of radio's commercial possibilities. Realizing that regular programming could stimulate a sizable market for its radio sets, in 1920, the Westinghouse Electric and Manufacturing Company engaged one of its employees, himself a dedicated radio amateur, to construct a broadcasting station atop one of the buildings of its Pittsburgh headquarters. On November 2, 1920, radio station KDKA went "on the air," giving up-to-the-minute results of the 1920 presidential election to an audience of several hundred. Within a matter of months Westinghouse and General Electric had set up radio stations in a number of cities. Other

entrepreneurs followed suit, and so by 1922, more than 500 stations were transmitting music, sporting events, speeches, and news programs. Commercial broadcasting took on a growing importance as radio began to reach the general public and not just a relatively small group of technically minded amateurs.



Bettmann/Getty Images

Radcliffe students operating an early radio station.

At first, many of these programs could be low-budget endeavors; phonograph records required only small initial costs, and most live performers were willing to appear free of charge. This did not last for long;

the American Society of Composers, Authors, and Publishers (ASCAP) began to demand payment for the broadcast of recorded music, and in 1923, it backed this demand with a successful lawsuit. In similar fashion, live performers started to expect payment for their services. Other countries, most notably Great Britain, had by this time established a national radio system through which the expenses of broadcasting were defrayed by licensing fees paid by owners of radio sets. But in the United States, free enterprise was the order of the day, and radio broadcasting was sustained by companies willing to sponsor programs in return for the airing of their commercials. In the years that followed, listening to radio programs became an integral part of American life as families gathered to listen together, much as was to happen during the early days of television. By this time, several decades had passed before radio technology had made the passage from wireless telegraphy to commercial broadcasting. Along the way, various entrepreneurs looked for ways to use radio technology as a basis for making money, just as has been happening with the internet today.



Archive Photos/Getty Images

In pretelevision days, radio was a chief source of family entertainment.

The Rise of Television

For all of radio's accomplishments, only a portion of the electronic media's potential had been demonstrated. Radio could only reach one of the senses; if sight could be added to sound, the appeal of electronic communications could be greatly enhanced. The dream had long been there; the idea of electrically transmitting and receiving visual images existed even before radio was a practical reality. In 1879, readers of the English magazine *Punch* were presented with an illustration of a couple watching a tennis match being shown on a large screen over their fireplace. Three years later, a French artist drew equally prescient illustrations that depicted people viewing television screens filled with pictures of distant lectures, wars, and even girlie shows.³ And in 1907, in the pages of *Scientific American*, the term "television" appeared for the first time in print.

A substantial amount of inventive activity took place in the 1920s on both sides of the Atlantic as inventors, government agencies, and private firms sought to make television a practical reality. The British Broadcasting Corporation (BBC) took an early lead in 1929 when it began to transmit half-hour television programs five days a week. The technology employed by the BBC used an electromechanical system in which a rotating disc was used to convert electrical signals into visible images. This technology had many drawbacks, not the least of which was that it required extremely high levels of illumination.

By 1937, the BBC abandoned electro-mechanical television in favor of an all-electronic system. The genesis of this technology went all the way back to a series of fundamental discoveries and inventions that began at the end of the nineteenth century. Most important of these was the cathode ray tube. This device was based on a principle, discovered by Ferdinand Braun in 1897, that a beam of electrons moving along a closed tube could be deflected by a magnet. In Russia, Boris Rosing used this tube for television reception by placing a screen of photoelectric cells in the tube and activating them with moving electrons.

This was only a laboratory demonstration and not a complete system of

sending and receiving television images. An important step was taken by Vladimir Zworykin, a Russian émigré who had served as an assistant to Rosing while a student at the Institute of Technology in St. Petersburg. After coming to the United States, he was employed by Westinghouse and then by the Radio Corporation of America (RCA), where he worked on television in addition to a number of other projects. In 1928, he produced the first workable electronic television camera, which he called the “iconoscope.” It employed a screen made up of thousands of individual elements that took on an electrical charge when they were struck by light reflected from the object whose image was to be transmitted. The screen was rapidly scanned by a beam from an electron gun, which resulted in an electrical discharge that was amplified and transmitted to the receiver. The receiver then reconstructed these electrical discharges into points of light on the television screen.⁴

Zworykin’s iconoscope was a major accomplishment, but as often happens in the history of technology, parallel inventions were being made elsewhere. While Zworykin was engaged in the early phases of his research, an Idaho farm boy named Philo Farnsworth astonished his high school science teacher by presenting him with plans for an apparently workable television system. A few years later, Farnsworth succeeded in getting financial backing for his research, and by the late 1920s, he had produced a viable, if crude, system of electronic television.

Both Farnsworth and Zworykin can be credited with the invention of television. Zworykin and his team did important work, while years of litigation culminated in Farnsworth’s patents being upheld. RCA paid a substantial sum in royalties for these patents, but it succeeded in putting together the first television network, the National Broadcasting Corporation (NBC), which began operations in New York City in 1939. A number of drawbacks were still evident; most of the early receiving sets had five-inch screens, and their dim pictures meant that they had to be viewed in darkness. Many technical problems remained to be solved in such areas as the design of antennas and the relaying of signals over large distances. Still, television had become a practical possibility.

The Federal Government Steps In

The development of radio and television in the United States was largely the work of private enterprise. Even so, the activities of the federal government gave a substantial boost to the electronic media. Military contracts stimulated a great deal of useful research. National security was also invoked when the government played the leading role in the creation of a unified radio industry. In the years after World War I, government officials, especially those in the Navy, were increasingly concerned about the monopoly that the British Marconi Company had over international radio communication. After some prodding by the Navy, the General Electric Company bought a controlling interest in Marconi's American subsidiary and transferred it to the newly formed Radio Corporation of America. There still remained the problem of RCA's gaining access to the numerous patents that covered various aspects of radio production and broadcasting. This was ultimately resolved by giving the two other major patent holders, Westinghouse and American Telephone and Telegraph, a financial stake in RCA in return for the use of their patents. The creation of a radio monopoly was thus the result of an action undertaken at the behest of the U.S. government.

In addition to these activities, the federal government used its regulatory power to ensure an orderly environment for broadcasting. For clear reception it is necessary for each broadcaster to remain on a single frequency. (When you "tune in" to a radio station, you are selecting a specific frequency, such as 790 kHz or 89.3 MHz.) Should a number of radio stations broadcast their programs on the same frequency, the result is a chaos of conflicting sounds. In order to address this problem, in 1912, the Department of Commerce and Labor began to require the licensing of all broadcasters. When a license was awarded, it stipulated the exact frequency on which the station could broadcast, as well as its times of operation. But this authority was successfully challenged in court, and by the mid-1920s, a large number of broadcasters were transmitting all over the frequency spectrum. The airwaves had become a cacophony of interfering signals.

To remedy this situation, Congress created the Federal Radio

Commission in 1927, giving it broad powers to issue licenses and assign frequencies. In 1934, government oversight of communications media was consolidated through the creation of the Federal Communications Commission (FCC). The licensing and frequency allocation powers of the FCC worked to the detriment of the very few stations whose licenses were revoked because their broadcasts were deemed not to be in the public interest. The strict assignation of frequencies also frustrated would-be broadcasters who were unable to gain licenses. But for the industry as a whole, the Federal Radio Commission and its successor, the FCC, were essential elements in the system of radio broadcasting. Without federal regulation, broadcasters could not be assured of their own special frequencies, and the air would be filled with signals that constantly intruded on one another. Most radio entrepreneurs probably believed in free enterprise, but they realized that in the absence of regulation their pursuit of individual self-interest would result in the destruction of their industry.

The issue of federal regulation once again came into prominence when television became ripe for commercial development in the late 1930s. One of the major issues confronting the industry was the setting of technical standards. Each one of the major companies involved in television research employed a different system for transmitting and receiving televised images. At the same time, one of these companies, RCA, had made the most progress in putting together a total television system. This meant that the standards employed by RCA would have to be used if the FCC decided to permit the immediate broadcast of commercial television programs. The other manufacturers knew that they lagged behind RCA, but they felt that their own technologies had a great deal of promise. They certainly were not eager to adopt RCA's standards and pay royalties for its patents.

Faced with these contentious issues, the Commission gave the go-ahead for commercial television broadcasting in 1940, only to rescind its decision less than a year later due to America's entry into World War II. A special engineering committee was then set up to consider the issue of standards. By the middle of 1941, these had been successfully resolved. When television went into its period of rapid growth in the late 1940s and early 1950s, some of its success could be attributed to the uniform technical standards that were developed under FCC sponsorship.⁵ Unlike the early years of the personal

computer, the television market was not fragmented by incompatible standards and equipment.

Problems of Regulation

The efforts of the FCC to promote uniform technical standards were essential to the growth of the electronic media industry. The consequences of the FCC's other activities, however, are more controversial. According to the 1934 Communications Act, the FCC is supposed to grant and renew broadcasting licenses on the basis of "the public interest, convenience, and necessity." In fact, the FCC has been quite reluctant to influence the radio and television industries through the exercise of its licensing powers. Very few licenses have not been renewed; as long as a station has met some minimal level of community service it is deemed to have met the letter, if not the spirit, of the regulations. An FCC chairman might indict American television as "a vast wasteland," as Newton Minow did in 1961, but other than sponsoring the development of noncommercial television, his agency had scant influence over the quality of television programming.

It can be fairly argued that the FCC's active involvement in the shaping of television programming amounted to unwarranted government interference with the private sector. There have been times when FCC actions have had significant consequences for the broadcasting industry, and its decisions have on occasion benefited particular firms at the expense of other firms. One particularly notorious example was the FCC's role in reallocating established FM frequencies in the 1930s, a move that was advantageous to the dominant radio corporation, RCA, but detrimental to the interests of FM's inventor, Edwin Armstrong.⁶ RCA also reaped considerable benefits from the FCC's decision in 1953 to support its color television technology rather than the one developed by CBS. Seven months after this decision, the chairman of the FCC resigned his post and took a high executive position with NBC, at that time an affiliate of RCA.⁷ Much the same had happened during the controversy over the shifting of FM frequencies, when the FCC's chief engineer left his post to become the head of RCA's engineering department.

More recently, Michael K. Powell, a former chair of the FCC, left that position to head the National Cable & Telecommunications Association, the industry's chief lobbying group.⁸ In similar fashion, Meredith Attwell Baker left her position as FCC commissioner to become a lobbyist for Comcast NBC Universal, a few months after favorably ruling on a proposed merger of

Comcast and NBC Universal.⁹

Examples of regulators passing through the “revolving door” to take positions with enterprises they had previously regulated are not confined to the FCC, nor are they illegal. But they are cited as evidence that regulatory agencies such as the FCC are vulnerable to “capture” by the industry they are regulating. It should not be too surprising that this occurs; “regulation” has become a dirty word in some political circles, and the lack of support for regulatory agencies forces them to find it in the very industries that they are regulating. Moreover, regulatory agencies depend on the regulated industries for expertise and information. Compounding a potential conflict of interest, there is often close personal contact between the personnel of these agencies and representatives of the industry that they are supposed to be regulating. And, as in the case of the FCC officials who took positions in media organizations, they are often alert to the possibility of going over to the other side.

Occasionally, a regulatory issue will leap into political prominence and disrupt the comfortable relationship between a regulatory agency and the industry that it is regulating. This is what happened when a major accident at the Three Mile Island nuclear power plant in Pennsylvania put the Atomic Energy Commission’s role in regulating nuclear power into the political spotlight. But this is rare; for the most part, regulatory agencies view the industry that they regulate as a client to be served, sometimes to the detriment of the public interest.

The FCC’s proclivity for maintaining existing arrangements and avoiding conflict may have retarded technological innovation as a result of the agency’s weak support for innovations such as FM broadcasting, UHF, and pay and cable TV.¹⁰ But to reiterate a key point, political realities sharply limit the ability of regulatory agencies like the FCC to act as independent and aggressive foes of the industries they oversee.¹¹

The Television-Viewing Public

Television ownership has been virtually universal for decades. Today, it no longer requires a conventional television set, as increasing numbers of viewers are accessing programs on their computers, tablets, and smartphones. Although the time spent watching television has declined slightly in recent years, it remains the number one leisure activity in the United States, accounting for an average of 2.8 hours of viewing each day in 2014.¹² Only work and sleep take up more time than watching television, and on an annual basis children spend more hours in front of a television set than they do in school.

In recent years, other screen-based activities like surfing the internet and playing electronic games have taken some time away from watching conventional programming. There have always been age-related differences in television-viewing time, and these have been magnified by the greater use of alternative forms of digital media by younger age cohorts. Children and teenagers watch less television than adults, while individuals over the age of 65 spend about 13 more hours per week watching television than the statistically average viewer.¹³ In regard to other social variables, the amount of time spent watching television is negatively correlated with educational attainment¹⁴ and it also declines at higher income levels.¹⁵ In both cases, the correlations are apparent, but the direction of causality is not self-evident; after all, it is possible that watching television takes away time that could have been used for educational purposes. One thing, however, is clear, although the extent of television viewing is affected by socioeconomic variables like education, income, and age, watching television is embedded in the daily routines of people in every station of life.

Violence on Television and Its Consequences

One of the most pervasive concerns about television's influence centers on the vast amount of violent and aggressive behavior depicted on the screen. Violence is a programming staple. According to one account, before reaching the age of 18, the average child in the United States will have viewed more than 200,000 televised acts of violence, including 16,000 acts of murder.¹⁶ With all of this mayhem appearing on television, it is understandable that critics have indicted television for contributing to aggressive and violent behavior of children.

A large number of studies have been devoted to this topic. Some of these studies have been based on laboratory experiments that allow the researcher to eliminate extraneous factors in order to determine the relationship between exposure to a filmed act of aggression and subsequent behavior. In a typical experiment, one group of children is exposed to a film depicting violence while a control group is not. The subsequent behavior of the two groups is then compared. A classic experiment of this sort was conducted in the 1960s. One group of preschool children witnessed an actor physically and verbally assaulting Bobo the Clown, a large, inflated plastic doll. The control group saw nothing. The children were then allowed to play in a room containing a Bobo doll and other toys. The results were unequivocal; the children who had seen the simulated aggression displayed higher levels of aggressive behavior toward the hapless toy, in some instances even directly imitating the acts they had viewed, such as yelling out "Lickit! Stickit!" while pounding on the toy with the handle of a mallet.¹⁷

Many studies of this sort have been conducted. Some have found indirect as well as direct consequences of exposure to filmed violence. For example, children are more likely to play with toy guns after seeing filmed aggressive acts, even if gunplay did not appear in the film. All in all, these experimental studies are nearly unanimous in finding a connection between seeing acts of violence and subsequently engaging in aggressive acts.¹⁸

Laboratory experiments such as these can always be criticized because of

their artificiality. In their attempt to reduce or eliminate extraneous influences, experimenters may create an environment that bears little resemblance to reality. A film clip presenting violent behavior is not a television program, in which violent acts are presented in conjunction with a variety of other messages. Experiments also deal with only immediate cause-and-effect relationships. They therefore do not take long-term, cumulative effects into account. Finally, in these experiments the subjects may think that aggressive acts are permitted and even expected. For all these reasons, the real-world applicability of these experiments can be questioned.

Other researchers have attempted to circumvent the inherent limitations of laboratory experiments by conducting more “naturalistic” studies. In these, one group of children views “normal” violent programming, while another group does not. Their subsequent behavior in everyday settings is then directly observed or is reported by parents or teachers. Although they have a somewhat contrived quality, these studies can be taken as a reasonable reflection of real-world situations. And as with the experiments previously noted, viewing violent programming was associated with subsequent aggressive behavior, while neutral programming had no such effect.¹⁹

A third type of research examines actual viewing habits to see if there is an association (or “correlation”) between viewing violence on television and aggressive or violent behavior. These studies generally use interviews and self-reports as their primary source of information about viewing habits and behavior. For the most part, research of this sort does show a positive correlation between watching violent television programs and aggressive behavior. Children and adolescents who prefer violent television programs tend to be more aggressive in their behavior.

There is a basic problem with correlational studies, however, for correlation is not the same thing as causation. The correlation of A with B does not necessarily mean that A causes B. It is also possible that B causes A, or that a third factor or factors could be the cause of both of them. Accordingly, a child who was already violence-prone might seek out violent programs. It is also possible that an impoverished, culturally deprived background may be the cause of both the viewing of violent programming and aggressive behavior. These are reasonable objections, but several research programs have been able to statistically isolate the viewing of

violent television programming from other factors that may cause violent behavior. When this is done, the viewing of violent television shows is shown to be an independent source of violent and aggressive behavior. It may most strongly affect those who are already predisposed to this kind of behavior, but it is not confined to them.²⁰

It must be stressed that the conclusions drawn from all of these different studies cannot be applied to the behavior of specific individuals. For most children, watching violent acts on television probably will not lead to aggressive or violent behavior, but for some children it may. Television affects different people in different ways. Hard-and-fast generalizations are difficult to come by, but what Wilbur Schramm noted many years ago still holds today: “For some children under some conditions, some television is harmful. For other children under the same conditions, or for the same child under other conditions, it may be beneficial. For most children, under most conditions, most television is neither particularly harmful nor particularly beneficial.”²¹

Like any voluntary act, violent behavior is a product of a complex set of motivations and inhibitions. All of us probably have had moments when we wanted to commit a violent act. We usually have not done so for three basic reasons: (1) we have learned that such actions are likely to result in retaliation, (2) we know that they usually do not solve the problem, and (3) we have internalized a code of behavior that discourages such acts. Most likely, the operation of all of these prevents us from giving vent to our violent urges.

Television has the capacity to alter all of these inhibiting factors. In some televised depictions of violence, the retaliation for the violent act is delayed and muted, if at all. For nearly 75 percent of televised violent scenes, there is no punishment or even condemnation of the violence that was depicted.²²

To make things worse, the second inhibiting factor, a belief that violence does not solve most problems, is not always supported by television programming. Illegal and violent acts are sometimes used to attain socially approved goals.²³ Finally, there is the problem of television’s contribution toward desensitizing people, especially children, to violence, thereby attenuating the development of a personal code of ethics that discourages violent acts. Such long-term effects of televised violence are difficult to

prove, but there is a fair amount of evidence that exposure to televised violence dampens a child's emotional response to the witnessing of violent acts and diminishes his or her concern about such acts.²⁴

Television can be a powerful influence on thought and behavior, although it does not necessarily override the influence of family, school, church, and peers. Research into the consequences of television viewing face formidable challenges in separating television's effects from other influences. Even so, the majority of the many studies that have been done have found a connection between on-screen violence and real-world violence. Based on these studies, the American Psychological Association, in 1985 and again in 2016, indicted media violence for contributing to violent and aggressive actions, desensitizing individuals to the consequences of violence, and increasing fears of being a victim of violence.²⁵

Television violence has been identified as a significant social problem, but it is not one with an easy solution. The depiction of violence may be essential to a story, even one with great artistic merit; many of Shakespeare's works include scenes of appalling brutality. Occasional violence also accounts for some of the appeal of sports like football and hockey. In the absence of widespread popular support for government censorship, which would likely be overturned on constitutional grounds, about all that can be hoped for is a greater degree of responsibility on the part of the television industry. A technological fix of sorts is available in the form of the V-chip, which can be used to block programming according to an age-based rating system.²⁶ But the most effective way of avoiding violent programming is for parents to take an active role in monitoring their children's consumption of television programs and to use the most effective way of regulating viewing: the on-off control.

Delivering the News

Until recent times, most people were blissfully ignorant of the world around them. Travelers might bring stories of distant places, and the literate few could read of them. Information traveled very slowly; the Battle of New Orleans was fought two weeks after a treaty formally ended the War of 1812, for the combatants were unaware of its signing. During the nineteenth century, the railroad, the telegraph, and the appearance of popular newspapers brought the world closer, but coverage was still slow, spotty, and often inaccurate. Past the borders of one's own community was a world dimly perceived by most people. All of that has changed today. Instantaneous communications tell us of uprisings in the Middle East, wars in Africa, and financial crises in Europe. Although we do not quite live in a "global village," modern communications technologies have extended our vision to a degree scarcely imaginable not long ago.

As we saw in the previous chapter, the rise of digital sources has brought important changes to the way that news is presented and consumed. This trend can be seen as a continuation of a process that began in 1960, when survey respondents indicated for the first time that television had replaced newspapers as their prime source of news.²⁷

For decades, television has been a prime source of news about the nation and the world; in 2015, the evening news programs on ABC, CBS, and NBC had a total viewership of 24 million.²⁸ But lying behind this figure is a steady erosion of viewership as the internet and social media have become a major source of news. This trend is especially notable when the viewing audience is broken down into age categories, as younger cohorts are much more likely to rely on digital news sources. According to one study, 71 percent of young adults aged 18 to 29 cited the internet as one of their main sources of news, while only 55 percent put television in the same category.²⁹

Although television has a great potential to bring the outside world into our homes, the effects of watching television news have been negligible for large segments of the viewing public. According to a survey conducted by the Pew Research Center in 2007, only 38 percent of the respondents who got

most of their information from evening television news programs correctly answered at least 15 out of 23 basic questions about current events. In contrast, 51 percent of respondents who were regular listeners to National Public Radio were able to do so. But NPR enthusiasts should not feel too smug; 54 percent of the surveyed population who listed *The Daily Show* and *The Colbert Report* as sources of their knowledge of current events also answered at least 15 out of 23 questions correctly.³⁰



Glenn Campbell/Newscom/United Press International (UPI)/AMMAN JORDAN

A family in Jordan gathers around the “electronic hearth.”

The way the news is covered in print differs significantly from televised coverage. Newspaper reporting tends to be detached and impersonal, whereas television reporting is more like storytelling. A news report is presented in narrative form, with a theme being developed through the use of sound and pictures as well as verbiage. A great deal of television news is presented as a kind of visually oriented entertainment, narrated by newscasters who are selected, at least in part, on the basis of their physical attractiveness. The stories are short and fragmentary, with very little contextual information. This

is inevitable since the average network news story runs for only 1 minute and 20 seconds.³¹ News of this sort is quickly forgotten; one study found that more than 20 percent of the viewers of television news could not recall a single item of news an hour after having seen a news broadcast. Another study found that the average viewer retained only 20 percent of the information presented in a simulated news story.³²

In contrast, newspaper stories are written so that the key item can be quickly grasped. Background and analysis then follow for the reader who wants to continue with the story.³³ Viewers of television news and casual newspaper readers may have equally superficial understandings of the events in the news, but at least the latter can extend their knowledge. Television news gives few such opportunities.

Television and Politics

Numerous analysts have charged that both cable and over-the-air television has fundamentally altered the political process. Television, they assert, has reduced political campaigns to trivial “media events,” selected the sensational over the substantive, undermined political parties, greatly inflated the cost of political campaigns, and made “image” the primary criterion of a candidate’s appeal. Are these accusations true?

There can be little question that the politics of the television age is different from the politics of earlier times. In 1948, Harry Truman could wage a successful presidential campaign from the back of a railroad car. Today, political commercials have taken the place of the whistle-stop tour yet television advertising is not always decisive. In the course of his “unusual” campaign, Donald Trump benefited from a great deal of free media publicity, but spent relatively little for TV ads. By the end of October 2016, Hillary Clinton’s campaign had burned through about \$141.7 million on television advertising, considerably more than the Trump campaign’s outlay of \$58.8 million.³⁴ This anomaly aside, televised political advertising is usually a critical part of electioneering, as the typical congressional campaign budgets at least one-third of its funds for television advertising. Presidential campaigns devour enormous amounts of money (after all, \$58 million is not exactly chump change), much of it used for televised appeals.

As television has increased the costs of conducting campaigns, the need for large campaign contributions has mounted. This, in turn, has increased the danger of successful candidates being beholden to the special interests that supply a significant portion of these contributions, especially now that there are no limitations on the amount that can be spent by political action committees. As cynics (or maybe realists) have suggested, we may end up with “the best elected officials that money can buy.” Corruption has always been a part of political life, but the demands of television campaigning have created something new, a scramble for campaign funds that is perfectly legal but nonetheless a threat to democratic political institutions.

As the Trump campaign has shown, although television has become a

major force in American political life, there are limits to its influence. Televised political advertising is not always decisive, and money does not always win elections. In most elections, the majority of voters have made up their minds about who will get their vote well before the campaign gets under way. For these voters, televised advertisements help to crystallize their choices and reinforce their existing beliefs but do not produce any fundamental alterations. At the same time, however, there are many elections where the outcome hinges on the choices made by voters who make their decisions late in the political campaign. Television can, therefore, be decisive when an election hinges on the choices made by these voters.

In most cases, the voters who have made up their minds long before the election takes place are the ones most strongly influenced by party loyalties. This makes them fairly impervious to televised appeals to vote for another party's candidate. Yet, identification with a particular party has been eroding in recent years, and many people who call themselves Democrats or Republicans do not have a strong sense of commitment to their party. Television has been responsible for a good deal of the erosion of party loyalties because a candidate can use the medium to appeal directly to the electorate. Also, presidential and other candidates for national office are no longer selected by party bosses in smoke-filled rooms. They usually are the products of state primaries, in which televised appearances and political commercials are usually the most important part of the campaign.

At first glance, the ability of candidates to use television in order to directly appeal to the electorate seems like a good thing, an improvement over the days of party bosses and political machines. In reality, electronically transmitted communications from candidates to voters are usually devoid of substance. Numerous critics of television have pointed out that the effectiveness of a television presentation hinges on visual appeal and a memorable sound bite, with content a secondary consideration. Recent trends have exacerbated this tendency. One study found that from 1968 to 1992, network news programs reduced the average length of presidential candidates' spoken comments from 1 minute to 10 seconds. Since then, coverage has dropped to an average of 8 seconds, and only a third of these clips addressed substantive policy issues.³⁵ Televised political appeals make little room for ideas, policies, and well-articulated political positions; what

really matters is the kind of personality and presence that a candidate projects on the screen. At the same time, television often conveys the idea that problems can be quickly resolved—requiring less than 30 minutes in the case of a particular show, and 30 seconds for individual commercials. It is no wonder, then, that the electorate is often attracted to candidates who offer simple and quick solutions. And these “solutions” are, of course, neatly packaged for television; instead of lengthy discussions of a candidate’s stand on particular issues, the typical commercial consists of 30 seconds of visual images and a few empty slogans.

The pervasive influence of television on political life should worry anyone concerned about the fate of our political institutions. As some critics have argued, the greatest threat to democracy may come not from the assaults of hostile nations but from the trivialization and even corruption of the political process that occurs when television dictates the basic mode of discourse and comprehension.³⁶

Television and Thought

For some students of the media, the effects of television go well beyond the ones just described. The most notable of these has been Marshall McLuhan, whom we met briefly in the preceding chapter. In McLuhan's schema, television is a "cool" medium: The televised image is indistinct and requires that viewers "fill in the blanks" in a way that involves all of the senses. Viewing television is not a single-minded, linear process, as reading is. Exposure to television in turn leads to a mode of perception that affects many other aspects of life. For McLuhan, a television-based culture is less concerned with sequence than with complete, all-at-once involvement. In his view, these changes in perception are transforming every aspect of our lives; McLuhan attributed everything from a desire for small cars to changes in church liturgy to the influence of television. Examples such as these seem far-fetched, and some of his predictions have not been borne out, such as his prophecy that baseball will necessarily decline because it is a "linear" game. McLuhan's focus on the influence of different types of media opens up all kinds of fascinating possibilities, but his conclusions lack clear proof, and in fact the basic thesis is virtually unprovable.

More concretely, it has been claimed that television helps young children to develop visual perception, such as learning that an object viewed on a two-dimensional television screen actually has three dimensions, and that an object viewed from different perspectives is still the same object.³⁷ This may be true for programming that has been consciously designed to develop these skills, but most television shows have little to offer in this regard. Moreover, when they occur, advances in perceptual skills are limited and temporary. Even these gains are largely restricted to children with low language ability and visual skills; television viewing may actually be detrimental to the perceptual development of children not deficient in these areas.³⁸

Other deleterious effects of television on children can be noted. Experimental studies have shown that children supply more imaginative continuations to interrupted stories that they read than they do to televised stories. In similar fashion, young children who are heavy watchers of

television engage in less imaginative play than other children.³⁹ There is also a fair amount of evidence that television watching may contribute to underdeveloped reading skills in children. The relationship is not a perfectly direct one; it may emerge only when a certain threshold of television watching is reached, and it seems to be affected by the kind of programming selected.⁴⁰ Still, it seems evident that for many children television is a negative influence in this regard. Finally, one might also speculate that the lack of concentration and the short attention spans that seem so common today are at least partially the result of growing up with television programs that are constantly punctuated by commercial messages and other distractions.

Television was the most pervasive and significant medium for most of the second half of the twentieth century. But just as it brought about a revolution in how we are informed and entertained, it too is being reshaped by technological change. A television set is no longer the only way of viewing televised programming. In recent years, growing numbers of viewers have been able to watch television—everything from network shows to the latest YouTube clip that has gone viral—on laptops, tablets, game consoles, and smartphones. At the same time, television viewers are no longer limited to programming supplied by cable and over-the-air networks; increasing numbers of them are subscribing to online video services like Netflix and Amazon Prime.⁴¹ Although long-established television networks are providing much of the content being viewed today, many media analysts foresee a time when most programming will be supplied by streaming services operating independently of these networks. Conventional television viewing has also been affected by digital video recorders (DVRs) that allow prerecorded programs to be accessed at a viewer's convenience. This often brings the added benefit of eliminating commercial interruptions, a boon to viewers but a source of considerable consternation for advertisers. Meanwhile, the integration of television and the internet is proceeding apace, as a new generation of sets allows viewers to simultaneously watch television, access the internet, access and apply various apps, and communicate through social media sites.

While television is being reshaped by new technologies, other forms of electronic media have been taking on growing importance for communication

and entertainment. In the next chapter, we will take a look at video games, social networking, and the many components of the internet. In so doing, we will consider the economic, political, cultural, and social contexts that have shaped their development. We will then bring radio and television back into the picture for an overall assessment of the electronic media's place in shaping our world and being shaped by it.

QUESTIONS FOR DISCUSSION

1. In many countries, a considerable amount of television and radio broadcasting is done by government organizations such as the BBC. In the United States, most broadcasting is done by commercial stations. What are the advantages and disadvantages of the two systems?
2. Political scientists have noted that government regulatory agencies tend to be “captured” by the industry that they are regulating. Is this inevitable? Is it possible for regulatory agencies to prevent this from happening?
3. Do you agree with this chapter’s general conclusions about television’s influence on violent behavior? Do you think that there is too much violence on television? Should television be more closely regulated so less violence appears on the screen?
4. Television commercials are a major part of campaigns for the presidency and congressional offices. In what ways has television affected the way that campaigns are run? On balance, has television been a positive or negative influence on political campaigns and campaigners?
5. Should parents try to control the television-viewing habits of their children? To what extent is it even possible to do so?
6. How do you watch televised material? Do you use a conventional television set or a new media platform like a smartphone? What are the advantages or disadvantages of each?
7. Although many thought that radio would be completely replaced by television, this never happened, and, in the aggregate, radio stations are quite profitable today. How is radio programming today different from the “golden age of radio” in the 1930s and 1940s? Might network television also have to undergo major changes if it is to survive?

CHAPTER FOURTEEN

| The Internet Age

As we saw in the past two chapters, a succession of technologies has vastly enhanced the ability of people to send and receive messages. Today, we are experiencing the latest phase of this ongoing revolution as the internet, mobile phones, and social media are reshaping the ways in which we communicate with one another. But to repeat what by now should be a familiar theme, these advances have been accompanied by a number of new issues and problems. The same free flow of information that enhances our ability to communicate also gives rise to a number of concerns: the protection of information that we do not want to move so freely, such as intellectual property and personal data; unequal access to information, exacerbating the gap between the haves and have-nots; cyberbullying; and the difficulty and expense of filtering, managing, and using so much information. This chapter traces the development of digital communication technologies and the challenges they pose, and also shows how technological advances can move along unanticipated paths.

The Birth and Growth of the Internet

The internet can be described as a giant network of smaller computer networks that allows users to access files located anywhere within these individual networks. These files can be email messages, Web pages, YouTube videos, and social networking updates, to name the most prominent. As with many technologies, the invention of the digital network that eventually evolved into today's internet began with the needs of the military. The sponsoring agency for the development of the first computer network was the U.S. Department of Defense's Advanced Research Projects Agency (DARPA), hence the name of the first computer network, ARPANET. Its initial purpose was to tie together a small number of mainframe computers so that data could be uploaded and downloaded to and from any computer in the network.¹

An important aspect of ARPANET was the division of each block of data into a number of smaller "packets." In this way, the capacity of the network could be maximized by sending each packet over the route that was least congested at the time.² This technique had the additional virtue of ensuring that messages would go through even if some routes were destroyed by an enemy attack, although this was not its primary purpose.

By the early 1970s, the sending of digitized messages, which became known as electronic mail or simply email, constituted three-quarters of ARPANET's traffic, a function that had not been considered when ARPANET was first established. In this sense, the network was a social construction, one that resulted from its users taking it well beyond its intended purpose.³ This was not a unique occurrence; as we have seen before, technologies created for one purpose can end up being used for something quite different, as when radio mutated from wireless telegraphy into commercial broadcasting.

Computer networking through ARPANET remained largely in the military realm in the 1970s, but the appeal of networked computing stimulated the development of alternative systems. Responding to growing demand, the National Science Foundation (NSF) provided financial

sponsorship for the Computer Science Network (CSNET), which went into operation in 1982. Computer networks expanded throughout the 1980s, facilitated by the development of programs for the efficient routing of digitized information, notably TCP (Transmission Control Program). It was during this period that the power and utility of the internet was given a massive boost when programmers began to build systems that allowed users to access other network sites by clicking on highlighted text or an icon that appeared on the on-screen document. By clicking on these links, users could easily move all over the internet as they accessed related text, image, and sound files.

The first of these networks were proprietary, and to be included required the payment of a fee. A different approach was taken by Tim Berners-Lee at the European Organization for Nuclear Research (known by its French acronym, CERN), who was the primary developer of another software system for accessing files within computer networks. Known as hypertext transfer protocol (http), it was released in 1991 and formed the basis of a network that Berners-Lee called the World Wide Web (WWW). Two years later, the WWW team announced that they had made a crucial decision; CERN would not attempt to patent or claim any copyright fees for the technology underlying the Web. This meant that there would be no restrictions on becoming part of the Web, and as a result it became a virtually universal repository of computer-based information and entertainment.⁴

The Web underwent explosive growth in the years that followed. In December 1993, there were 623 websites. Today, there are over a billion, double the number of only five years earlier.⁵ The growth of the Web has been paralleled by the unprecedented growth of the internet as a whole. Its expansion constitutes one of history's fastest rates of technological diffusion. According to a United Nations study, it took radio broadcasters 38 years to reach an audience of 50 million, while television took 13 years. For the internet, only four years were required to assemble 50 million users.⁶ By 2015, more than 2.9 billion people, about 40 percent of the world's population, were "netizens."⁷ But as we shall see, worldwide internet usage is very unevenly distributed, with high rates of usage in some places offset by low rates in others.

The revolutionary changes wrought by the internet reflect rapid advances

in the development of computer hardware and software. But as has been noted earlier, large-scale changes are not just the product of solitary inventions. Rather, they entail the prior existence or creation of complementary elements. This is particularly evident when we consider the use of the internet for the buying and selling of goods—e-commerce, as it has come to be called. The internet and the means to access it are not enough; online buying also requires credit or debit cards and the security measures employed to protect the customers using them. For sellers, successful e-commerce depends on the use of barcode readers for selecting and keeping track of items, forklifts for retrieving them from high shelves, and conveyor belts to move them to the packing room.⁸ The transport of these items to the customers who ordered them is usually performed by nothing more avant-garde than a delivery truck, often in the service of the venerable U.S. Postal Service. The internet has brought substantial changes to retailing, but much more has been required than computers and software.

Social Media and the Network Effect

People have always sought to connect with one another; it is one of the defining characteristics of our species. But for most of human existence, the ability to interact with one another and to create, join, and participate in social networks did not go beyond face-to-face interactions. As we have seen in Chapter 12, written language and printing greatly expanded the boundaries of communication, and during the last two centuries the telegraph, telephone, radio, and television stretched these boundaries even further.

What has differed from old patterns is the speed at which digital communications have gained large audiences. For example, Facebook, the most commonly used social media site, began with a few dozen users at Harvard University in 2004. It had one billion users in 2012, and by 2016, 1.71 billion users had Facebook pages.⁹ Other, more specialized, social networking sites also exhibited impressive rates of growth, LinkedIn, a site oriented toward work and careers, reached 396 million members by 2015, 12 years after its initial launch.¹⁰ Twitter, despite that, or perhaps because, its messages (“tweets”) are limited to no more than 140 characters, has also grown at an impressive rate; founded in 2006, nine years later, it had 304 million active users¹¹ who collectively accounted for an average of 500 million tweets every day.¹²

Facebook was not a unique service; other general social media sites such as Friendster and Myspace were created at about the same time. But having a multitude of sites is like having a multitude of telephone companies, each issuing their own telephone numbers. Communications systems like telephones and social media sites are governed by the “network effect.” This simply means that an interconnected system becomes increasingly valuable as more members are connected to it. A telephone, computer, or any kind of communication device would be of limited use if it were connected to only a few dozen similar devices. But anyone with a Facebook account and a device to access it has the potential to connect with hundreds of millions of people. The growth of a network also illustrates the power of positive feedback; as a network expands it becomes of greater potential value to people and

organizations that are still outside the network. This motivates them to join the network, which makes the network even more valuable, which induces more people and organizations to join it, and so it goes until a saturation point is eventually reached.

There is no upper limit to the number of individuals who can be counted as one's Facebook "friends," although in many cases, the term "friend" has been stretched almost beyond recognition. As of 2014, 39 percent of adult Facebook users had 1 to 100 Facebook friends, while 15 percent had more than 500. As with many aspects of digital technologies, sharp age differences are apparent in Facebook use. Users between the ages of 18 and 29 have an average of 300 friends, but those between 50 and 64 average only 75, and seniors aged 65 and above have an average of 30.¹³

Unlike the number of "friends," the amount of time that can be spent on Facebook necessarily has some limit, as there are only 24 hours in a day. Facebook users in the United States spend an average of 35 minutes a day on the site, less than the time spent watching television (2.8 hours), but considerably more than the time spent reading (17 minutes).¹⁴ Not all of that time is necessarily well spent. Many Facebook pages contain messages and pictures of what a friend had for dinner, or a picture of their dog wearing a Spiderman costume, and so on. Facebook users are also exposed to a lot of advertising. With such a large number of users, Facebook has been very successful as a vehicle for advertisers. Its pages feature a plethora of ads along with "clickbait" that encourages a reader to view sites featuring such attractions as photographs of movie stars who have not aged gracefully, all the while presenting still more advertisements.

More ominously, some users of Facebook and other social media sites have been subjected to cyberbullying, where cruel comments and ugly photographs have been posted for all to see. According to the U.S. Department of Education, during the 2012–2013 school year, 1,713,000 students or 6.9 percent of students between the ages of 12 and 18 were victims of some form of cyberbullying, not all of which was done on social media sites.¹⁵ In some cases, there have been tragic consequences when cyberbullying has resulted in a victim's suicide.

Sometimes damage due to misuse of social media is self-inflicted. Prospective employers may look at the sites of job seekers and discover

pictures or information that are anything but beneficial to a job applicant. Another potential pitfall is sexting—sending sexually explicit pictures and texts over social media and other digital sites. According to a study conducted at one university, 54 percent of respondents said they had done so before the age of 18.¹⁶ Although these were often sent to boyfriends, girlfriends, or close friends, there is no guarantee that they would not be sent elsewhere. Would-be sexters should also be aware that sending or receiving sexually explicit materials may result in prosecution under laws covering child pornography.

For individual users, Facebook and other social networking sites bring evident benefits and potential liabilities to individual users. Less clear, however, are their effects on society and culture in general, and on communication in particular. In contrast to firm statistics on the number of users, an accounting of social media's influence on society and culture is necessarily speculative. The relative newness of social media means that definitive statements are premature and are subject to later review, but some interesting ideas and findings have emerged. On the one hand, social media and other internet-related media such as email have moved us closer to Marshall McLuhan's "Global Village" by connecting people on the basis of interests, work relationships, and political causes rather than geographical proximity. At the same time, however, digitally mediated connections may be undermining person-to-person relationships by making it all too easy to substitute the former for the latter. As Sherry Turkle has observed, "We expect more from technology and less from one another and seem increasingly drawn to technologies that provide the illusion of companionship without the demands of relationship. Always-on/always-on-you devices provide three powerful fantasies: that we will always be heard, that we can put our attention wherever we want it to be, and that we never have to be alone. Indeed our new devices have turned being alone into a problem that can be solved."¹⁷

This is a powerful indictment of digitally based relationships, but other studies have found that an expansion of online relationships has not in fact led to a decline of traditional, face-to-face interactions or displaced traditional, nondigitized social relationships.¹⁸ Moreover, while involvement with social media sites absorbs a fair amount of time, it does not come at the

expense of traditional face-to-face contacts. If anything is displaced, it is the time spent eating, sleeping, and watching television.¹⁹ All in all, the effects of digitally based social media seem remarkably similar to those in the early days of the telephone; despite widespread concerns at the time, chatting on the phone did not displace traditional modes of communication and socialization. If anything, telephone communications appear to have extended and intensified existing social relationships.²⁰

Mobile Communications

Many social media sites are now accessed on smartphones. The rapidly increasing capabilities of these devices have expanded to the point that their ability to send and receive telephone calls seems almost incidental to their other functions. In parallel with the spread of smartphones, the introduction of tablet computers such as Apple's iPad has given their owners a larger screen and new functions. The expanded capabilities of smartphones and tablets have made them the favorite devices for social networking, game playing, email, and other internet-based activities. In addition, their portability allows their users to do a variety of things that would be impossible or impractical with a personal computer, such as GPS navigation and paying for purchases. Their specific features aside, smartphones and tablets have ushered in a new phase of human existence, what has been called "The Age of Connection," an era in which anyone with a telephone or an internet account can potentially reach anyone similarly equipped almost instantaneously.

As with the other elements of twenty-first-century information and communication technology, the number of smartphones has grown dramatically: In 2015, global smartphone sales reached 1.4 billion units, an increase of 14.4 percent from the previous year.²¹ By 2015, nearly two-thirds of Americans were equipped with smartphones.²²

Much of the attractiveness of smartphones and tablets lies in the applications ("apps" for short) that have been developed for them, allowing their users to track their investments, receive sports scores, get turn-by-turn driving instructions, find their cars in a parking lot, and much more. According to one survey, by the middle of 2015, 100 billion apps for the Apple iPhone had been downloaded since the firm first opened its app store in 2008.²³ The development of these apps has become an industry in itself that collectively produces thousands of different apps. The value of many of these apps is, however, open to question. While vast numbers of them are available for downloading, only a few account for the majority of actual downloads. According to one study, on average one smartphone app

accounted for half the time spent with all apps. The second most used took up 18 percent of app time and the third accounted for 10 percent. Everything else accounted for only about 20 percent of app use.²⁴



Jon Bower/LOOP IMAGES/Corbis

Mobile phones have had an impact everywhere, but perhaps their greatest influence has been in poor, developing countries.

Although we tend to associate twenty-first-century technologies like mobile phones with the industrially developed countries, these phones have become widespread in the poorer parts of the world. Most of them lack the features of smartphones, but they have facilitated communications while eliminating the need for a wired infrastructure. Mobile phones are used to maintain family ties for migratory workers, to apprise farmers of crop prices, and even to provide basic medical diagnoses.²⁵ Some mobile phone users in Africa are able to use their phones as mobile banks that allow them to electronically store money, transfer funds, and pay bills.²⁶

Social Media and Social Movements

Networks based on smartphones and tablets can promote stability within a society by forging and strengthening linkages between individuals. At the same time, however, they can be powerful tools for undermining an existing social order. Turning individual grievances into a mass movement requires communication links to create a sense of common purpose, to forge a group identity, to recruit new members, to inform participants of intended actions, and to schedule these actions. The power of social networks to do all of these was demonstrated in August 2011 after the death of a man who had been killed by London police officers in the course of a bungled arrest. After a day of rioting, some individuals began to use a smartphone app that made it possible to send the same message to everyone in their phone's directory. The message was simple: it told them to congregate at a particular time and place so they could "linkup and cause havic [sic], just rob everything. Police can't stop it."²⁷

The looting conducted by the resultant flash mob was only one of many recent examples of collective action by individuals who coalesced and took action in accordance with mobile phone messages. Other mass movements energized by social media have been oriented toward political transformation rather than illegal personal enrichment. Up to now, the most far-reaching of these has been the use of social media to bring down the dictatorial regime of Hosni Mubarak in Egypt during the "Arab Spring" of 2011. At that time, hundreds of thousands of disaffected Egyptians had been regular readers of and contributors to Facebook pages that aired their grievances and motivated them to demonstrate against the government at particular times and places. Twitter feeds provided up-to-the-minute information, and mobile phones served as crucial communication links during this turbulent period. For some of the insurgents, these new communication technologies were viewed as powerful but nonviolent weapons for successfully challenging oppressive regimes and effecting political transformation. As the creator and administrator of the most influential Egyptian Facebook site put it:²⁸

Now that so many people can easily connect with one another, the world is less

hospitable to authoritarian regimes. Humanity will always be cursed with power-hungry people, and the rule of law and justice will not automatically flourish in all places at all times. But thanks to modern technology, participatory democracy is becoming a reality. Governments are finding it harder and harder to keep the people isolated from one another, to censor information, and to hide corruption and issue propaganda that goes unchallenged. Slowly but surely, the weapons of mass oppression are becoming extinct.

Might this evaluation of new communications technologies be excessively optimistic? Social networking sites and mobile phones helped to create the collective identity and actions that rocked Egypt and other parts of the world, but it is important to note that they were an enabling factor, not an independent force for change. As ever, we have to avoid invoking implicit technological determinism that would make digital media autonomous sources of political transformation. In Egypt and other places where users of social media challenged the existing order, grievances had long festered within a significant portion of the population. The Mubarak regime was associated with decades of corruption, political repression, economic stagnation, and severely limited opportunities for young people. It was a tinderbox waiting for a spark; this was supplied by the self-immolation of a young vegetable seller in Tunisia. New communication technologies helped to organize and energize the movement, but they did not start or sustain it.

No less important, digital communication is a two-edged sword that can be a force for oppression as well as of liberation. Technologically sophisticated authoritarian regimes can tap into email accounts and mine social networking sites in order to locate associates of known dissidents and to track their activities. They can also plant bogus Web pages, blogs, and videos to discredit their opponents. Also, it cannot be assumed that widespread connection to digital media will impart unity. Tweets, blogs, and instant messages are inherently decentralized communication modes, and their fragmented nature may prevent disaffected citizens from coalescing into a unified opposition movement.²⁹



AFP/Getty Images

Facebook and other social media sites were important catalysts for overthrowing dictatorships in the Middle East and North Africa, but establishing viable democracies will be a long, difficult process.

Even when the effective use of social media helps to foment a large-scale uprising, it is less useful for generating long-term purposive action, especially when this requires discipline, organization, and sacrifice. As Malcolm Gladwell has argued, Facebook and similar sites excel at constructing networks, but these are not permanent structures with well-defined individual responsibilities and unambiguous centers of authority. As seen by Gladwell, social networks are deficient when it comes to setting long-term goals and creating effective strategies for achieving them.³⁰ The case of Egypt seems to bear out Gladwell's critique. Mubarak and his henchmen were swept aside by a movement that involved millions of Egyptians, but after the dust had settled, the army was in control and democracy faced an uncertain future.

In the broadest terms, the role of digital media in the Egyptian revolution is reminiscent of the connection between printing and the Protestant reformation nearly five centuries earlier. Neither movement would have unfolded the way it did in the absence of new media, but much more has been involved than enhanced communications capabilities. Without denying their

unquestioned importance in promoting social and political change, printing, social media, and mobile phones by themselves do not a revolution make.

Internet Access: Net Neutrality and Walled Gardens

As a force for social change, social media has its limitations, but it still can be a powerful weapon when used against entrenched powers. Consequently, authoritarian governments always strive to control who can connect with the internet and what they can access when they are connected, as exemplified by what has been called “The Great Firewall of China.”³¹ Even in free societies, access can be an issue; what matters here is “net neutrality,” the expectation that every internet site will be accessible, no matter which internet service provider (ISP) is providing the access. Without net neutrality, an ISP could enable access to its chosen sites while restricting access to those of its competitors, as when private-sector ISPs have been accused of giving preferential treatment to allied TV services over other providers.³² In order to maintain net neutrality the Federal Communications Commission ruled in 2013 that ISPs could not favor one internet site over another, a decision that was upheld by the appeals court of the District of Columbia in 2016.³³

Another restriction on complete access to the internet occurs when users confine their usage to what have been called “walled gardens,” ISPs that facilitate internet access but control and limit access to particular internet sites. Selective access began during the early days of personal computer ownership, when providers like America Online offered an easy route to using the internet. Today, Apple, Facebook, and Google serve as portals to the internet for many users, while at the same time retaining some degree of control over access.³⁴ This is particularly evident with Google searches that provide links in accordance with the user’s search history. Although perhaps convenient, this practice may result in individuals with a perceived political orientation being presented with links to sites that are in accord with that orientation. This is analogous to what has been termed “narrowcasting,” the tailoring of radio and television programming to fit the interests and beliefs of specific audience segments.

The Digital Divide

A computer, tablet, or smartphone along with an internet connection are all that is needed for buying things online, staying in touch with friends through email, or using social media to foment revolution. But for many people, access to cyberspace remains limited. The internet has been characterized as a highly democratic system of communication because it is not under centralized control, yet it continues to reflect inequalities within and between nations. According to statistics compiled toward the end of 2015, although 46.4 percent of the world's population used the internet to some extent, vast disparities existed within different regions of the world. To take one of the starkest contrasts, 87.9 percent of North America's residents were internet users, but only 28.6 percent of Africa's population had this capability.³⁵ To take another example of a significant disparity in internet connectivity, 98.2 percent of the population of Iceland, the country with the greatest degree of internet penetration, used the internet, while only 12.3 percent of Afghans could connect to it in 2015.³⁶

As might be expected, all of the countries with high rates of internet usage lie within the developed world, but substantial disparities in usage can be found within these countries. Numerous critics have pointed to the "digital divide" that separates people with easy access to the internet from those with no access. In the United States, access in schools is virtually universal, but the ability to go online at home has differed according to race, ethnicity, and especially social class. According to the U.S. Department of Commerce, 84 percent of Americans used the internet in 2015.³⁷ Differences of race and ethnicity are evident but not massive; 85 percent of white households had an internet connection, while 78 percent of African American and 81 percent of Latino households had one.³⁸ Much more significant is financial status; 97 percent of households with incomes over \$75,000 were connected, considerably more than the 74 percent of households with incomes under \$30,000.³⁹ Geographical location is also significant; 85 percent of urban households have an internet connection, whereas 78 percent of rural households are connected.⁴⁰

The way that different groups log onto the internet also shows some interesting differences. The growth of smartphone ownership has created an important means of access. African Americans and Latinos own smartphones at about the same rate as whites, but they are more likely to use these devices for online access.⁴¹ This may result in another manifestation of the “walled garden” phenomenon whereby control by mobile carriers, which are not governed by net neutrality laws, results in more limited access to the internet, as when content deemed “controversial or unsavory” has on occasion been blocked by mobile carriers that serve as ISPs.⁴²

In a world where the ability to acquire and make use of information has taken on increasing importance, the internet has the potential to empower people by making information more accessible than it ever has been. But the internet is not a technological fix. As we have just seen, while the internet has been a revolutionary technology, access to it also reflects prevailing social and economic conditions. Perhaps of equal importance, even with widespread online access there remain significant disparities in the ability to make effective use of it. In the absence of parallel social changes, the internet may intensify rather than diminish global and national social inequalities.

Video Games

In 1972, Pong, a table tennis simulation, became the first commercially successful electronic game. At first confined to video arcades, within a few years, it was a staple for Atari home computers. Today, a multiplicity of electronic games are available on smartphones, tablets, computers, and the consoles and hand-held gaming devices found in 80 percent of American households.⁴³ On-screen games now constitute a significant portion of leisure activity for many individuals. The technical development of video games has proceeded rapidly in recent years, providing amazingly realistic depictions of everything from bowling alleys to combat zones to rock concerts.

Once comprising little more than a cluster of cottage industries, the video game industry has become a very big business, one that pulled in \$61 billion in 2015.⁴⁴ Globally, revenues generated by electronic games are now double those of the entire music industry and are one-quarter greater than those of the magazine business.⁴⁵

Although the typical video gamer is often envisaged as an adolescent boy, the audience for video games has gone well beyond this stereotype. The average age of gamers is 35, with 47 percent between the ages of 18 and 49. Women now comprise 44 percent of gamers, and it is worth noting that women over the age of 18 now comprise a larger percentage of gamers (33 percent) than do boys 17 and younger (15 percent).⁴⁶ Of all the games sold in 2015, 14 percent fell into the “mature” category, which also encompassed 6 out of the top 10 sales of video games.⁴⁷

There is no escaping the fact that games featuring violent action are an important source of revenue and profit. The most successful game of this genre, “Call of Duty: Modern Warfare 3,” brought in \$775 million in the first five days of worldwide sales,⁴⁸ and continues to be the top selling video game. Concerns about a possible connection between violent video games and real-life violence bring us back to some of the issues voiced by critics of violence on television. As is the case with televised violence, the influence of violent video games on behavior varies according to age, gender, and other individual and social variables. Gaming preferences also differ. Not only are

males somewhat more likely to be video gamers, their choice of games tends to differ from those of female players. Males are drawn to sports and action games (not all of which are violent), while their female counterparts generally prefer strategic and puzzle games, although one study found no gender differences in regard to interest in adventure games.⁴⁹ Other studies have found that girls and women tend to play for social interaction and to form relationships. In contrast, boys and men prefer games where winning is the most important outcome.⁵⁰ And as has been the case of television, the American Psychological Association has noted a clear correlation of playing violent video games and aggressive behavior.⁵¹ But once again, inferring causality from correlation can be problematic. For the majority of players, participation in violent on-screen activities may be “just a game,” but these games may catalyze aggressive and even violent acts for those who are already disposed toward this kind of behavior.



Agencja Fotograficzna Caro/Alamy

Young men playing video games at an exhibition in Germany.

Today’s video games have reached impressive levels of realism, so much

so that some are now being used to prepare soldiers and the police to operate in dangerous and frightening situations. It is certainly possible that graphic on-screen violence can have a stronger and more lasting effect than watching TV on the players of these games.⁵² Along with the realism that they bring, video games also require a level of attention and involvement that television viewing does not require. This greater degree of participation was highlighted in a report issued in 2001 by the U.S. Surgeon General, which speculated that video games might stimulate more aggressive and violent behavior than television viewing because the player is a participant in on-screen violence and not simply a vicarious consumer of it.⁵³ “Speculated” is the proper term here. A considerable amount of methodologically sophisticated research will be required before the consequences of violent gaming are fully comprehended. These reservations aside, an interesting *negative* correlation between the spread of video games and society-wide violence merits our consideration. The hypothesized connection between violent behavior and violent video games is belied by a substantial *decrease* in the rate of violent crime in the United States and most other countries in recent decades. The reasons for the drop in violent crime have been the subject of much debate, but this trend makes it hard to argue that violent video games have triggered a wave of violence across the land.

It should be noted at this point that the primary victims of video games are some of the players themselves. Although the American Psychiatric Association decided that existing research did not justify including video game addiction in the most recent edition of its *Diagnostic and Statistical Manual of Mental Disorders*, it is a problem for some individuals.⁵⁴ Psychologists who have treated video game addiction note that the majority of their clients are young men under 30 with poor self-esteem and limited real-life social networks. They are especially drawn to role-playing games that allow them to assume a new identity as they inhabit a virtual world that is more appealing than the one in which they live. As with other addictions, video game addiction is characterized by the need to devote large amounts of time to gaming, withdrawal from other activities, and feelings of anger and depression when one is unable to play or prevented from doing so. Addiction to technology in general may be an inescapable part of modern life, but with excessive video game play, it may become self-destructive.

On a more positive note, some organizations have begun to experiment online with applying gaming mechanics as motivational devices in behavior change—for example, providing real or virtual rewards as a user completes a sequence of stages on the way to achieving a goal, often within a framework that encourages competition and interaction. The term used for this is “gamification,” which, according to its exponents, makes work and other activities more engaging and enjoyable.⁵⁵

The awarding of points, badges, or other rewards for doing certain things and completing particular tasks is not a novel technique, of course; psychologists have long known that frequent feedback generally improves performance, whether it be of workers, students, or other participants. What is new about gamification is that it depends on the existence of social media and the drive for constant connectedness. Gamification also taps into a universal attribute of human culture; in virtually every kind of society, men and women and boys and girls play games of some sort. However, the extent to which human activities can be made to resemble games is open to question. The history of business strategies is replete with many examples of fads that achieve considerable popularity and influence, only to eventually fade away as their impracticality, triviality, and ineffectiveness become evident. Gamification may fall into this category, or it may flourish because its intended group of users has been involved with electronic games for much of their lives.

Intellectual Property

One of the most contentious issues surrounding the use of computer networks has been the innocuous-sounding practice of file sharing. In this context, a file can be anything in a digital format—text, sound, or pictures. No one objects when people use the internet to send a Christmas letter or a photograph of a new grandchild to friends and family, but a host of legal and commercial issues arise when a digitized movie or song is sent to members of a file-sharing service. At the heart of the matter is intellectual property, the ownership of a product of one’s creativity, such as a novel or a musical performance. Written works, music, and movies intended for commercial use are protected by copyrights, which prevent the unauthorized use of the material and usually require the payment of fees when they are legally used. Governments grant copyrights for the same reason that they issue patents: both are thought to stimulate creative efforts by giving individuals and firms monopoly control over their creations, and with it the chance to reap financial rewards.

In previous decades, the development of radio, television, movies, and recorded music greatly expanded the commercial value of creative efforts. Generations of actors, artists, musicians, and others have owed their livelihoods to media in its various forms, but more recent technologies have been more problematic, and their use has exemplified the ways in which new technologies may create winners and losers, as noted in Chapter 1. One early example is the videocassette recorder (VCR). When the VCR first came out, it was thought that its primary function would be the playing of prerecorded tapes of movies rented from video stores. But many VCR owners also used their machines to record programs that had been broadcast on commercial television. The movie industry sued the manufacturers of VCRs and videotapes, claiming copyright infringement. In a case that eventually went all the way to the U.S. Supreme Court, the court ruled in 1984 by a 5 to 4 margin that home recording constituted “fair use” under existing copyright laws, allowing individuals to record movies and TV shows with impunity.⁵⁶

In the late 1990s, the rapid spread of computer networks presented a new

challenge to existing conceptions of intellectual property, because after being compressed and digitally encoded, a musical selection could be sent to anyone with a networked device and the requisite software. By the start of the new century, 60 million people were sharing music that was being routed through Napster, the most prominent file-sharing service at the time. This was done by connecting one's computer to Napster's network servers, which kept a list of all the music that was available on clients' computers in the MP3 format. Napster and its clients claimed that all that was going on was the sharing of files by private parties, which constituted "fair use" under existing copyright laws. But the courts did not agree, ruling that Napster's central database of music titles gave it primary responsibility for what was deemed illegal downloading.⁵⁷ Napster tried to reconstitute itself as a commercial distributor of digitized music, but it failed to survive in this guise. Napster's demise did not put an end to file sharing, however. New services allowed individuals to access music residing in millions of individual sites but avoided the legal problems caused by maintaining a central database that used the internet to channel requests and to inform users of available music, movies, and other digitized files.

While the music industry was trying to stop "piracy," growing numbers of individuals were subscribing to fee-based services that allowed them to stream or download music and movies without fear of legal reprisals. The services provided by iTunes, Rhapsody, Amazon, and others were quite successful in getting people to pay for downloaded music. Apple, which had pioneered the sale of downloaded music for its line of iPods, tallied its 10 billionth iTunes download in early 2010.⁵⁸ The growth of these enterprises made major inroads into the practice of unauthorized file sharing.⁵⁹ After all, it did not require much of a financial commitment, usually not much more than a dollar, to obtain a hit song. Legal downloading also retained a key advantage of illegal downloading—the convenience of instantly acquiring a song without having to go to a store or wait for a mail delivery.

The rise of file sharing, both legal and illegal, coincided with a significant drop in CD sales, but there is no agreement that this reflected a cause-and-effect relationship. As might be expected, the music industry attributed falling sales to widespread "piracy" and claimed that the very survival of the music industry depended on the suppression of unauthorized file sharing.

Although the person-to-person transfer of files was a common occurrence, the industry may have overstated its impact. One study concluded that unauthorized file sharing had only a minimal effect on CD sales;⁶⁰ falling CD sales, it was argued, were the result of high prices, the lack of new and interesting music, and the appeal of alternative forms of entertainment such as video games, smartphones, tablet computers, and movies on demand. These claims were of course challenged by the music industry, which pointed to other studies that purportedly proved that file sharing definitely damaged CD sales.



James Leynse/Corbis

Congressional efforts to deter illicit downloading through the Stop Online Piracy Act (SOPA) and the Protect Intellectual Property Act (PIPA) met with large-scale resistance and were withdrawn.

Neither the industry nor file-sharing services were right. The real culprit in the decline of CD sales has been the rapid growth of music streaming through subscription services like Spotify or internet radio like Pandora. These sites now account for \$1.2 billion, or 34.3 percent, of music industry sales, more than the revenues earned through digital downloads. In 2006 (well

into the era of illicit file sharing), the music industry earned \$9.4 billion from CD sales in the United States. By 2015, CD sales stood at just \$1.5 billion. Ironically, the only bright spot in this dismal financial picture has been a resurgence in the sale of vinyl records, which earned \$416 million for the industry.⁶¹

Privacy in the Digital Age

Keeping private information out of the hands of marketers, potential blackmailers, nosy neighbors, and ex-boyfriends and girlfriends will pose continual challenges for everyone who lives in the digital era. All of the communications technologies covered in this chapter have the potential to undermine personal privacy, sometimes seriously. As users of email messages know (or should know), an email message is more like a postcard than a letter. Its contents can be easily accessed and used against senders or receivers to embarrass or even blackmail them. The use of internet search engines leaves a record that contains quite a lot of information about the user. These can create new marketing possibilities, but sometimes at the expense of individual privacy. Social media are no different. Facebook users were outraged in 2007 when they discovered that the social networking site was tracking their activities on participating websites and reporting them to their Facebook friends.⁶² This eventually resulted in a settlement with the Federal Trade Commission (FTC) whereby Facebook agreed to a number of stipulations aimed at protecting the privacy of its users and to monitoring by the FTC of its practices for 20 years.⁶³

Recent years have seen the rapid expansion of data mining firms which use easily accessible records to gather detailed information on individuals. This information is then processed by sophisticated algorithms to determine the likelihood that a particular individual will buy a particular product or support a certain candidate for political office. Once this has been determined, they can be targeted by advertisements that play to their particular interests and beliefs.⁶⁴ It can be debated whether or not this practice is effective in getting people to buy these products or vote for these candidates, but the danger that all this information can be misused by hackers and “legitimate” businesses is all too evident. Moreover, simply using a mobile phone may expose the user to a variety of privacy breaches.⁶⁵ The emerging technology of Radio Frequency Identification (RFID) gives governments, businesses, and individuals the ability to track the movements of people who have RFID tags incorporated into their passports, drivers’

licenses, credit cards, employee access badges, student ID cards, and even library cards.⁶⁶ Word processing documents may contain hidden “metadata” such as the name of the writer and the type of computer that was used.⁶⁷ The installation of a GPS device on a person’s car also offers new opportunities to know the whereabouts of an individual, although the U.S. Supreme Court, in the first decision regarding digital searches, ruled that such an action requires a court order.⁶⁸ Finally, drones, also known as unmanned aerial vehicles (UAVs), offer many opportunities for spying on people and places. One computer entrepreneur has famously claimed, “You already have zero privacy. Get over it.”⁶⁹ It can be safely countered that this statement is not entirely true today, for there are many defenses against privacy-invading technologies. But those of a pessimistic disposition may argue that this obituary for personal privacy, while not completely applicable today, is not wrong, only premature.

The Electronic Media in Modern Society

In considering the consequences of electronic media, beginning with radio and television, and continuing with the numerous forms of digital media available today, we are left with many unresolved issues. As with other major technological changes, the electronic media have advanced in conjunction with other historical changes, making it very difficult to come to an exact reckoning of their unique contributions to culture and society. To put it slightly differently, to understand the influence of the electronic media, it is necessary to consider the larger contexts within which they emerged and diffused.

The electronic media are only the latest in a series of technologies that have expanded our ability to communicate with one another. As human societies have expanded in size, complexity, and mobility, the need to tie them together through improved communications media has increased apace. As we have seen, visionaries described technologies that would transmit sounds and pictures over great distances long before the realization of these dreams was technically possible. Even so, the need for something does not ensure that it eventually will be produced. The technical capacity has to be created, and individuals and organizations have to come forward with money and other resources to support it. One of the major reasons for the success of radio, television, and the internet can be found in the solid financial support that they have attracted. During its early years, radio advanced because military, governmental, and business organizations perceived its relevance to their needs. Later, the profit-making potential of radio and then television was eagerly exploited, and the market created by commercial broadcasting further stimulated technological development. More recently, the internet began as a creation of the military, was further developed as a means of business and personal communication, and toward the end of the twentieth century emerged as a popular medium with seemingly endless commercial possibilities. In the opening years of the twenty-first century, there has been a massive expansion in the products and services tied to the internet, and we surely have not seen the last of it.

The electronic media have become essential features of modern life because they have helped to mitigate the disruption of stable community ties that has been a prominent feature of the modern era. Economic and social changes have produced a great deal of social and geographic mobility, as well as corresponding feelings of rootlessness. In response, first radio and then television contributed to the construction of a common culture that served as at least a partial substitute for attenuated local ties. The effects of the internet, social media, and other digital media are less easily characterized. Whereas television and radio formerly attracted large audiences through the broadcasting of a small range of programs, cable television and some of the key products of the internet—websites, blogs, tweets, and social networks—are engaged in narrowcasting that plays to a much more limited audience. The consequences of audience segmentation are still somewhat speculative, but there can be little doubt that they have contributed to the political and cultural polarization that is characteristic of our times.

Although participants in social media sites may list hundreds of “friends,” a virtual community is not the same as one based on long-lasting face-to-face relationships. As we have seen, person-to-person media such as the telephone and Facebook can strengthen existing social connections, but they should not be seen as substitutes for them. The loosening of local ties has not been reversed by the spread of new media, and according to some social scientists we have become an increasingly individualized society.⁷⁰ For many people, the electronic media have filled a void by bringing information, entertainment, and new means of communication that have helped to mitigate weakened connections to family, friends, and community.⁷¹ These media can be characterized as “technological fixes,” and as we have seen, technology cannot always fix problems that are social and cultural rather than technical in nature.

QUESTIONS FOR DISCUSSION

1. For long-range communication, do you prefer email, Skyping, texting, tweeting, or the telephone? Are some communications more suitable for email and others for the telephone? Why? Are there times when a barrage of email messages leaves you feeling overwhelmed and frustrated?
2. As noted in this chapter, most smartphone owners use only a few apps for their phones. Are you one of them? Have you downloaded some apps only to later delete them? Why?
3. Some of the most devoted designers and players of games have argued that game playing can impart many useful virtues such as cooperation with others, optimism, and feelings of leading a purposeful life. Do you agree? Do the benefits of gaming outweigh the drawbacks?
4. The rapid expansion of the internet has put vast amounts of information and entertainment within easy access. The internet also contains many sites that dispense pornography, gambling opportunities, and the ravings of hate groups. Although these sites can be blocked through the installation of filters, these are not completely effective and may limit access to important information such as AIDS awareness. Should efforts be made to limit the spread of “objectionable” material? How might this be done? What could be lost as a result?
5. Have you or any of your friends ever shared a file that was protected by a copyright? Did you have any qualms about doing so? Are the big media firms justified in treating file sharing as a criminal activity to be prosecuted to the fullest extent of the law?
6. How much do you worry about the potential and real loss of your privacy due to increasingly sophisticated technologies for eavesdropping, tracking, recording, and general snooping? Is the loss of some privacy a fair price for the increased communications capabilities made possible by today’s electronic technologies?
7. How many friends and associates do you have in your social media

network? Do you feel that the number of social media “friends” is a good indication of popularity? What is the relationship of your social media friends to those with whom you interact off-line?

PART SIX

The Tools of Destruction

War presents the dark side of technological advance. It is a sad fact of human history that a large portion of human ingenuity has been directed toward improving the ability to kill and destroy. Chapter 15 traces the evolution of weapons from ancient times to the present, paying particular attention to the reciprocal relationships between weaponry on the one hand, and military organization, cultural orientations, and political structures on the other.

Chapter 16 picks up where the previous chapter ended with a description of today's arsenal of cruise missiles, smart bombs, spy satellites, and drones. The development and deployment of these devices has come at considerable expense, yet for all of their improvements in accuracy and destructive power, these devices have not conferred unchallenged military supremacy. Relatively simple weapons continue to be used to deadly effect by forces with limited financial resources. Moreover, a high level of technological sophistication increases vulnerability to cyber attacks that can cripple a modern economy.

Chapter 17 reprises a now-familiar theme: the influence of culture, social arrangements, economics, and politics on the development and application of technology. It describes how the advance or the retardation of particular weapon systems has been associated with particular social arrangements and organizational interests. The chapter ends with a consideration of one of the greatest imperatives of our time: the reduction and eventual elimination of

nuclear weapons. The history of earlier efforts to eliminate or control new weapons shows that efforts of this sort have had mixed results at best.

CHAPTER FIFTEEN

| Weapons and Their Consequences

For most of human existence, the baser instincts of humanity were checked by the limitations of the weapons that could be used. Clubs and stone knives could be used at close range, and rocks and other missiles could be hurled at a target a few dozen yards away. There are still places in the world where warfare is conducted as it was thousands of years ago. Unfortunately, however, human ingenuity has not always been confined to activities that make our lives better. On many occasions, our most inventive minds have used their talents to find new ways of wreaking havoc on other human beings. Warfare presents the dark side of technological progress; although technological advances have bettered many aspects of human life, they have also led to a terrifying expansion in the ability to kill and destroy.

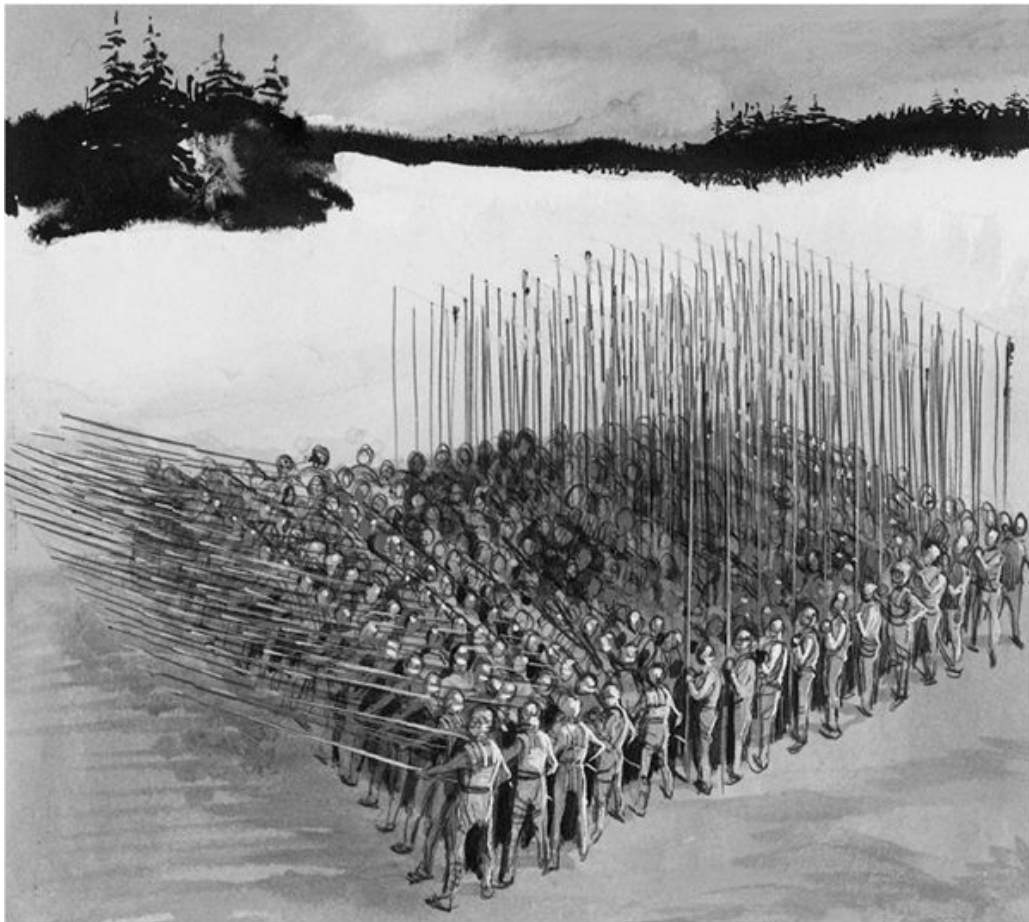
Military Technology in the Ancient World

The technological changes that marked the beginning of civilization's development were from the start used for martial purposes. The production of metals, first bronze and then iron, resulted in more lethal weapons, as well as armor to protect against them. Around 4,000 years ago, armies in the Middle East began to deploy archers in horse-drawn chariots, greatly increasing the mobility and striking power of their attacking forces. So equipped, the armies of Assyria and Persia successfully invaded their neighbors' territories and established extensive empires.

Effective as they were, military forces based on the chariot and bow did not conquer everything in their path. Horses and chariots operated with great effectiveness in the open expanses of Central Asia and the Middle East, but they were far less useful in mountainous areas. Equally important, horses had to be fed, and in the absence of adequate forage an army using large numbers of horses quickly outran its supply lines. In contrast, the armies of ancient Greece relied on the hoplite, a foot soldier armed with a spear and a short sword and protected by a shield, helmet, breastplate, and shin guards. The effectiveness of a Greek fighting force derived from its being organized into a phalanx, a mass formation of infantrymen at least eight rows deep. Deployed in close ranks, the warriors' shields offered a modicum of protection, while the spears projecting out from the first three rows presented a fearsome offensive threat. A collision between two phalanxes was the essence of Greek warfare, with victory usually going to the side that demonstrated the greater degree of discipline and cohesion.¹

The Romans brought a greater degree of mobility to infantry combat by deploying their soldiers in smaller units of 60 to 80 men each, who in turn were aggregated into larger units that together formed a legion of 3,600 to 4,600 infantry and 300 cavalry.² Although armaments were little changed from the time of the Greeks, the Romans carved out a vast empire by employing superior tactics and, above all, because they could rely on the discipline and coordination of their legions. Mobility, after all, is no advantage if it leads to the dispersal of troops and the lack of unified action.

The cohesion of the Greek phalanx depended on its being composed of groups of warriors belonging to social networks of friends and relatives. The cohesion of the Roman legions derived from two elements unknown to the Greeks: extensive drilling in combat procedures, and the leadership of a permanent officer class, the centurions.³ The genius of Rome was at least as much organizational as it was technological, and it gave the Romans a military superiority that lasted for centuries.



A phalanx of ancient Greek soldiers/English School (20th century)/LOOK AND LEARN (A & B IMAGES)/Private Collection/Bridgeman Images

The wall of spears of the Greek phalanx was a fearsome sight for enemy combatants.

While the weapons of the infantry soldier changed little in the ancient world, significant strides were made in the development of siege machinery.

The most fearful weapons of antiquity were catapults, first used in Sicily during the fourth century B.C. They were then employed with considerable success by Philip of Macedon, the father of Alexander the Great, and played an important role in many of the battles waged by the Greeks and Romans, as well as by their enemies. It is also significant that siege machinery was the creation of some of the first specialists in technology; indeed, the word *engineer* is derived from the Latin *ingenium*, an ingenious device used for siege warfare.⁴

Catapults hurled rocks or large arrows by releasing the stored-up energy of a torsion spring, made of twisted cords of animal sinew and human hair. Hair was much prized as a military supply; there is an ancient report of thousands of pounds of hair being sent as a present from one king to another.⁵ The most powerful catapults were capable of hurling a bolt or a small stone a distance of 800 yards (although 400 yards was a more normal range), while a 60-pound rock thrown a distance of 150 yards produced the best effect when fortifications were the target. A smaller catapult (known as an *onager*) used by the Romans for battlefield service was capable of flinging an eight-pound projectile up to 500 yards.⁶ The main limitation of all catapults was that hair and sinew stretch when wet, so in damp climates the springs lost their resiliency and therefore much of their power. Despite this limitation, these devices played an important role in siege warfare. Each Roman legion was supported by 55 catapults, and 300 catapults were deployed by Rome during the siege of Jerusalem in 70 A.D. Even after the invention of gunpowder and cannon, many decades were to pass before the destructive power of these weapons was surpassed.

The use of such siege machinery conferred great strength on offensively minded empire builders like the Romans. The crude fortifications of the “barbarians” usually provided scant defenses against invading armies armed with these early missile launchers. Conversely, Roman military superiority was less evident when Rome itself was put on the defensive during the barbarian invasions. Roman defensive technology was inferior to the offensive weaponry of the time; this incapacity, when coupled with the many internal problems besetting Rome, resulted in the eventual disintegration of one of the world’s greatest empires.

Military Technology and the Feudal Order

Military technologies made few advances during the centuries following the fall of Rome. But in the sixth century, a new technology emerged that added a new dimension to warfare. This innovation was not itself a weapon, but it made existing weapons far more effective. The device was the stirrup, an invention of Chinese origin that had diffused to Europe by the ninth century. Horses had long been used in battle; as we have seen, many battles were won through the use of horse-drawn chariots from which arrows could be shot and spears thrown. But a warrior mounted directly on a horse was precariously perched. Although cavalry charges were sometimes employed in battle, in most cases when it came time to fight, the warriors dismounted and fought on foot.

The stirrup greatly amplified the destructive potential of a warrior by fixing him firmly to his horse. The horse was no longer merely a means of conveyance; its power could now be used to augment the striking force of a spear or lance. As we shall see, the horse-mounted knight was by no means invincible, but his determined charge could be devastating. Although mounted combat was not the dominant mode of medieval warfare, in many places, the local populace suffered considerable insecurity if they lacked the protection of a mounted warrior.

The central importance of the mounted knight produced some significant economic and political changes. A horse was an expensive item, and its maintenance required considerable outlay. At the same time, the mounted knight was the product of years of specialized training, during which time he could not be engaged in productive activities. The maintenance of a horse, knight, his assistants, and their training required 300 to 400 acres of land.⁷ Even kings lacked the financial means and administrative capacity to raise and support an army of knights on their own. Instead, they gained the military support of mounted warriors by granting them tracts of land in return for their military support. This was the basis of the feudal order, the dominant form of political organization throughout the Middle Ages.

Feudalism was an inherently decentralized system, and armies often were

temporary and disorderly assemblies. Knights relied on their individual skill and courage, and were disinclined to submit to centralized discipline and strategic planning. Battles were often chaotic affairs involving a great deal of individual combat and little in the way of careful tactical planning. On occasion, opposing forces might spend several days just trying to find each other so that a battle could take place. The military technologies of the Middle Ages thus led to a retreat from the principles of discipline and precise organization that had made Roman armies so formidable.

Horse-mounted combat also generated the culture of chivalry. The word itself derives from the French *cheval*, or horse. The horse-mounted knight was different from ordinary soldiers by virtue of his noble birth and the long period of training that was required to develop his proficiency in combat. The chivalrous knight lived by a code that regulated certain aspects of warfare. Noncombatants—provided that they were Christians—were to be left in peace, and combatants were supposed to adhere to specific rules of battle. Above all, war was seen primarily as a contest between members of a distinctive warrior class, in which individual glory could be as important as the attainment of military objectives. War still remained a grisly business, but as long as it was considered to be a contest between participants in a common culture, some limits were set on the manner in which it was waged, and the land was usually spared the total devastation that has been a hallmark of more modern conflicts.

New Weapons and the Decline of Feudalism

Knighthly combat was only one aspect of medieval warfare, and usually not the most important one. Sieges were the most common military engagements, while in pitched battles foot soldiers outnumbered mounted knights by five or six to one.⁸ Cavalry charges against numerically superior infantrymen were rarely successful, and beginning in the fourteenth century the utility of the mounted warrior was further undermined by the widespread deployment of the pike. Used to especially good effect by the Swiss, the 19-foot-long pike was wielded by a solid formation of soldiers with four rows of pikemen extending their weapons to the front line—a formation that resembled the ancient Greek phalanx in many respects. United by an iron discipline and a high morale that came from being free men in the service of their canton (a mini-state that often had its own army), the Swiss pikemen became the most feared soldiers in late medieval Europe. Hard-charging knights were dispersed by the pikemen and then assaulted by other soldiers wielding halberds (long battle axes).⁹

The vulnerability of mounted knights was further increased by the use of another infantry weapon, the longbow. Archers had been part of combat since Neolithic times.¹⁰ But they were limited by the design of the weapons they used. The bow was transformed into a decisive weapon simply by making it longer. At the same time, however, the longbow was a difficult weapon to use properly, for it required considerable strength and skill, and that came only with extensive practice.¹¹

First used by the Welsh during their resistance to English conquest, the longbow was adopted by King Edward I during the early fourteenth century. In skilled hands, this bow, which was six feet or more in length, could be a devastating weapon, capable of rapidly firing arrows that could do damage up to 650 feet away.¹² Drawn back to the ear instead of the chest, as was the case with smaller bows, the longbow was capable of driving an arrow through several inches of oak, and although it could not penetrate the best plate armor, it could pierce chain mail or the joints in plate armor.¹³ The prowess of English archers was clearly demonstrated at the Battle of Crecy in

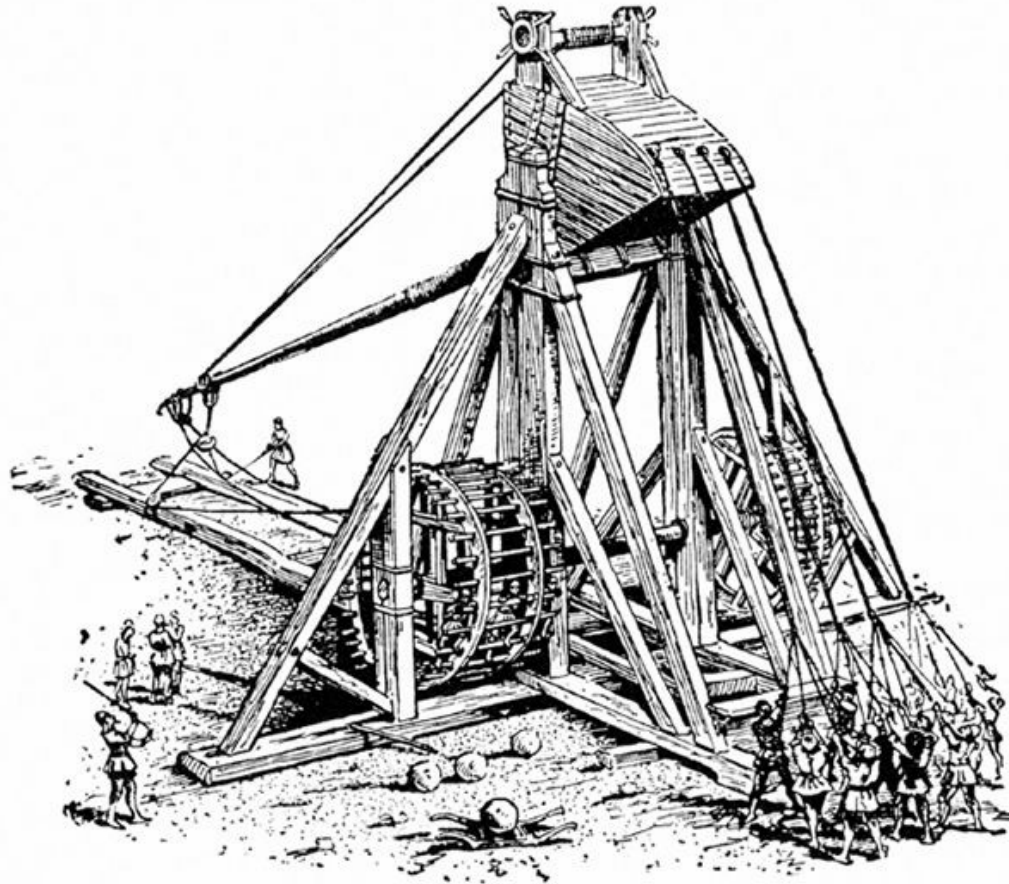
1346. Despite a two-to-one numerical inferiority, the English forces won a decisive victory. A rain of arrows penetrated the chain-mail armor of the French knights and wrought even greater destruction on their horses.

The mounted knight was also threatened by an eleventh-century invention, the crossbow. A mechanically sophisticated device, the crossbow used a lever or a crank-and-ratchet assembly to draw the string. The crossbow had a lot of stopping power, as it fired a bolt that weighed a half pound or more. Its range and accuracy were superior to that of the longbow, but the cumbersome process of winding it restricted its rate of fire to only two bolts per minute. It was thus most effective when the archer could find cover where he could safely reload.¹⁴ Despite this deficiency, the crossbow was a formidable weapon that made the life of the knight all the more precarious.

One answer to these new offensive weapons was the replacement of chain mail by plate armor. This armor became increasingly thick, until by the late sixteenth century a mounted knight was weighted down with as much as a hundred pounds of armor. His horse, too, required protection, for a felled horse often meant death for its dismounted rider. The result was a crippling loss of mobility for the knight and his steed. Maneuverability and speed, hitherto the great virtues of the mounted warrior, were lost, and the knight ceased to be the mainstay of the European battlefield. Much later, mounted soldiers played a significant role in combat, not as lance-wielding knights but as cavalry armed with pistols and sabers. If carefully coordinated with artillery salvos, a cavalry unit could force the enemy to maintain solid ranks, thus presenting a convenient target for artillery.¹⁵ But the traditional knight was no longer a major player in the game. At best, he was an auxiliary; at worst, a vulnerable target.

The castle, the other great symbol of the Middle Ages, was also challenged by new military technologies. Early medieval fortifications were little more than mounds of earth surrounded by wooden walls, a far cry from the elaborate defenses constructed by the Romans. During the Crusades, Europeans learned a great deal by observing the castles constructed by their Muslim opponents, and this knowledge diffused through Europe after they returned home. Throughout the early Middle Ages, castles stood as virtually impregnable redoubts that conferred as much security as could be hoped for during those turbulent times; about the only way to conquer a fortified

position was to starve it into submission.



Granger, NYC—All rights reserved.

The medieval trebuchet used a counterweight and some human assistance to hurl a projectile placed at the end of the long lever arm.

Attackers attempted to breach the walls of castles and other fortifications with weapons little changed from Roman times, until in the twelfth century besieging armies began to employ a device known as a trebuchet. This weapon consisted of a long arm that was unequally balanced on a fulcrum. The long end, which held the projectile, was held in place by a catch, while the short end was loaded with heavy weights. When the catch was released, the long arm flew up and hurled the projectile in the direction of the enemy. These could be formidable weapons, capable of delivering a 300-pound projectile a distance of up to 300 yards and weights of more than a ton for

shorter distances.¹⁶ Although some trebuchets had less range than the catapults of antiquity, the greater weight of the projectile made it a more effective siege weapon.¹⁷ Also, since it did not depend on torsion springs made from hair as the older missile launchers did, it was effective in all kinds of weather. While improved siege engines were not always up to the task of battering down sections of walls, they could be used to demoralize a castle's inhabitants by lobbing incendiaries, live snakes, and dead horses over the walls. And on occasion they were used to speedily return a prisoner to their place of origin on the other side of the wall.¹⁸

The Gunpowder Revolution

The crossbow, longbow, pike, and trebuchet posed a severe challenge to the knight and the feudal system that maintained him. New weapons based on gunpowder sealed his fate. Incendiary weapons had long been used in combat. Flaming arrows, vases filled with a mixture of pitch, sulfur, and boiling oil, and primitive grenades filled with naphtha were all used in battle. One of the most terrifying weapons used in antiquity was Greek fire. Although its ingredients are a matter of debate even today, there can be little doubt of its effectiveness. Like modern-day napalm, it clung to whatever it came into contact with and burned fiercely, even on water. First used in seventh-century Byzantium, it served as a decisive weapon in naval engagements and as an anti-siege weapon. Despite the tactical advantage that it offered, Greek fire was used only sparingly because the rulers of Byzantium always feared that it would fall into enemy hands, a concern that has limited the diffusion of many other “secret weapons” throughout history.¹⁹

The First Gunpowder Weapons

Early incendiary devices were generally employed as auxiliaries to armies whose main weapons continued to be swords, spears, and bows. With the invention of gunpowder, the nature of warfare underwent a profound transformation. As with many of the inventions that transformed medieval European society, gunpowder originated in the East. First used for medicinal purposes by its Chinese inventors, gunpowder became the propellant for simple rockets during the Tang Dynasty in the eighth century.²⁰ When first used in Europe during the early fourteenth century, gunpowder was used to fire large arrows and stone cannonballs. At first, these artillery pieces were little more than a nuisance. They had less destructive power than a good trebuchet, and their chief advantage was that they could be built more cheaply and be more easily transported than mechanical missile launchers. Their barrels were often made of wood; when iron was used the barrel was made from parallel strips that were welded together. In neither case could the cannon withstand repeated firing, and their projectiles were stone balls that often shattered when fired.

Artillery began to be used against fortifications by about 1420, and by 1453 Turkish attackers successfully used cannon to batter down the walls surrounding Constantinople prior to taking the city. In the succeeding years, a number of improvements resulted in larger, more accurate and reliable weapons. Iron and bronze gun barrels were cast through the use of techniques that had been used for the production of church bells—an ironic application of a peaceful technology to a martial one. Iron cannonballs replaced stone ones. “Corned” gunpowder, which was made into coarse grains, produced a more consistent and rapidly burning charge. As a result of these innovations, by the middle of the sixteenth century the fortified castles that had long been immune to direct attack were now vulnerable.

Still, the age of the castle was by no means at an end. Military engineers strengthened castles by backing their walls with loose dirt, which absorbed much of a cannonball’s force, and by constructing bastions protruding from castle walls, from which their own cannon could be fired in multiple directions. Such fortifications provided a good deal of security until mobile artillery, developed during the late eighteenth century, concentrated the

firepower of several cannon, once again tipping the balance in favor of the besiegers. Until then, castles conferred a great deal of security against attack and did much to preserve the independence of smaller states, thereby preventing the political consolidation of Europe.²¹

Smaller, more mobile artillery pieces were also used to good effect on the battlefield. Of particular importance were the innovations of Sweden's Gustavus Adolphus during the Thirty Years' War (1618–1648). Instead of deploying the large field pieces commonly used, Gustavus relied on cannon that fired nine- or four-pound balls. Light in weight, these could be handled by a small crew and rapidly deployed during the course of battle. Artillery took on its classic role in battle: softening up the enemy's lines in preparation of a charge by the cavalry and infantry.

Arming the Infantry

As we have seen, technological advances often occur through the expansion of a small-scale device or process. In the case of firearms, however, the process was reversed. Handheld guns were at first nothing more than small cannon, lacking even a stock that would allow them to be tightly held and accurately aimed, and it was not until a century after the introduction of cannon that useful handheld firearms began to appear in battle. Still, they had many shortcomings. Large artillery pieces were aimed at a fixed target and then had their charge lighted through a touchhole. In contrast, small guns had to be used against rapidly moving targets. They could not be aimed with any degree of precision if a soldier had to shift his gaze to the weapon's touchhole. The answer to this problem was the matchlock, which used a smoldering wick held by a trigger-operated clamp to ignite the powder. Even so, firing this gun was a cumbersome process, requiring no fewer than 28 separate procedures to load, fire, and clean the gun.²²

Despite these shortcomings, by the first quarter of the sixteenth century small arms had graduated from being battlefield auxiliaries to indispensable articles of combat.²³ Subsequent improvements made firearms all the more significant. The cumbersome matchlock eventually gave way to the wheel lock and then the flintlock musket, which was capable of firing three rounds per minute.



Springfield musket rifle, model 1861 (wood & metal)/American School (19th century)/
CIVIL WAR ARCHIVE/Private Collection/Bridgeman Images

The Springfield rifled musket was the standard infantry weapon for the Union army during the Civil War.

The firepower and accuracy of these weapons greatly augmented the offensive power of armies, provided that they were used in conjunction with

proper battlefield procedures. Military commanders learned to deploy their soldiers in rows, so that a soldier could fire his weapon and then retreat to the back rows where he could reload in relative safety. Still, troops could not always be depended on to use their weapons effectively. Although a musket could fire a ball several hundred yards, it was accurate to a distance of only about 80 yards. The familiar “don’t fire until you see the whites of their eyes” was a wise admonition, but one difficult to adhere to under combat conditions. In the heat of battle, soldiers were inclined to fire prematurely, and many were so distracted that they completely botched up the necessary routines used for loading these single-shot weapons, as one report from the American Civil War indicates:²⁴

The official report of the examination of the arms collected upon the battle-field of Gettysburg, states that “Of the whole number received, 27,574, we found at least 24,000 of these loaded; about one-half of these contained two loads each, one-fourth from three to ten loads each, and the balance one load each. In many of these guns from two to six balls have been found, with only one charge of powder. In some, the balls have been found at the bottom of the bore with the charge of powder on top of the ball. In some cases as many as six paper regulation caliber ’58 cartridges have been found, the cartridges having been put in the gun without being torn or broken (preventing them from being exploded by the percussion cap). Twenty-three loads were found in one Springfield rifle-musket, each loaded in regular order. Twenty-two balls and 62 buckshot with a corresponding quantity of powder, all mixed up together, were found in one percussion smooth-bore musket.”

This sort of bungling could be expected, given the panic and paralysis often experienced by men in combat. In order to counter it, successful military leaders had to institute rigid battlefield procedures that had been deeply imbued through countless parade-ground exercises. The numerous steps required for the effective use of firearms were incessantly driven into the troops until they became virtually automatic, even in the face of withering attacks from the enemy. In complete contrast to the unruly egocentricity of knightly combat, warfare had become a routinized procedure, and soldiers “became replaceable parts of a great military machine just as much as their weaponry.”²⁵

Earlier chapters have stressed the complementarity of organizational and technological changes, and nowhere is this better illustrated than in the military realm. A well-drilled army always has an advantage over one that is

lax in its ways, and the technological development of warfare made this even more the case. The handling of firearms required a precise series of operations; incessant drill was required if soldiers were not to be totally unhinged during the course of battle. Adhering to an iron discipline created by constant drilling and blindly obedient to a rigid chain of command, European armies of the eighteenth century had become some of the most grimly efficient organizations the world had ever seen.

The creation of these armies had a significance that transcended their importance in the military sphere, for they served as the prototype of new forms of civilian organization: routinized, regimented, and hierarchical. Obedience to authority is nothing new in human societies; it is, after all, one of the most important lessons learned by young children. But this sort of authority is embodied in a particular person—first a parent, and then another authority figure. Soldiers of this era obeyed the authority of a king and his delegates, but, equally important, they had to submit to standard procedures drummed in through constant repetition. In time, churches, schools, and factories made abundant use of these principles, and even in our own times this mode of organization is predominant in many areas of life.

War and the Centralized State

Artillery and firearms expanded the scope of warfare. Battles were more complex, organized affairs, while at the same time sieges became more elaborate. Both forms of warfare intensified logistical problems; according to one calculation, maintaining an army of 50,000 required the daily provision of 475 tons of food for soldiers and horses.²⁶ Bullets and powder also had to be readily available. This meant that an army required long supply lines, giving rise to continual strategic problems of maintaining these lines, as well as considerably enlarging the zone of military operations.

New forms of warfare greatly increased the cost of military campaigns. The feudal nobility had the means to pay for their own arms and armor, and a longbow did not entail large expenditures. In contrast, large contingents of musketeers and artillerymen required heavy financial outlays if they were to be adequately trained and equipped. In most cases only the monarch of a country could meet these demands.²⁷ At the same time, firearms gave centralized states a decisive advantage in expanding their territory and increasing control throughout their domain.²⁸ New weapons technologies thus reinforced the rising tide of nationalism, centralization, and royal absolutism that characterized European history from the sixteenth century onward. The converse was also true; the growth of the nation-state generated a large demand for improved weaponry. As Charles Tilly has summed up this positive feedback loop, “War made the state and the state made war.”²⁹

The active involvement of centralized governments was also evident in the standardization of weaponry. Prior to the seventeenth century, most soldiers did not wear uniforms and the weapons they used were of great variety. Successful military leaders such as Gustavus Adolphus and Oliver Cromwell strove to standardize weaponry and the other accoutrements of war. Standardization, however, often acts as a brake on technological progress. Once a gun or cannon becomes an army’s standard weapon, its replacement or substantial modification requires a multitude of parallel changes. Not only will the weapon’s auxiliaries, such as bullets, have to be changed, but so will a host of procedures, as well as the culture that has

grown up around it. Soldiers, like the rest of us, can become quite attached to doing things in a particular way, and they may be especially prone to adhere to established routines when engaged in such an inherently risky business as warfare.

Accordingly, the revolutionary changes brought on by the use of gunpowder lost momentum. During the eighteenth and early nineteenth centuries, improvements in weapons were few and far between. The invention of rifling—cutting a spiral groove inside the barrel to impart a spin on a bullet—greatly improved the accuracy and range of firearms, but they did not supplant the traditional musket. The “Brown Bess” flintlock musket remained the standard English infantry weapon for 160 years before it was replaced by breech-loading rifles (in which the bullet is loaded from behind the barrel, rather than through the muzzle) during the mid-1800s. Artillery fared no better; according to A. Rupert Hall, “The guns of Queen Victoria’s wooden ships were capable of little more accurate practice than those of Drake’s fleet which defeated the Armada.”³⁰

Yet after decades of stagnation, military technologies changed dramatically during the long reign of Queen Victoria (r. 1837–1901). The invention of bullets that expanded as they were fired made rifled firearms much easier to load because bullets did not have to be laboriously rammed into the bore. The development of breech-loading weapons had the added benefit of allowing soldiers to remain prone while reloading instead of standing upright, where they presented a conspicuous target. Improved powders produced higher muzzle velocities, allowing the use of smaller bullets and lighter firearms. These new powders also had the advantage of being smokeless, so a soldier did not give away his position when he fired. But none of these changes can be attributed to developments exclusively within the realm of weapons production; they were products of an emerging industrial order, and as such, they will be considered in greater depth in Chapter 17.

Technological Change and Naval Culture in the Era of the Battleship

While land warfare in the nineteenth century was being transformed by the use of new weapons, a similar revolution was taking place on the sea. One key element of this revolution was the use of steam engines to propel oceangoing vessels so they were no longer affected by the vagaries of the winds. Moreover, steam propulsion was the perfect complement to steel construction, since the new energy source allowed the construction of much larger and heavier ships. The ships used by England's Admiral Nelson at the beginning of the nineteenth century displaced 2,000 tons at most; by the 1860s, such ships were up to 9,000 tons, and by the end of the century they displaced 20,000 tons.³¹

Ships of this size were able to carry a formidable array of guns, made more accurate and rapid firing by rifling, breech-loading, and improved powders and projectiles. All of these developments reinforced a trend that had begun when significant numbers of cannon first began to be mounted on ships during the sixteenth century. Before this time, the traditional pattern of naval combat had been based on closing with the enemy vessel (ramming it if possible), boarding it, and then subduing its crew through the naval equivalent of battlefield combat. Ship-mounted cannon made these tactics obsolete; opposing ships now attempted to sink or disable their foe through long-distance cannon fire. Countries such as Spain and the city-states of Italy that clung to the old methods of combat put themselves at a great disadvantage, and over time the naval balance of power began to shift to England and the other nations that embraced the use of shipboard artillery.³² By the beginning of the twentieth century, the steam-powered battleship with its collection of heavy ordnance had become the very embodiment of modern weaponry, the most fearsome military artifact the world had ever seen. More than simply a weapons system, it came to symbolize a nation's armed might, both for traditional naval powers like England and aspiring ones like the United States and Japan.

As with any profound technological change, the development of the

battleship presented numerous problems of adjustment. Modern navies became dependent on the availability of coaling stations located along their areas of operation, and this gave a strong impetus to imperial expansion, an expansion that was facilitated by growing naval power. Navy officers basked in the reflected glory of modern warships, but at the same time, the modern naval vessel forced changes in military routines that were accepted with great reluctance. In the days of sail, a seaman's life revolved around a unique set of routines that had imbued navies with a distinct culture. Steam changed many of these; many sailors were now little more than floating factory workers—stoking coal, watching gauges, and keeping the machinery in good repair.³³ The result was a serious erosion of traditional maritime virtues, and the eventual replacement of old-guard officers with more technically minded ones. Just as the longbow and the gun destroyed the medieval knight and the culture of chivalry, advances in naval technology put an end to a way of life that had been common to generations of sailors.

Weapons and the Making of the Modern World

All these military innovations changed the conduct of war markedly. Although the full implications of new military technologies were not always quickly grasped by military planners in Europe, they were put to devastatingly good use abroad by the European armies and navies that brought large portions of Asia and Africa under imperialist domination. The technological superiority of Western military forces was clearly demonstrated during the first Opium War (1839–1842), when the cannon of British gunboats battered down Chinese fortifications and the superior firepower of British soldiers routed a numerically superior Chinese army. A single British ship armed with two 32-pound cannons destroyed nine war junks, five forts, a shore battery, and two military stations—all in one day.³⁴ China, the originator of gunpowder and many other advanced martial technologies, had fallen woefully behind the Western world—and paid the price in its subjugation by the West.

By the second half of the nineteenth century, the technological gap between the Western powers and the rest of the world had grown even larger. Improved weaponry and military auxiliaries like the steamboat, railroad, telegraph, and medicines for the treatment of tropical diseases sharply divided the world into winners and losers. Nations with industrial economies were able to expand their domains to the point that, by 1914, European nations directly or indirectly controlled most of the world's landmass. The disparity in military capability was most marked in Africa, where breech-loading repeating rifles allowed small military contingents to prevail over native troops that at best were armed with flintlock muskets, and often with only spears and shields. Numerous instances could be cited of a few hundred European soldiers utterly routing native armies that numbered in the thousands.³⁵ To take the most prominent example, in 1898 at the Battle of Omdurman in the Sudan, a British force, assisted by a gunboat on a nearby river, confronted 40,000 Dervishes. After five hours of combat, 48 British soldiers and their Egyptian allies had been killed. For the Dervishes, the

battle was more costly; more than 10,000 of them lay dead.³⁶

The most effective weapon of European imperial advance was the machine gun. Used sparingly during the American Civil War, the machine gun came into its own during the colonial wars of the late nineteenth and early twentieth centuries, when a single gun crew could cut to shreds any native force foolish enough to attack them. But little did the bearers of “the white man’s burden” realize that this product of Western ingenuity would soon be used against their own kind. Smug with the belief that the machine gun took its lethal toll when directed only against “lesser breeds of men,” Europeans were slow to realize that the machine gun had transformed the conditions of warfare.³⁷ That realization came with frightening force during the first years of World War I, as generals on both sides continued to hurl their troops against enemy lines fortified by machine gun nests. The result was an appalling slaughter, as attested by 60,000 British casualties during the first day of the Battle of the Somme.

While the machine gun was rewriting the rules of land warfare, the submarine was doing the same thing to war on the sea. Slipping beneath the ocean’s surface and firing its torpedoes at enemy ships blind to its presence, the submarine defied all of the conventions of naval combat, as well as the international laws that covered the attack of commercial vessels. Instead of adhering to established prize rules that stipulated that passenger and crew be allowed to board lifeboats before the sinking of their ship, submarines remained beneath the surface and summarily sunk their unsuspecting prey. The submarine was the cornerstone of Germany’s naval strategy, and during World War I their U-boats wreaked havoc on Allied shipping. But Germany’s success was fleeting; unrestricted submarine warfare ultimately brought the United States over to the side of Britain and France in 1917, decisively tipping the military balance in their favor.



Corbis

A World War I machine gun crew wearing gas masks deployed during the catastrophic Battle of the Somme.

At the same time that improved artillery and the machine gun were bringing new horrors to the battlefield, the airplane was beginning to demonstrate what modern technologies could do to civilian populations. First confined to observation and reconnaissance, by the third year of World War I aircraft were being employed as strategic weapons. Bombs dropped on England from German airplanes and Zeppelins killed about 1,400 people and injured another 3,400, as well as doing a fair amount of material damage.³⁸

Later wars were to eclipse these figures by huge margins. Even before the first atomic bomb was dropped, American bombing attacks on Japanese cities during World War II killed at least 260,000 and injured 412,000, and destroyed 40 percent of 66 cities' built-up areas.³⁹ A single incendiary attack on Tokyo destroyed more than a quarter-million buildings, killed 84,000, injured more than 40,000, and left more than a million homeless.⁴⁰ On August 6, 1945, the first atomic bomb was dropped on Hiroshima, killing an estimated 66,000 people, injuring as many more, and destroying half of the city. A second A-bomb had similar results when it was detonated over Nagasaki three days later.⁴¹

Aerial bombardment also devastated much of Germany. Tens of

thousands of bombs were dropped on urban industrial centers, leaving thousands dead and many more homeless. A single raid on Berlin that took place toward the end of the war may have killed as many as 25,000 civilians.⁴² Yet it is evident that for all the destruction it wrought, the bombing of industrial centers with large civilian populations during World War II was not the decisive factor in winning the war in Europe. In part, this was due to the inaccuracy of strategic bombing; only about 30 percent of the bombs dropped from American bombers landed within 1,000 feet of their intended targets.⁴³ Although large portions of cities were leveled and many industrial plants were damaged or destroyed, German industry was never brought to its knees. Many factories were put quickly back into operation after apparently having been destroyed, and substitutes were found for components that could no longer be produced. German industrial production increased each year until 1944, reaching its highest level in the year when Allied bombardment was at its greatest. Despite massive bombardment in 1944, German industry produced three times as many military aircraft, five times as many armored vehicles, and eight times as many artillery weapons as it had in 1941.⁴⁴



Corbis

Hiroshima in the aftermath of the first use of an atomic bomb.

Equally important, civilian morale never broke down in the face of continual air raids. It may even have been the case that bombardment resulted in a stiffening of the German and Japanese resolve to continue the war. Although there is ample room for debate concerning its contributions to winning World War II, there is little doubt that strategic bombing failed to live up to the extravagant claims made by its proponents prior to the war. The official U.S. Strategic Bombing Survey that was conducted after the war noted the accomplishments of strategic bombing, but it also called attention to its costs and shortcomings. In Walter Millis' words, "It would probably be fair to summarize the net conclusion as showing that strategic bombing, when armed only with TNT and incendiary weapons, had involved much greater casualties and had produced much smaller military results than had been expected."⁴⁵

Part of the explanation for this ineffectiveness lies in the nature of long-term bombing attacks. According to B. H. Liddell Hart's analysis, strategic

bombing with conventional weapons puts pressure on an enemy but does not produce the decisive result that comes with a sudden shock. Instead of producing quick, widespread results, strategic bombing, even if it results in considerable devastation, only increases pressure slowly. But, as Liddell Hart noted, “Human beings have an almost infinite power of accommodation to degradation of living conditions, so long as the process is gradual.”⁴⁶

Yet, once again, technology has altered the rules of war. Missiles with nuclear warheads are shock weapons of the greatest magnitude. A nuclear war would be like no other war of the past, and would result in death and destruction on a scale that can scarcely be imagined. A single one-megaton bomb would dig a thousand-foot-wide crater to a depth of 200 feet. No structures would be standing within a radius of nearly two miles, and damage would be heavy for a considerable distance beyond this. If the area had a normal urban population density, at least 200,000 people would be killed immediately, and half a million would be injured. Fires would spread through the city, killing thousands more. After this initial shock, radiation would spread through the area, killing many more in a few weeks or months. And, of course, this would not be an isolated attack.

The arms race between the United States and the Soviet Union culminated in the two countries collectively amassing an arsenal of over 4,000 nuclear-tipped ballistic missiles, along with hundreds of manned bombers and cruise missiles with nuclear capabilities. If even a small number of them had been used in anger, devastation would have been immense.⁴⁷ The basic structures of society would undoubtedly have snapped under the strain, leaving civilization perched on the threshold of barbarism. Had this happened, it might have been better if mankind’s long history of technological advance had never occurred. Wars of the past, whatever their horrors, at least left some room for individual valor; a nuclear war would be depersonalized, push-button destruction on a massive scale. In this way, nuclear warfare would be a culmination of an important trend of military technology.

Increasingly sophisticated weapons have opened the psychological distance between the warrior and his victims. To some extent at least, modern warfare can be seen as an extreme example of the rational mindset discussed in Chapter 1, the psychological distancing of oneself and one’s actions from

the people and things that suffer the consequences of these actions. In the past, the inhabitants of a village might be slaughtered by troops wielding swords and axes; today the same thing can be accomplished by dropping an incendiary bomb or launching a drone from an altitude of 25,000 feet. The result is the same (or worse), but soldiers, sailors, and airmen, as well as the engineers who have designed their weapons and the political leaders who sent them into battle, are removed from the fray. As Charles Lindberg reflected after flying a World War II bombing sortie, “You press a button and death flies down.... How can there be writhing, mangled bodies? How can this air around you be filled with unseen projectiles? It is like listening to a radio account of a battle on the other side of the earth. It is too far away, too separated to hold reality.... In modern war one kills at a distance, and in so doing he does not realize that he is killing.”⁴⁸

QUESTIONS FOR DISCUSSION

1. Can any equivalents of medieval knights be found today? In what ways do they resemble medieval warriors? How do the technologies they use shape their activities and attitudes?
2. The use of gunpowder changed the nature of warfare and played a significant role in the transformation of European society. Yet in China, its land of origin, gunpowder did not have this effect. Why do you think this was so? Can you think of any possible differences between medieval Europe and traditional China that might have been responsible for their different experiences?
3. To make effective use of firearms, soldiers had to be well-drilled and subjected to rigid discipline. How have military models of organization influenced nonmilitary social institutions? What are the advantages and disadvantages of military styles of organization when they are applied elsewhere?
4. For all of its horrors, war has historically provided opportunities for people to demonstrate some real virtues, such as resourcefulness, initiative, and courage. Have modern military technologies made these virtues irrelevant? If so, does the loss of these virtues make war more absurd than ever before?
5. To what extent, if any, should an engineer feel a sense of individual responsibility for designing a weapon that is used to kill large numbers of people? What about the combatant who is ordered to use the weapon? Do the citizens whose taxes were used to design and build the weapon also bear some responsibility?

CHAPTER SIXTEEN

| The Era of Smart Weapons

The last chapter noted that advances in military technologies have created a spatial and often a psychological gulf that has separated combatants from the consequences of their actions. This trend has intensified in the opening years of the twenty-first century. To be sure, much of the burden of fighting still falls upon infantry soldiers close to the action, but a great amount of killing and destruction is now done by remote control. Moreover, although many combatants were detached from the consequences of their actions in past wars, their own lives were at risk. In World War II, aerial combat was a highly dangerous enterprise in which 19,876 American airmen lost their lives in the European Theater of Operation alone, a toll greater than the number of U.S. Marines killed in the Pacific Theater.¹ Today's weapons have removed much of that risk, but their use has been the source of many strategic, political, legal, and ethical issues.

Cruise Missiles

Although some of its functions have been taken over by unmanned aerial vehicles (discussed next), cruise missiles remain crucial components of a modern nation's arsenal. Cruise missiles are relatively small pilotless craft that can be launched from land, submarines, surface vessels, and aircraft. Through the use of sophisticated navigation devices, cruise missiles can hone in on their target while eluding radar detection by flying close to the ground. Some cruise missiles are capable of supersonic speeds and many are capable of delivering nuclear weapons.

As with many other technologies, the concept underlying cruise missiles has been around for a long time, but its practical realization required the development of many complementary technologies. Back in 1917, Charles Kettering—who later headed General Motors research laboratories—demonstrated an “Aerial Torpedo” that came to be known as the “Kettering Bug.” Built largely out of papier-mâché with cardboard wings, the Bug was powered by a 40 horsepower engine and carried 300 pounds of explosives. Although several dozen were manufactured, none saw action during World War I. The first operational cruise missile appeared during World II in the form of Germany's V-1. Powered by a simple pulse-jet engine and stabilized by a gyroscope, the V-1 had a top speed of about 400 miles per hour and a range of 200 miles. From 1944 to the end of the war, about 10,000 were launched at England, of which 2,410 reached London, where they killed more than 6,000 and injured nearly 8,000.² Unlike the rocket-powered V-2, the V-1 flew at subsonic speeds, which made it vulnerable to attacks by fighter pilots, who either shot it down or sent it out of control by putting their plane's wingtip under its wing and flipping it.



The LIFE Picture Collection/Getty Images

A Tomahawk cruise missile being fired from a truck-mounted launcher. Each missile can be armed with a conventional or nuclear warhead.

Although a single cruise missile can cost more than a million dollars, their use has been ordered on several occasions by American presidents who wanted to take action against a country or an insurgent group but were reluctant to put American soldiers, sailors, and airmen in harm's way. On

several occasions, cruise missile strikes were directed against Serbian forces during the conflicts that followed the breakup of Yugoslavia in the early 1990s. Since then, the major theater of operations for cruise missiles has been the Middle East. Two hundred eighty-eight Tomahawk cruise missiles were launched during the 1991–1992 Gulf War, which was waged to repel Iraq’s occupation of Kuwait. Cruise missiles were also fired from U.S. Navy vessels in the Arabian Sea in 1998 to attack suspected al-Qaeda sites in Sudan and Afghanistan in retaliation for the bombing of U.S. embassies in Kenya and Tanzania. Cruise missiles again targeted Iraq when 725 were launched by the United States when it invaded that country in 2003.³ More recently, cruise missiles have been used by the United States, Russia, and France to attack Islamic State (i.e., ISIS) positions in Syria and Iraq.

Smart Bombs

As we saw in the previous chapter, the expectation that the strategic bomber would be the decisive weapon of war was thwarted by the inaccuracy of bombing attacks. What was needed was an unpowered explosive device that could be accurately guided to its target. Germany developed such a weapon during World War II, the FX-1400 “Fritz,” a four-winged glide bomb that targeted armored ships. With a warhead containing 660 pounds of explosives, it was dropped from an airplane and steered by radio. In 1943, it succeeded in sinking an Italian battleship that was attempting to defect to Allied forces after Italy’s surrender. It went on to sink or damage several more ships, but the vulnerability of the airplane carrying the flying bomb limited its deployment.⁴

During the 1950s, advances in solid-state electronics created new possibilities for remote-controlled ordnance. The first “smart bombs,” or “precision-guided munitions” (PGMs), to use the military’s preferred term, employed a television camera to provide a bomb’s-eye view of the terrain below. The bomb could then be guided through the use of steerable fins as it zeroed in on its target. In the 1960s, the emerging technologies of lasers and integrated circuits were employed in a new generation of PGMs. These achieved a fair measure of success during the Vietnam War when strategic targets such as bridges that had withstood dozens of conventional bombing attacks were brought down by a few laser-guided bombs. The capabilities of PGMs were further demonstrated during the Gulf War when television viewers got a real-time view of targets being destroyed by a smart bomb. These attacks made for good television, but in reality, most bombing attacks used conventional “iron bombs.”

Whether guided by television or a laser, PGMs were ineffective when adverse weather conditions obscured an intended target. This deficiency began to be overcome through the use of another emerging technology, Global Positioning Systems (GPS), for the guidance of a bomb’s trajectory. Yet, as ever, defensive countermeasures were adopted; the intended victims of a PGM were often able to jam the radio signals guiding the bomb, forcing

it to depend on its less accurate internal navigation system to guide it to its target.

Cruise missiles and smart bombs seem to have realized the prophecies made back in the 1920s and 1930s by the early apostles of air power. With the emergence of solid-state electronics, onboard computers, and GPS navigation, the dream of precision bombing has become a reality. But pinpoint accuracy is of no value if military intelligence fails to accurately identify a target's location. During the invasion of Iraq led by the United States in 2003, at least 50 "decapitation strikes" using precision-guided weaponry were launched with the intent of killing Saddam Hussein and members of his leadership cadre. None of the targeted individuals was hit, but dozens of civilians died or were injured as a result of these attacks.⁵ Although his country's military was decisively routed after a few days of fighting, Saddam Hussein was able to evade capture for many weeks, until he was finally caught by ground troops acting on information derived from the interrogation of his former bodyguards and members of his family.

A tragic example of smart weaponry and defective intelligence came in 1988 when crewmen aboard the USS *Vincennes* in the Persian Gulf identified what they thought was an Iranian Air Force F-14A. Attempts at radio contact were unsuccessful, and under the impression that they were about to be attacked, crewmen aboard the *Vincennes* fired two SM-2MR surface-to-air missiles at the presumed attacker. The missiles accurately honed in on their target and destroyed what turned out to be a civilian Airbus A300 bound for Dubai. All 290 passengers and crew, including 66 children, were killed. Although there had been some ambiguity about the identity and intentions of the aircraft, it is evident that the crew of the *Vincennes* made critical mistakes when assessing the situation, errors that were compounded by the attitude of the ship's captain, who had a known penchant for aggressive and even reckless actions. The United States, while not apologizing for what had happened, eventually paid reparations amounting to \$131.8 million. Two years after the incident, the Navy awarded the retiring captain with the Legion of Merit for his service in the Persian Gulf.

High-Tech Surveillance

The tragic fate of the crew and passengers on the airliner brought down by a “smart” weapon is one of untold numbers of breakdowns in military intelligence. Throughout history, military operations have been hampered by an inability to effectively identify and track an enemy. One technological response to this age-old problem has been the development of satellites capable of providing highly detailed views of Earth’s surface. Although much of the information about the performance of these satellites is cloaked in secrecy, a general understanding of their capabilities can be derived from nonclassified sources. The first “reconnaissance satellites,” to use their official name, used film cameras to record features on Earth’s surface. The exposed film was ejected and captured in midair by specially equipped aircraft. Subsequent generations of satellites have used digital imagery that can be directly relayed to stations on Earth. Satellite-based spying by the United States is the responsibility of the National Reconnaissance Office, an agency so secretive that its existence was not publicly acknowledged until 1992, and much of its budget is “black,” known to only a small number of elected representatives and government officials.

At the outset, America’s satellite program was aimed at the surveillance of the Soviet Union, although it was originally presented as a means of collecting scientific data. Officially known as the Discovery Project, this supposedly scientific endeavor was in reality a facade for the Corona spy satellite program, which over the years relayed many highly detailed pictures of militarily significant sites.⁶ In recent years, satellites and the ability to launch them have developed to the point where commercial firms are able to deploy satellites that can relay images nearly as good (and often at lower cost) as those produced by the National Reconnaissance Office. This has led to considerable disagreement within the government regarding how much satellite surveillance should be handed over to private firms.⁷

Drones

Although it is possible that the most current spy satellites are capable of retrieving images even when clouds obscure Earth's surface, their orbits limit the amount of time they can be within range of an area of interest.

Consequently, they cannot be expected to provide up-to-the-minute images of particular locations. For these, the military has made increasing use of low-flying unmanned aircraft that are collectively known as drones, or unmanned aerial vehicles (UAVs) in military parlance. Some of these craft are the size of a conventional airplane, while others are no bigger than a radio-controlled model airplane. Classified research is also being done on drones that are no bigger than a large insect but are equipped with sensors and miniaturized cameras that offer the prospect of getting inside a building and obtaining information about its interior.⁸ In addition to being used for aerial surveillance, some drones are able to fire missiles, and others are intended for "suicide missions" in which they crash into a target.



U.S. Air Force photo/Tech. Sgt. Erik Gudmundson

An MQ-9 Reaper landing after a mission in Iraq. A widely used drone, the Reaper is 36 feet long with a wingspan of 66 feet. It can carry 3,800 pounds of reconnaissance gear or 14 Hellfire air-to-ground missiles.

The absence of a pilot and a support system means that UAVs can be lighter than a manned airplane, allowing them to fly higher and at greater distances while staying aloft for long periods of time. The use of reconnaissance drones goes back to the Vietnam War, where the Fire Fly

drone flew 3,435 missions, but insufficient research was done to accurately adjudge their effectiveness.⁹ Widespread awareness of drones and their capabilities came with the American invasion and occupation of Iraq. There, Predator drones logged hundreds of thousands of air miles annually. So extensive has been the use of UAVs in recent years that in 2009, Secretary of Defense Robert Gates stated that the U.S. Air Force was training more drone pilots than pilots of conventional aircraft.¹⁰

As noted earlier, in addition to their ability to gather accurate and up-to-date information, drones have the added attraction of serving as offensive weapons. Hellfire missiles carried by Reaper UAVs have been effectively used as antitank weapons. More significantly, drone strikes have also been used in Somalia, Yemen, Afghanistan, and the tribal areas of Pakistan to kill suspected al-Qaeda and Taliban insurgents. These attacks have also produced considerable “collateral damage,” especially the deaths of civilians, as admitted by John Brennan, the Obama administration’s counterterrorism adviser.¹¹ The extent of these deaths has been a matter of contention. One rough estimate made in 2015 based on averaging casualty counts of three independent organizations indicated that 522 drone strikes resulted in 3,852 deaths, of which 476 were civilians.¹² Although drone strikes are widely supported by the American public, many critics believe that they have engendered considerable anti-American sentiment within the Middle East.¹³



Getty Images News/Getty Images

A drone pilot trains at Creech Air Force Base in Nevada. Drones used for missions in Afghanistan, Iraq, and Pakistan are also piloted at this base.

One of the striking things about the use of drones as offensive weapons is that they are “flown” by “pilots” who are situated on the ground thousands of miles from their targets. Drone attacks on Afghanistan and Pakistan are controlled from Nellis Air Force Base in Nevada, where pilots guide their craft and fire their onboard missiles while sitting in front of television monitors. At a superficial level at least, this ability to engage in remote-control warfare has made combat seem like just another high-tech job, but this is hardly the case for drone pilots, who complain about fatigue, high levels of stress, and poor prospects for promotion.¹⁴

The Cost of Technological Sophistication

The ethical and legal issues engendered by the use of UAVs and other advanced military technologies will be discussed later in this chapter, but first, we will consider a more mundane yet still significant aspect of high-tech weaponry, the financial burden that they place on governmental budgets.

In the opening decades of the twenty-first century, the United States has at its command the most formidable collection of weaponry in human history. But do cruise missiles, smart bombs, imaging satellites, and UAVs guarantee security in an unstable world? Military strength is undeniably important, but a healthy economy is also essential for national well-being. The decision to orient government policies toward either military strength or a thriving civilian economy has been (erroneously) attributed to the nineteenth-century German Chancellor Otto von Bismarck as the choice of “guns or butter.” From the 1940s onward, the United States has not stinted when it has come to the acquisition of guns and other weapons of war. In absolute terms, the defense budget of the United States is enormous, coming in at \$495.6 billion for fiscal year 2015.¹⁵ This amounts to about 4.35 percent of the country’s gross domestic product, less in percentage terms than defense expenditures at the height of the Cold War but still a lot of money, more than one-third of the world’s collective military expenditures.¹⁶

There are many reasons for such a large budget, but there is no question that technology has been a major driver. As we saw in Chapter 3, a single Air Force F-22 fighter costs U.S. taxpayers \$412 million when research and development (R&D) and testing costs are taken into account. This is a far cry from the World War II era, when a P-51 Mustang cost about \$650,000 in today’s dollars. Much of the difference between the two airplanes can be attributed to vast improvements in engine power, materials, armaments, avionics, ability to evade radar, and all of the other technological advances that separate the World War II era from the present day. But can such cost increases be sustained indefinitely? This question was answered by Norman Augustine, an aerospace executive and former undersecretary of the Army, who plotted the increasing cost of fighter planes over time. Extrapolating into

the future, he noted: “In the year 2054, the entire defense budget will purchase just one aircraft. This aircraft will have to be shared by the Air Force and Navy 3½ days each per week except for leap year, when it will be made available to the Marines for the extra day.”¹⁷

Other examples of high-priced military hardware are not hard to find. The development and production costs for the 74,000 bombs that comprise the current generation of PGMs used by the U.S. Air Force and Navy come to more than \$4.65 billion.¹⁸ A single M1A2 Abrams battle tank costs \$6.2 million,¹⁹ and a fleet of ten nuclear attack submarines comes with a price tag of \$17.6 billion—if there are no cost overruns.²⁰

A less obvious cost of a technologically advanced military force is the large number of scientists and engineers who are engaged in defense R&D. In a world in which scientific discoveries and technological innovations are crucial for economic advance, a lot of talent is expended on projects and activities with little or no relevance to the civilian economy. There have always been spin offs from the defense to the civilian sector—DARPA’s (Department of Defense’s Advanced Research Projects Agency) early sponsorship of what became the internet is a recent example—but most defense R&D remains confined to that sector.

It is an irony of modern technology that the military sector, which is tasked with death and destruction, bears a number of similarities with medical care, which is supposed to be about health and healing. In both cases, there is a strong tendency to be satisfied with only the most sophisticated technologies, which usually means the most expensive technologies. A fighter pilot does not want to engage an enemy who is flying the world’s best combat aircraft when he is in the seat of the world’s second-best airplane, just as a patient suffering from a life-threatening disease would not be happy with the second-best medical treatment. The two sectors also receive much of their funding from third parties—insurance companies and local, state, and federal governments in the case of medical care, and the federal government for military expenditures. It also has to be noted that both the medical and the defense sectors are prolific spenders on lobbying efforts when they interact with Congress and other agencies. More politics is involved when some projects owe their existence to their location in states and districts represented by influential members of Congress.

Asymmetrical Warfare

High defense expenditures may be justified as the cost of protecting a country and its inhabitants, but to what extent does modern weaponry make a nation more secure? Military engagements in recent decades, most notably the Vietnam War, showed that wars are not won by advanced technologies alone. Since the Korean War, the United States has been engaged in a number of conflicts that can be characterized as “asymmetrical warfare,” engagements where the United States was vastly superior in the quantity and quality of its matériel. In regard to quantity, during the Vietnam War, the United States dropped 7.8 million tons of bombs in Indochina, far more than the 2.7 million tons dropped by the Allies against Axis targets during World War II.²¹ The United States also was vastly superior to North Vietnam in military technology. Infrared goggles gave American soldiers the ability to see in the dark, smart bombs destroyed their targets with pinpoint accuracy, and surveillance satellites and first-generation drones provided detailed views of the terrain below. More recently, during the invasion of Iraq in 2003, Saddam Hussein and his military forces were quickly routed by a “shock and awe” campaign waged with cruise missiles, smart bombs, depleted uranium ordnance, and many other examples of advanced military technology. But these weapons did little to quell the subsequent insurgency that took place during the coalition occupation, resulting in the deaths of 4,495 Americans, 320 British, and others.²²



PALMER/SIPA/Newscom/Sipa Press/Near FOB Kalsu
North Babil Iraq

Improvised explosive devices (IEDs) may be triggered remotely with this simple cell phone–based detonator.

In Iraq and Afghanistan, the insurgents' principal weapon has been the improvised explosive device, or IED, planted in a roadway. Early versions consisted of nothing more than explosives connected by wire to a detonator. Later examples were more sophisticated; some used timers or wireless triggers such as modified car door lock openers and cordless telephones so a wire could not be followed to where the insurgents were hiding. Over time, Iraqi insurgents devised more than 90 ways of setting off an IED. Coalition forces were eventually able to deploy robots to disarm IEDs, but even these could be thwarted by placing roadside bombs so they were out of the robots'

reach.²³

Technology and Terrorism

In some quarters, justification for the invasion of Iraq rested on the assertion that Saddam Hussein had conspired with al-Qaeda to attack the World Trade Center in New York City and the Pentagon on September 11, 2001. This supposed conspiracy was unlikely from the start, but the belief persisted long after it was proven to be a fabrication. It did, however, focus the world's attention on a new set of security issues. While the spread of nuclear weapons among established nation-states remains a grave potential threat, the world is now focused on a different source of danger—global terrorism. Terrorism is closely related to asymmetrical warfare in that a militarily weaker side is able to challenge a stronger one through the use of simple but effective weapons such as roadside bombs and car bombs. Terrorism is not a new phenomenon; a depressing litany of examples can be found throughout human history. What has changed in recent years is the increasing technological sophistication of terrorists and their use, or potential use, of weapons of vastly greater destructive power.

Nuclear weapons are unparalleled in their destructive power, and the acquisition of a multimegaton atomic bomb would provide terrorists with the ultimate weapon. At the same time, however, the likelihood of this happening is relatively low. The construction of a nuclear bomb requires a high degree of expertise and access to specialized equipment, along with the production of sufficient quantities of fissionable materials like plutonium or uranium-235. The production of a workable bomb is likely to be beyond the capabilities of terrorist groups lacking the assistance of a nation that already has nuclear weapons, but fissionable material for a crude bomb could be bought or stolen. A terrorist group does not need a military-grade nuclear bomb to induce widespread terror and panic; the detonation of a “dirty bomb,” a conventional explosive device that would spread radioactive materials like cesium-137, iridium-192, or cobalt-60, could induce radiation sickness on a significant scale.²⁴ More importantly, it would engender panic over a wide area even if actual loss of life were not great. Since the primary goal of terrorist organizations is to spread fear and disruption, a bomb of this sort would be a highly effective weapon.

Much easier than the development of nuclear weapons are the

manufacture and use of chemical weapons. Poison gas was not deployed as a combat weapon during World War II, although it was used in the 1920s and 30s by Spain and Italy to subdue indigenous populations while securing and expanding their colonial possessions.²⁵ Poison gas reemerged as an offensive weapon when Saddam Hussein used it during the Iran–Iraq War (1980–1988) and then against the Kurdish population of his own country in 1988. Saddam’s weapon of choice was a combination of mustard gas and one or more nerve agents: sarin, tabun, and VX.²⁶

In general, chemical weapons fall into four main categories: nerve agents; blood agents, notably hydrogen cyanide and cyanogen chloride; blister agents, like the mustard gas that was first used in World War I; and choking and incapacitating agents, such as chlorine, another gas used in that war.²⁷ Up to now, the most destructive use of a chemical weapon by a terrorist organization occurred in March 1995 when a Japanese religious cult known as Aum Shinrikyo (Aum Supreme Truth) released sarin gas into the Tokyo subway system, killing 12 and injuring more than 5,000. In the years leading up to the attack, the sect had accumulated considerable expertise in the manufacture of sarin and other chemical weapons, an endeavor that was facilitated by having a number of scientists and engineers in its ranks. At the same time, however, the mode of delivery was distinctly low-tech, entailing nothing more than placing plastic bags containing sarin in five subway cars and then puncturing them, allowing the volatile liquid to disperse as a lethal vapor.

The third category in the unholy trinity of terror weapons consists of biological weapons. The list of these weapons is extensive, including bacteria that are the sources of anthrax, tularemia, and plague, and viruses that cause smallpox, yellow fever, dengue fever, and Ebola. All of these are capable of producing death and grave injury, but the most effective weapon employed so far has been the bacteria that cause salmonella, a much less lethal disease. This was used by a group of religious extremists in Oregon in 1984 to contaminate salad bars in local restaurants in the hope of incapacitating a large number of people prior to a local election.



Noboru Hashimoto/Corbis

Workers decontaminate a Tokyo subway car after the 1995 sarin gas attack perpetrated by Aum Shinrikyo.

As with chemical weapons, biological weapons are easy to manufacture, and they certainly do not require the assistance of a “rogue state.” Biological weapons can be made in small facilities using little in the way of sophisticated equipment, and the basic materials can be obtained from commercial sources or cultivated from naturally occurring sources.²⁸ Effective distribution is more problematic, however. Even if there were effective means of spreading the pathogens, contaminating a large area would be difficult because most of the released organisms would not survive for long (anthrax is an important exception, because its spores can survive for an indefinite period). Most biological agents are not highly infectious and generally require close contact or exposure to bodily fluids for transmission. But biological weapons do not have to operate at a high level of effectiveness and efficiency; as with terror weapons in general, their significance lies in their ability to spread fear on a massive scale. The novelty of biological weapons and the fear engendered by an invisible attacker, coupled with the difficulty of administering antidotes or immunization on a large scale, makes them particularly attractive terror weapons.

Cyberterrorism and Cyberattacks

While modern technologies have enhanced the capabilities of terrorists, they also have created new vulnerabilities for these terrorists to exploit.

Technologically sophisticated societies are highly dependent on a variety of infrastructures, such as electrical grids run by computers and other digital devices. In the defense sector, a nation's ability to protect itself rests heavily on computer networks and equipment to detect an imminent enemy attack and take measures against it. The large-scale crippling of a country's computers would undercut the use of radar and other detection technologies, cut off military communications, and prevent the use of most weapons. In the civilian realm, the disabling of computers and their associated networks would bring chaos to transportation systems, communications of all sorts, banking and finance, manufacture, retail trade, and virtually every other aspect of modern society.

Dependency on computers and their networks can be exploited by terrorists through the use of tactics that fall into two broad categories: information attacks and infrastructure attacks.²⁹ Information attacks are attempts to access, destroy, or alter the information retained, processed, and distributed by computers and their networks. Some of these attacks are fairly trivial—such as the defacement of a Web page—and can be easily remedied. Others could pose a serious threat to national security if, for example, a terrorist gained access to vital information for espionage, or simply to destroy or alter it.

Infrastructure attacks are potentially more dangerous than information attacks because they can damage or disable critical services. Obvious targets are the computer networks essential to the distribution of electricity, gas, and water; air traffic control; and critical government services like policing and firefighting. Although much of this infrastructure is protected by the use of redundant networks, it would be overly optimistic to believe that these systems are invulnerable. There have been numerous occasions when individuals have done millions of dollars of damage by hacking into computer networks. As with the dangerous and expensive mischief caused by

these hackers, cyberterrorists also have the ability to infect computer programs and files with disabling and self-replicating viruses, worms, and Trojan horses.

A cyberattack planned and implemented by a sovereign country began in 2008 when the United States, working in collaboration with Israel, was able to introduce a computer worm (called Stuxnet) into the computers running centrifuges used by Iran for the enrichment of uranium. As a result, at least 1,000 centrifuges were put out of commission. The extent to which these attacks put a serious crimp in Iran's nuclear program is still a matter for debate, but they certainly did not put an end to it. Critics of the attack have pointed out that the unleashing of Stuxnet will lead to a new kind of arms race based on expanded abilities to launch and repel cyberattacks.³⁰ As we saw in the previous chapter, during World War II, there was a tacit understanding that the use of poison gas would be met with retaliation in kind, leaving the warring countries with no military advantage and more casualties. By launching a cyberattack, the United States and Israel gained a temporary advantage over a potential nuclear adversary, but it may have come at the cost of long-term security.

Another striking example of a major attack on a government network, but not one directly tied to military matters, occurred in 2015, when the computer network used by the U.S. government's Office of Personnel Management was breached, resulting in the exposure of personal information of 19.7 million federal employees who had undergone background checks, as well as 1.8 million others, including neighbors, friends, and spouses. The information collected included Social Security numbers, home addresses, past foreign travel, financial transactions, and even information about acquaintances.³¹ The source of the attack, if known, has not been revealed, although China is a prime suspect. If this indeed had been the case, it would not have been a terrorist attack per se, since by definition terrorism is the work of actors not directly connected to a legitimate state.

A modern nation-state's ability to launch a cyberattack can be seen as a continuation of a high-tech arms race that has been going on since the invention of gunpowder. In contrast, the development of this capability by terrorist groups poses a certain irony. A cyberattack requires a high level of technological sophistication for its planning and execution. In this sense,

terrorists are effective participants in the modern world. At the same time, however, in a number of countries and regions, the rapid development of a globalized and networked world has been viewed as a threat to established cultures and religious beliefs.³² The response of some disaffected groups and individuals has been to attack those nations that have been the source of the ideas and images diffused throughout the world via the internet and other electronic media. The so-called Islamic State (often rendered as ISIS, ISIL, or by an Arabic acronym Daesh)³³ has been particularly adept in this regard; every day on average it releases 38 items of digital propaganda into cyberspace—documentaries, photo essays, pamphlets, and audio clips in a variety of languages.³⁴

In considering the novel threats posed by cyberterrorism, along with nuclear, chemical, and biological weapons, it is important to keep in mind that effective terrorist attacks do not require the use of high-tech weapons. The destruction of the Alfred P. Murrah Federal Building in Oklahoma City in 1995 was accomplished by a bomb made from nothing more sophisticated than a mixture of ammonium nitrate fertilizer and fuel oil. The attacks on three railway stations in Madrid that killed nearly 200 people and wounded 1,450 on March 11, 2004, were done with conventional explosives. The horror of 9/11 entailed the destructive use of the embodiment of modern technology, a jet airliner, but the terrorists were able to hijack three planes by incapacitating their crews with nothing more sophisticated than a few small edge weapons.

Although chemical, biological, and even nuclear weapons do pose potential threats, it can be argued that modern technology's greatest contribution to terrorism has been the electronic media. Just as the internet, social media, and mobile phones have helped to peacefully unseat repressive dictators, they can also be employed to promote the goals of violent terrorists. Mobile phones have facilitated coordination of terrorist operations and have been used to detonate bombs, and the internet has been an invaluable means of recruiting terrorists to serve the Islamic State, presenting detailed information on how to make weapons and publicizing grievances and demands while extolling life in the caliphate. Above all, the global reach of television has brought terrorist acts into the consciousness of the whole world. The hundreds of millions of people who watched broadcasts of the

collapse of New York's Twin Towers after the 9/11 attacks were suddenly aware of the intent of Osama bin Laden and al-Qaeda to remake the world by waging holy war.

Military Technologies in a Changing World

Although the use of today's weaponry has extended the ability to kill and destroy to a level scarcely conceivable to earlier generations of warriors, many of the issues presented by advanced military technologies have been around for centuries, if not millennia. New kinds of weapons promise impressive tactical and strategic gains, but they have also called into question traditional martial virtues as they redefined what it means to be a warrior. As one Spartan king lamented when he witnessed the demonstration of an early catapult, "O Hercules, the valor of man is at an end!"³⁵ A similar attitude was expressed during the Middle Ages, when military leaders were infuriated by the insidious way in which crossbowmen and musketeers could pick off their soldiers from afar. Their anger was reflected in their harsh treatment of captured soldiers using these weapons, which often extended to cutting off their hands and having their eyes put out.

Needless to say, punitive measures and an occasional disdain for new weapons did not stem the advance of military technology. We continue to struggle today to find ways to limit the consequences of advances in military technology for soldiers and civilians alike. The development and spread of smart bombs, drones, cruise missiles, and the other components of high-tech warfare has raised many questions about the conduct of wars and individual warriors. One of the most striking changes centers on the ability to wreak havoc from halfway around the globe. The use of remotely controlled drones has put their pilots out of harm's way, but it has also engendered a psychological as well as spatial remoteness from the realities of warfare; a drone pilot may launch an attack on a suspected terrorist base, witness the ensuing destruction, and then go to a PTA meeting a few hours later.³⁶ The use of drones and other high-tech weapons also presents some thorny legal issues. Are drone pilots bona fide combatants, and if so, would that justify an enemy killing them in cold blood as they walked out the front door of their homes? Who is at fault when a drone or smart bomb is guided to the wrong target; is it the officer in the field who ordered the attack or the pilot in Nevada who flew an incorrect course? And who is to blame if innocent

civilians are killed because the program used to control a weapon had a glitch of some sort? Should the programmer who made the error be blamed for the loss of lives?³⁷ The use of drones and other robotic weapons may be counterproductive if it convinces an opponent that their adversaries are cowards who are unwilling to put their lives on the line in combat situations, thereby increasing the enemy's will to fight on.³⁸ Also, the effects of these kinds of weapons reprise a familiar theme of winners and losers amid technological change; younger soldiers who grew up with video games may take over the jobs and responsibilities of older soldiers whose skills have become less relevant.³⁹ Finally, and most disturbingly, by promising lower casualty rates, remote-control warfare may lower the inhibitions for going to war.

While high-tech weapons have presented a number of new issues and dilemmas, changing configurations of power have called into question their relevancy. For more than four decades after the conclusion of World War II, an immense amount of money and expertise was expended on defending the United States and its allies from a nuclear attack carried out by missiles and bombers. The dissolution of the Soviet Union in 1991 lowered global tensions and reduced the threat of a nuclear war, but in some respects, the world is a more uncertain and dangerous place than it was during the Cold War. Instead of facing one powerful foe, the United States and its allies have to contend with a multitude of potential adversaries. Some of them are nation-states, while others are terrorist organizations. None of them has anything like the military might once possessed by the Soviet Union, but many have the capacity to produce significant damage through the use of biological, chemical, cyber, and perhaps nuclear weapons.

Despite ongoing efforts to settle disputes without recourse to war, the world remains an unsettled place, torn by a multitude of grievances and disputes between and within nations. Many of these could erupt into wars made more destructive than ever by the use of increasingly lethal weaponry. While the possession of modern weapons may have a deterrent effect in cases of state-to-state conflict, the threats posed by terrorists are more problematic. Drones and reconnaissance satellites can identify areas that harbor terrorists, and missiles launched from drones can kill and injure suspected terrorists. At the same time, however, the dispersal of terrorist cells can make the whole

enterprise feel like playing Whac-a-Mole, the arcade game in which a mechanical mole is knocked back into its hole, only to be replaced by another one popping out of its hole.

In addition to the tactical difficulties of dealing with terrorists, there is the larger problem of living on a planet that includes people whose beliefs, anger, and grievances are the underlying source of terrorist attacks. There is no technological fix, military or otherwise, for this situation. As one former Army officer mused, “The great paradox of this high-tech age is that its security problems arise from the human heart and soul, domains which remain opaque to technology (and to those who worship it).”⁴⁰

For all of the present dangers engendered by terrorism, it is still the case that nuclear proliferation poses the greatest long-term threat to humanity. Despite, or perhaps because of, mutual hostility, the United States and the Soviet Union were able to forge a number of arms control agreements from the 1960s onward. At the same time, the prospect of mutually assured destruction further restrained whatever aggressive tendencies the two nations may have had. But while the Soviet Union is now a receding memory, other nations have advanced their ability to manufacture and deliver nuclear weapons. Preventing or at least limiting the further spread of these weapons will be one of the major tasks in the twenty-first century. Some of these efforts are explored in the next chapter, but before taking up this subject, we should know something about the forces propelling technological advance in weaponry. This will be the theme of the first part of the next chapter.

QUESTIONS FOR DISCUSSION

1. “Collateral damage,” in which innocent people are killed or injured and their homes destroyed, has been an inevitable feature of warfare. World War II was particularly lethal, as millions of civilians died as a result of enemy actions. Do modern weapons have the potential to reduce civilian casualties? If so, what prevents them from doing so?
2. Drones are now used extensively for reconnaissance in combat areas, and they can also be used by the police and private parties to gain information about activities below them. Do they pose a serious threat to privacy? Should anything be done to prevent or limit the use of drones?
3. A major goal of antiterrorist operations is to deny safe havens in countries or parts of countries that support or tolerate terrorists. Does harboring terrorists justify military actions that amount to waging an undeclared war on a sovereign power?
4. Could the United States survive an extensive cyberattack? Should the federal government take steps to limit the damage done by such attacks? What sort of things could be done to blunt the force and mitigate the consequences of a cyberattack?
5. In recent wars, the number of uniformed men and women engaged in support activities far outnumber those who are involved in combat. Are they really soldiers? What about drone aircraft operators who are located far from the field of combat?

CHAPTER SEVENTEEN

How New Weapons Emerge—And How They May Be Contained

The last two chapters outlined some of the consequences of technological change for the conduct of wars, as well as the effects of advances in military technology on the world as a whole. But what is the source of technological change in the military realm? Why has the development of weapons accelerated at such a frightening rate within our own lifetimes? Why have some weapons been adopted while others have languished? How have social and cultural conditions stimulated the development and use of some weapons and not others? In the first part of this chapter, we will try to address some of these questions, and at the same time provide some background for the last sections of this chapter, which deal with past and present efforts to limit the use of new weapons.

Action and Reaction

The most obvious reason for the development of new weapons is that combatants or potential combatants continually strive to gain the upper hand over their enemies through superior weaponry. When one succeeds in doing so, its enemies are strongly motivated to develop new weapons that can neutralize this new threat. New offensive weapons are countered by new defensive weapons, which in turn stimulate the development of better offensive weapons, and so on. The process is one of constant action and reaction, as rival nations thrust and parry, each seeking to neutralize their opponent's capabilities, while at the same time augmenting their own. The development of military technologies thus becomes an endless cycle in which each new weapon stimulates the invention of another, and the capacity to kill and destroy proceeds without limit.

History supplies us with many examples of this process. We have seen how the offensive power of the mounted knight was checked by the pike and longbow. Cannon threatened the security of medieval castles, until their destructive force was temporarily diminished by improved fortifications. The machine gun produced a stalemate during much of World War I, but the armored tank made the machine gun a much less potent weapon and tipped the balance back in favor of the offense. Since then, however, a number of military actions have powerfully demonstrated the vulnerability of tanks to precision-guided weapons.¹

Useful as this action–reaction schema is, it does not tell the whole story. In the first place, it is not always a simple matter to categorize military tactics as either offensive or defensive. When a war is being fought, the contestants do not neatly think in terms of offense and defense. Wars are won by defeating an enemy, which means offensive action, but at the same time, defensive measures are necessary to protect the capacity to wage an offensive campaign. And even if a country seeks to only protect itself from an aggressor, it may still find it necessary to go on the attack, for as the old maxim has it, “The best defense is a good offense.”

In similar fashion, many weapons can be used for either offensive or

defensive purposes. For example, the possession of a more accurate, faster-firing gun may allow an army either to rapidly advance against the enemy or to more easily defend their positions in the face of enemy attack. Also, a strong defensive capability enhances the capacity to engage in successful offensive actions. Nineteenth-century imperialist powers were able to conquer less technologically advanced lands—an obviously offensive purpose—because their superior firepower allowed them to easily hold off the attacks of the natives.

The close relationship between offensive and defensive capabilities is a particularly important matter today as billions of dollars are being spent to develop an antiballistic missile defense system. Should a workable system be implemented—which is unlikely, given the immense technical obstacles to be overcome—this defense would allow the United States to launch its own missiles with impunity, for an enemy would be incapable of retaliation. A defensive system thus becomes the basis of an overwhelming offensive superiority.

Social Structure and the Development of Military Technologies

Be they offensive or defensive, weapons are not developed and put into service simply because of their intrinsic superiority. As has been noted throughout this book, the creation and use of technologies are social constructions to a significant degree, shaped by larger processes that involve existing social patterns, cultural orientations, political power, and the motivations of individual people. The development of military technologies is no different. A weapon is part of a larger system, and its use reflects the basic features of that system along with its strengths and deficiencies. This is well illustrated by the adoption of firearms and the eclipse of the longbow as the basic infantry weapon.² When viewed solely in terms of effectiveness, the longbow was by no means inferior to early muskets. Fired by a competent bowman, an arrow could penetrate the armor of that era just as easily as a bullet propelled by a firearm. Its range was greater, and it could be shot far more rapidly. In addition, it was less expensive, it was not subject to the continual misfires that plagued early firearms, and its effectiveness was not diminished by wet weather, as was the case with early matchlocks. Why then was the bow replaced by firearms despite all their imperfections?

Archery versus Gunnery

In narrating the virtues of the bow, it was necessary to preface the list with “fired by a competent bowman.” The bowman was, of course, an essential element in the technological system of medieval archery, and the level of his skills determined the bow’s effectiveness. This skill could not be taken for granted; proficiency with the bow required some natural ability and a great deal of practice. In medieval England there was a strong expectation that men and boys would devote a considerable amount of time to archery practice; indeed, it amounted to the national sport of England.

Even so, not everyone was willing to submit to the rigors of archery practice. Many preferred to spend their spare time engaged in card playing, bowling, shooting dice, and the medieval version of football. On several occasions, royal edicts banned these activities, in the hope, as one Elizabethan act put it, that “archery may be revived and practiced and that kind of ancient weapon whereby our nation in times past has gotten so great honor may be kept in use.”³ As might be expected, these laws were almost impossible to enforce, and the quality of English archery underwent a steady decline.

In other nations, matters took a different course. During the late fourteenth century, the king of France also promoted archery by banning all other diversions. The quality of French archery surpassed that of England, to such a degree that the ruling elite began to fear that their bowmen could pose a challenge to their rule. Consequently, mass archery was superseded by requirements that a limited number of bowmen be cultivated in each town and district, and the masses went back to their traditional pastimes.⁴ In general, rulers were not inclined to support the military prowess of their citizens, which could just as easily be used in the service of rebellion. Rather, autocratic states were predisposed to build up permanent professional armies composed of soldiers lacking high levels of individual skill.

Firearms fitted perfectly into this system, for they allowed the use of poorly paid mercenary soldiers drawn from the dregs of the society. Unlike archery, the use of firearms did not require high levels of skill; as Bert Hall has noted, “It was far easier to learn to use guns ... than it had been to use most of the weapons that had preceded them, especially longbows, and this

reduction in the fundamental skill component meant that masses of untrained men could be made into competent soldiers in six months or less.”⁵ To be sure, the use of early firearms was by no means a simple matter, requiring numerous operations in precise sequence. But none of these, not even aiming and firing the weapon, required a great deal of skill. Nor was there much opportunity to instill higher levels of proficiency even if it were desired; gunpowder and bullets were expensive, and as a result practice time was sharply limited, amounting to the firing of only a few dozen rounds per year. In any event, individual skill in handling weapons was far less important than maintaining a concentrated rate of fire. Battles were won by the discharge of withering volleys, not by individual sharpshooting. What counted, therefore, was iron discipline. The main requirement for effective use of harquebuses and muskets was that soldiers have the proper procedures drummed into them through rigorous drill, and that they adhere to these procedures in the heat of battle. Ranks of soldiers were expected to advance as a single line toward the enemy and to maintain formation despite the prospect that as many as a third of them would fall victim to enemy gunfire.

Mercenary soldiers of this sort were effective in battle because they had been transformed into virtual robots, who, as Frederick the Great of Prussia wanted, feared their own officers more than they did the enemy.⁶ Firearms were thus particularly well suited to armies raised by centralized, bureaucratically organized states where discipline was much more highly valued than freedom and individual ability. Troops of archers made up of independent yeomen were appropriate to the political and social setting of late medieval England, while gun-wielding mercenary armies were well suited to the social structures found in most of Europe from the sixteenth century onward.

It should also be noted that the advantage of firearms was not confined to their appropriateness to a particular mode of political organization. Technologies are sometimes embraced because of the psychological needs they meet. Although early firearms had a number of deficiencies when compared with the bow, they did have the advantage of producing a great deal of noise. Despite being inaccurate and cumbersome to use, early firearms certainly conveyed the impression that they were dangerous and terrifying weapons. And one could also speculate on the sexual connotations

that have long been attached to guns; one need not be a close follower of Sigmund Freud to realize that handguns and cannon can easily serve as symbols of male virility and potency.⁷

Learning How to Use the Machine Gun

As the adoption of firearms shows, the motives for using one military technology instead of another do not necessarily stem from the objective capabilities of a weapon. The fit of a military technology with established interests and ways of doing things may be of paramount importance for its adoption. At the same time, stupidity and shortsightedness can delay the adoption of a weapon and retard its effective use when this finally occurs. Although political and military leaders might be expected to employ new military technologies that confer specific advantages, some weapons have languished due to misperceptions of their potential.

A failure of this sort was evident in the slow adoption of the machine gun by late nineteenth-century armies. This was a particularly ironic situation in the United States, for the first practical machine guns, the Gatling gun and the Maxim gun, were American inventions. But France and England were equally slow in recognizing the machine gun's potential. The problem with these weapons was that they were heavy, cumbersome devices that had to be supported by large gun carriages. Since they looked like conventional artillery pieces they were treated as such. The leaders of the armies of late nineteenth-century England, France, and the United States did not grasp the unique capabilities of the machine gun, and they made no effort to develop new tactics that could take advantage of the machine gun's rapid rate of fire.⁸

In contrast, the German General Staff had a strong interest in the machine gun because a central element of their military plans was the massive use of reservists whose marksmanship was necessarily poor. In this way, the German army at this time was quite different from the small, professional armies of England, France, and the United States. Given this basic difference, the machine gun was particularly appealing to the Germans since its firepower more than made up for the deficiencies of its operators.⁹



Popperfoto/Getty Images

British soldiers leave their trench to go “over the top.” Assaults such as these gained little if any enemy territory at the cost of enormous numbers of casualties.

Finding a Role for a Revolutionary Weapon

As we saw in Chapter 15, the capabilities of the machine gun were soon demonstrated in the early battles of World War I. Combat bogged down into trench warfare, with neither side capable of advancing in the face of machine gun fire. Decisive breakthroughs became possible only after the deployment of the armored tank, which was largely impervious to machine gun fire. But again, military planners were slow in realizing how a new technology drastically altered the nature of warfare. Just as the machine gun caught World War I military leaders unprepared, the military value of the weapon developed in response to it, the tank, was not always appreciated during the years leading up to World War II. This situation was particularly evident in England, France, and other countries where military officers tended to be recruited from the traditional elite—the figurative and in some cases literal descendants of the knights of the feudal era. A good bit of their lives still centered on the horse, and prowess on horseback was an essential requirement of aristocratic manliness. In this culture, noisy, smelly machines were no match for a noble steed. Thus, a successful demonstration of an armored car in Austria during 1910 came to naught because the vehicle had frightened the horses upon which the observing generals were mounted; worst of all, the emperor's horse came close to bolting while he was in the saddle.¹⁰

Although the use of tanks during the final years of World War I gave a strong indication that land warfare was entering a new phase, the military establishment was reluctant to alter battlefield tactics in order to take advantage of these new weapons. In the years that followed the war, armored vehicles usually remained under the control of long-established combat branches within the army—the infantry and the cavalry—which hardly provided a supportive environment for their development. Convinced that the old rules of combat still applied, infantry and cavalry officers were not eager to see the foot soldier and cavalryman displaced by armored vehicles and other advanced weapons.

At best, tanks were combat auxiliaries; as the U.S. Army's chief of the infantry put it in 1928, "The tank is a weapon and as such it is an auxiliary to the infantryman, as is every other arm or weapon."¹¹ Even as late as 1938,

the Army's cavalry chief was arguing that mechanization "has not yet reached a position in which it can be relied upon to displace the horse cavalry.... For a considerable period of time [mechanization is] bound to play an important but minor role while the horse cavalry plays the major role so far as our country is concerned."¹² In Britain, Field Marshal Douglas Haig, whose tactics sent hundreds of thousands of men to their deaths in hopeless assaults against enemy lines protected by machine guns, was quite clear on this point: "I am all for using aeroplanes and tanks, but they are only auxiliaries to the man and the horse."¹³ As a consequence of this sort of thinking, twice as much money was spent in Britain in 1935 on cavalry as on tanks.¹⁴ In France, the situation was no better. According to the official Directive on the Use of Tanks, "In battle, tanks, whether singly or in groups, act within the framework of the infantry. Tanks are merely support weapons, which may be assigned to the infantry for a limited time; they considerably augment its striking force, but they do not replace it."¹⁵ Accordingly, tanks were to be commanded by infantry officers and were not intended to serve as independent strike weapons. Throughout the 1920s and 1930s, tanks were designed to move at the speed of the foot soldier. They were expected to rip through barbed wire and neutralize the weapons that threatened the infantry's advance, but they were not to play an independent role in combat.

In contrast, the army of the Soviet Union, which had been formed in the wake of the Russian Revolution and was led by an entirely different breed of officer, was far more alert to the new opportunities presented by these weapons. In similar fashion, the military forces of Nazi Germany were commanded by a new generation of officers, for Germany's defeat in 1918 had discredited the old military leadership, and the post-World War I disarmament of Germany left no entrenched military structure to resist new weapons and tactical concepts. The military staff that guided Germany's rearmament in the 1930s was highly receptive to the deployment of new weapons, as can be seen in the circulation of 30,000 copies of a translation of General J. F. C. Fuller's prescient book on tank operations. In Fuller's native Britain, only 500 copies were printed.¹⁶ Fuller's lessons were taken to heart by the German army, which made good use of the tank in the blitzkrieg attacks that conquered much of Europe during the first two years of World War II.



The LIFE Picture Collection/Getty Images

Although inferior to the German Tiger and the Russian T-34, the Sherman tank was produced in huge numbers and was the mainstay of U.S. armored forces during World War II.

Organizational Interests and the Air Weapon

The resistance to new technologies by entrenched military establishments was also evident in the development of a weapon that had begun to demonstrate its capabilities during World War I, the airplane. Here, however, the story diverges from that of the tank. During the interwar years members of fledgling air corps defied conventional military thinking and aggressively pushed the idea that the airplane had initiated a new era in warfare.

According to these proponents of “air power,” most notably General Billy Mitchell of the U.S. Army Air Corps, the airplane had rendered conventional warfare obsolete. According to this new doctrine, bombers now could wipe out ground armies and sink navies at little risk to themselves. Equally important, if horrendous in its implications, bombers could attack cities and industries with impunity, paralyzing economies and breaking the enemy’s will to resist.

As was noted in Chapter 15, the expectations of these prophets of air power were at best only partially realized. Although aerial bombardment produced appalling devastation, bombers equipped with conventional bombs did not single-handedly win World War II. The expectations that aerial bombardment could play a decisive wartime role rested on a number of largely untested assumptions. More ominously, the doctrine of strategic bombing also served as a rationale for advancing particular personal and organizational interests.

During the years between the two world wars, members of the U.S. Army Air Corps were eager to see their organization transformed into an independent military arm equal, if not superior, to the Army and Navy. This would require a new theory of war based on “air power”—and a weapon capable of turning theory into practice. The Air Corps found that weapon in the B-17 Flying Fortress. First flown in 1935, the four-engine B-17 was not defined as a strategic bomber, since the isolationist climate of the time was not receptive to the idea of getting involved in conflicts with far-off nations; rather, it was portrayed as a weapon to be used against a seaborne invasion. It was designed to fly at very high altitudes and have great range so it could seek out an enemy fleet far out at sea. The bomber’s ability to survive the attacks of intercepting aircraft was questionable, for no escort fighters of the

time could begin to match its range, but it was believed that the massed machine gun fire of a tight formation of B-17s would stave off all attackers.



Archive Photos/Getty Images

The B-29 Superfortress was the larger and faster successor to the B-17 Flying Fortress. A B-29 dropped the first atomic bomb on Hiroshima in 1945.

None of these expectations were met. As combat experiences during World War II proved, the B-17 was just about worthless as an anti-naval weapon and had severe operational shortcomings, most notably a vulnerability to antiaircraft fire and an inability to defend itself from a determined fighter attack. It flew many missions, and inflicted a great deal of damage on the enemy, but it was not the weapon that vindicated the extravagant claims made for air power, nor could any airplane carrying conventional bombs have done so.

In one sense, the mentality of Billy Mitchell was diametrically opposed to the mind-sets of the hidebound officers who failed to perceive the value of

armored vehicles; an air force, unlike the infantry or cavalry, represented the future and not the past. But there was still a basic similarity; both were incapable of viewing weapons with much objectivity. Instead, personal interest and commitment to a particular service arm strongly influenced the way they looked at the utility of a particular weapons technology. The traditional military resisted new weapons and clung to the established ways of doing things, often with disastrous results. Adherents of air power, and especially of strategic bombardment, were correct in their assessment that their weapons could do an immense amount of damage, but they made the same mistake as the traditionalists in believing that their personal and organizational interests were identical with the military needs of their countries.

Expanding the Scale and Scope of War

We have just seen how personal and organizational interests can affect the course of technological change. It is to be hoped that this discussion has illuminated a recurrent theme in this book: that technologies are shaped by the societies in which they develop, and as such they reflect culture, the distribution of power, and economic, organizational, and social relationships. At this point, it may be appropriate to expand on this theme by considering how social and political changes on a massive scale have altered not only weapons but the very nature of war.

During the late eighteenth and early nineteenth centuries, a series of social and political revolutions profoundly changed the conduct of warfare. The effects of these revolutions can clearly be seen by briefly examining warfare in the period immediately prior to this era. Throughout the eighteenth century, most European wars were rather limited affairs. War was the ultimate “sport of kings,” fought to advance the interests of a ruler rather than the country as a whole. Most of the populace remained aloof from these conflicts; the dirty work was done by small contingents of professional soldiers, social outcasts who were drilled to perfection by noncommissioned officers equally removed from the larger society. Commissioned officers came from the upper class of society and had little emotional connection with their soldiers. But these officers and their ruler valued them all the same, for they knew that well-drilled, effective fighting men could not be quickly replaced. As a result, soldiers were used with great care. When a major battle did occur, it produced frightful casualty rates that could decimate an army. This in turn could fatally weaken a country. Military and political leaders therefore preferred to avoid these confrontations and were eager to arrange compromise peace settlements instead of engaging in go-for-broke military actions.¹⁷

At the same time, war was constrained by the temper of the times. The wars between Catholics and Protestants that had convulsed Europe during the previous centuries were frightful examples of what happened when wars were fought over great principles. In place of zealotry, eighteenth-century

political thinkers preached a code based on reason or at least reasonableness. Wars might be an unfortunate consequence of human nature or political policy, but their worst effects could be constrained by the mutual agreement of the combatants to observe proper rules of behavior. Civilians were to be spared, hatred of the enemy kept in check, and terms of peace kept moderate.¹⁸

The great forces of democracy and nationalism changed all that. In an earlier time, the Swiss had shown the power of a disciplined, armed citizenry motivated by a fierce desire to fight for their homeland. The American Revolutionary War also showed the power that could be unleashed when large numbers of combatants took up arms in support of national self-determination and a more democratic form of governance.

These principles, and their military consequences, were driven to new heights by the French Revolution (1789–1799). This movement was energized by a desire to overthrow France’s traditional ruling class and substitute democratic rule. But along with the rights engendered by democracy there came responsibilities. The people of France were no longer passive subjects of the king; they were now citizens of their nation, a nation that now faced the hostility of countries governed in the traditional manner. At the same time, the revolution had produced a zeal to extend the new order across the boundaries of France. Territorial conquest was therefore undertaken in order to extend liberty, equality, and fraternity throughout Europe. Warfare now involved a newly emergent citizenry, who fought for a cause far greater than the personal ambitions of traditional monarchs. The mercenary army had been replaced by “the nation in arms,” where, as a report to the French Assembly in 1789 put it, “every citizen must be a soldier and every soldier a citizen.”¹⁹

Not everyone subscribed to these lofty principles. But for those who were unwilling to voluntarily take up arms in the service of their nation, there was always the draft. Partial conscription had been employed in many places at many times, but these limited efforts were completely overshadowed by the universal conscription that was proclaimed by France’s revolutionary government in 1793, which expanded the French army to nearly 750,000 men. In turn, the increased number of soldiers changed the ways that wars were conducted. Moderation and practical restraints on warfare were swept

away, and military actions became far more massive in scope. Whereas the key battles of the eighteenth century had been fought by armies rarely exceeding 80,000, in 1812, Napoleon was able to invade Russia with a force of 600,000.²⁰

These huge armies were expensive to maintain. A necessary consequence of the vast expansion in the size of armies was a substantial increase in taxation. Governments have always used their power to tax, and tax revenues have been disproportionately used for military purposes. But after the French Revolution, the close alignment between the individual and the nation expanded the willingness and ability of governments to tax their citizens, while large-scale military operations increased their need to do so.

Large armies required huge quantities of guns and other matériel. In revolutionary France these needs were met by mobilizing the population to produce weapons and equipment. The government drafted craftsmen of every description, as well as legions of workers with no prior experience in armament making. A good deal of waste resulted, and many of the muskets were of poor quality, but armament production was taken to new heights. While France's government arsenals never produced more than 25,000 muskets per year during the last decades of the monarchy, the Saint-Etienne armory alone produced 85,000 muskets in a 12-month period extending from 1793 to 1794.²¹

The days of restrained, limited warfare were over. The spread of democracy and nationalism brought with it mass-based warfare. And at the same time, this expansion of warfare created a receptive environment for the development of new weapons that made warfare far more destructive and terrifying than ever before. Equally important, the greatly enlarged scope of warfare stimulated the development of new production technologies that allowed the large-scale production of these weapons, as we shall see next.

Industrial Technology in the Service of War

Until the nineteenth century, military technology developed slowly. Science made few inputs into invention, and most work was done on a trial-and-error basis. As a result, guns were inaccurate and not very powerful because metallurgy was still in its infancy and chemistry had only recently separated from alchemy. This situation began to change dramatically during the nineteenth century as military technologies advanced rapidly. Smokeless powders resulted in more accurate gunnery and gave gunners a clear field of vision. The new powders also allowed the production of guns with smaller bores, making weapons lighter and allowing soldiers to carry larger loads of ammunition. The discovery of fulminates made the percussion cap possible, rendering the flintlock obsolete. Improved machining techniques stimulated the production of better weapons, such as breech-loading cannon and small arms. Accurate machine tools and the use of new alloy steels also made possible the mass production of guns with rifled barrels, which greatly increased their accuracy. By the middle of the century, these new technologies also facilitated the production of practical repeating weapons, culminating with the machine gun.

For much of the nineteenth century, most of these improvements occurred with little direct support from central governments. Invention was the work of individuals and firms that attempted to sell their devices to the armies and navies of their own nation, or failing that, to anyone who was willing and able to pay for them. By the end of the century, some of these firms had become quite large and powerful with steadily expanding political influence. Enterprises such as Armstrong-Vickers in Britain and Krupp in Germany employed scientists and engineers who had as their sole responsibility the development of new weaponry. Derided as “merchants of death,” these firms gave a powerful impetus to the invention and diffusion of new military technologies that further increased the destructiveness of warfare.

By the twentieth century, the state had ceased being a passive consumer of military technologies developed by private firms. Government sponsorship of technological innovation in the military sector resulted in the rapid

advance of martial technologies. This reached new heights during World War II, when the United States government employed 30,000 scientists and engineers for the war effort.²² During the Cold War that followed, the military continued to be a voracious consumer of scientific and engineering output. In the United States, by the mid-1980s, 70 percent of federal research and development funds was going to military projects,²³ while nearly one-third of the nation's total research and development (R&D) expenditures were absorbed by the defense sector.²⁴ Defense-related R&D has been less prominent in recent years; even so, for fiscal year 2014, nearly half of the federal government's R&D budget was absorbed by the Department of Defense.²⁵

The technological advances that occurred during the past 150 years transformed armaments. But of equal or greater importance was the development of industrial technologies that allowed great increases in their production. Gunsmiths organized along traditional craft lines could never produce weapons in the quantities that became commonplace during the second half of the nineteenth century. Nor could conventional means of producing uniforms, boots, and foodstuffs meet the immense requirements of modern armies. The expanding needs of the military were met through the development of mass production. The essence of mass production is the assembling of a product from standard parts so that no individual fitting is required. This in turn requires precision tools, assembly jigs and fixtures, accurate gauges and other measurement devices, and, in general, high degrees of accuracy. Mass production also requires a large market for its product; to put it another way, mass production requires mass consumption.

The military was an ideal consumer of the increased output made possible by mass production, and its needs generated a strong stimulus for the development of new production technologies. As we have seen in Chapter 11, the manufacture of pulley blocks for the ships of the Royal Navy was one of the first instances of mass production. The technique was soon adapted to the fulfillment of other military needs, most notably the production of firearms. According to popular belief, Eli Whitney was the first to employ mass-production techniques when, at the beginning of the nineteenth century, he undertook the large-scale manufacture of muskets at his factory in Mill Rock, Connecticut. In fact, Whitney never fully accomplished what he intended to

do, and other enterprises have a better claim to being the initiators of mass production.²⁶ But whatever the source, by the middle of the nineteenth century, weapons were being manufactured according to the principles of mass production, allowing huge armies to be sent into battle. At the same time, industrial technologies supplied them with mass-produced provisions, such as canned rations. Gone were the days when armies lived off the lands they marched through and fought on, often destroying more in the process than they did on the battlefield.

Large armies created immense logistical problems; the best army is worthless if it cannot be rapidly moved into a theater of war and then be continuously supplied with arms and provisions. By the middle of the nineteenth century, the railroad and the steamship made the movement of troops and the provision of their matériel a more regular and rapid process. Troops were no longer worn out by lengthy marches, and during the course of a campaign they were much better supplied. The wounded and exhausted could be quickly evacuated and replaced by fresh troops. This in turn expanded the scope of war, as railroads allowed military leaders to relentlessly use troops and supplies in numbers that hitherto had been impossible. Improved transportation technologies thus moved the world closer to an era of total war, in which the performance of industries operating on “the home front” took on at least as great an importance as the performance of soldiers on the battlefield.²⁷



Corbis

The application of modern industrial technology greatly increased the production of war matériel, as exemplified by this Armstrong-Siddeley aircraft engine factory in the 1930s.

Improvements in medical technologies reinforced the trend to larger armies, for far fewer soldiers were removed from combat by disease. Throughout the history of warfare, many more soldiers had died of disease than from combat wounds. This situation began to change noticeably toward the end of the nineteenth century. Before 1870, for every soldier that died of wounds, five died of disease; by 1918, this ratio had been inverted.²⁸

The technological achievements of the nineteenth and early twentieth centuries thus allowed a great expansion in the scope of warfare. In this way, technological development was a perfect complement to the social and political changes that put large armies at the disposal of rival states. All of this became painfully evident as unparalleled death and destruction followed in the wake of World War I. Enormous armies faced one another across fronts that stretched for hundreds of miles, and there were more casualties in a day's battle than were suffered in the course of many eighteenth-century

wars. The optimistic belief of the nineteenth century that technological advance would necessarily lead to a better life had been cruelly mocked by the second decade of the twentieth century.

Controlling Military Technologies

During the twentieth century, military technologies developed at an accelerating pace. When the century began, the battleship was the most technologically sophisticated weapon, infantrymen had only recently been armed with repeating rifles, and many thought heavier-than-air flight to be an impossibility. Today, manned bombers fly well over twice the speed of sound, the battlefield has been transformed by drones and precision-guided weapons, and a single intercontinental ballistic missile (ICBM) has the capability of destroying a large segment of a major city. On the not-too-distant horizon lies the possibility of laser-based weaponry, biological weapons, enhanced radiation bombs, and many other ghastly instruments of mass murder. Is there any hope that technological progress can be arrested in the military sphere so that we will not forever live under the shadow of increasingly lethal products of human ingenuity? The following sections will provide some perspectives that help to answer this question.

Historical Attempts to Limit New Weapons

The threat posed by new military technologies is nothing new. Horrible as our latest weapons are, they are only the latest in a long series of “advances.” On numerous occasions, people have surveyed the emergence of new weapons and fervently attempted to stop their spread. Pope Innocent II was aghast at the destructive power of the crossbow, and in 1139, the Second Lateran Council banned its use, although the ban did not extend to its use against non-Christians, so “infidels” such as Muslims continued to be fair game.

Leonardo da Vinci kept secret the details of a submarine he designed, “on account of the evil nature of men, who would practice assassinations at the bottom of the seas by breaking the ships to their lowest parts and sinking them together with the crews who are in them.”²⁹ In similar fashion, Niccolò Tartaglia, the first man to make a systematic study of ballistics, suppressed his own calculations because “it was a thing blameworthy, shameful and barbarous, worthy of severe punishment before God and man, to wish to bring to perfection an art damageable to one’s neighbor and destructive to the human race.”³⁰ But when the Turks threatened Tartaglia’s homeland, he put aside his moral scruples, and his treatise on gunnery was quickly published.³¹

Each succeeding advance in weaponry has raised the stakes of warfare. At the same time, many of these advances have elicited a desire to limit the spread of new weapons. The percussion cap, an important but not epochal change in armament, was viewed with great alarm by one correspondent to *The Gentleman’s Magazine* in 1837: “If ... this new system were applied to the military, war would shortly become so frightful as to exceed all bounds of imagination, and future wars would threaten, within a few years, to destroy not only armies, but civilization itself. It is to be hoped, therefore, that many men of conscience, and with a reflective turn, will militate most vehemently for the suppression of this new invention.”³²



Getty Images/Getty Images

The launch tubes of Ohio-class submarines hold 24 Trident II missiles. One missile carries 8 independently targeted warheads, each one of which could devastate a large portion of a major city.

A Successful Example of Arms Control

As things turned out, the nineteenth century had many nasty surprises that far exceeded the percussion cap. And, to their credit, political leaders made some effort to limit the spread of new weaponry. In 1899, delegates from 26 nations participated in a conference held at The Hague in the Netherlands that banned the use of asphyxiating gas and dum dum bullets (which caused large internal wounds by expanding as they entered a body) and put a five-year moratorium on aerial bombardment (which at that time meant dropping projectiles from balloons).

World War I demonstrated the terrible consequences of new military technologies, and in the early postwar period, several international conferences attempted to control one of the worst of them: poison gas. All but one of the signers of the 1922 Washington Conference on the Limitation of Armaments agreed to refrain from the use of poison gas in warfare. A similar resolution was contained in the Geneva protocol of 1925 and was ultimately ratified by 42 nations, although 19 of them reserved the right to use gas if they were attacked by an enemy that made first use of this weapon.³³

As with all such resolutions, there was no way of ensuring compliance, since there was no international organization with the power to do so. Still, these resolutions struck a responsive chord, for the terrible potential of poison gas had been amply demonstrated during World War I. Chlorine and then mustard gas killed an estimated 90,000 soldiers on both sides (more than half of whom were Russian), and permanent lung damage led to the premature deaths of many veterans after the war.³⁴ During the 1920s and 1930s, the threat of poison gas was quite pronounced, as military planners, novelists, and journalists presented scenarios of huge civilian populations annihilated by gas shells dropped from high-flying aircraft. During the early months of World War II, the fear of gas attacks was widespread, and in Britain, every man, woman, and child was supplied with a gas mask that they were supposed to carry with them at all times.

But the attacks never came. Over the course of a war made increasingly horrifying by the use of new military technologies—culminating with the dropping of the first atomic bombs—gas was never used. The declarations of

the Washington Arms Conference and other such pronouncements were not the main reason; its provisions were violated in a number of other areas. Part of the reluctance to use gas was due to inherent logistical problems. Troops had to be protected from the gas that they used, and shifts in the wind could upset a military operation. A conquered area would require detoxification before it could be occupied. But by themselves, these factors do not explain why gas was not used; any new weapon requires adjustments if it is to be successfully used, and ways could have been found to make gas a practical weapon. Yet civil and military leaders were not inclined to do so because they had every expectation that if they used gas, their opponent would follow suit, thus nullifying whatever advantage the use of gas conferred in the first place. The nonuse of poison gas indicates that in some instances deterrence really works; the deployment of poison gas would have subjected its user to a great deal of suffering in return for a transitory advantage.

Fear of retaliation was not the only reason that gas was eschewed. It is possible that military planners would have taken the risks inherent in the use of gas if they felt a greater affinity for it. In fact, they never felt comfortable with the use of gas. Poison gas was unlike all other weapons—silent, insidious, and even dishonorable. As one World War I German commanding general put it, “I must confess that the commission for poisoning the enemy just as one poisons rats struck me as it must any straightforward soldier; it was repulsive to me.”³⁵ At the same time, poison gas represented the sort of scientific advance that rendered obsolete many of the classic martial virtues. A technologically superior enemy with sufficient industrial capacity could triumph over superior training and leadership.³⁶ Some advances in military technology could be fitted into existing molds—an armored tank could be seen as a modern embodiment of the cavalry—but poison gas was something altogether different. Irrespective of their nationality, military leaders were disinclined to use poison gas, and their reticence helped to prevent modern warfare from being even more horrible than it actually was.



Corbis

Even little children had to undergo gas mask drills during the early months of World War II.

Gun Control in Old Japan

The nonuse of poisonous gas is not the only example of a potentially significant military technology falling by the wayside. During the middle of the sixteenth century, European traders introduced firearms into Japan, and guns rapidly diffused through the country during the succeeding decades and became dominant weapons on Japanese battlefields. But during the early seventeenth century, they began to disappear, and for 250 years, Japanese soldiers reverted to swords, spears, and bows. The eclipse of firearms was not caused by a lack of technological prowess. Although pistols and muskets were foreign inventions, Japanese craftsmen quickly learned to duplicate them, making some useful improvements in the process. Not long after the introduction of firearms into their country, Japanese gunsmiths were producing weapons that were the equal of any in the world. And they produced them in large numbers; in one battle, 10,000 soldiers on one side were armed with matchlock guns.³⁷ The Japanese had already demonstrated their technological virtuosity in building construction, metallurgy, agriculture, and a host of other areas; they certainly were not stymied by the demands of gun manufacture.

The reasons that firearms disappeared from Japan were cultural and political.³⁸ As had been the case in feudal Europe, the political elite of Japan were warriors, and Japanese culture was deeply suffused with a martial ethic. Even after the Tokugawa shogunate initiated a long period of peace, the nation was dominated by the samurai, a warrior class that comprised almost 8 percent of the total population. The ethos of this class centered on the military virtues of strength and courage. Their favored weapon was the sword, and only they had the right to wear and use it. Even if it was never used, the sword was the symbol of their special status, and it was much valued for its aesthetic appeal.

In contrast, firearms were foreign imports, with no connection to traditional Japanese ways. Of greater importance, the use of firearms in combat destroyed the time-honored way that the Japanese had gone about the business of warfare. War was a highly stylized affair that began with the ritual introduction of the main combatants. Its essence was hand-to-hand combat waged by heroic opponents who had ample opportunities to display

their bravery and prowess. Firearms were highly disruptive to this form of warfare. As had been the case in early modern Europe, a line of soldiers armed with muskets could quickly decimate the bravest and most skillful warriors. Adding insult to injury, soldiers with firearms were social inferiors to the soldiers that they picked off with such ease and impunity.

If Japan had been threatened by foreign armies, it undoubtedly would have been forced to adopt the same weaponry as its adversaries. But as an island nation, Japan was able to close its doors to the outside world and avoid foreign invasion. Only in the middle of the nineteenth century did foreign powers begin to threaten Japanese independence. When that happened, the Japanese wasted no time in arming themselves with modern weaponry.

But before this happened, Japan enjoyed two and a half peaceful centuries in which the most dangerous weapon was the samurai's sword. The government achieved this by centralizing the production of guns in one city and then strictly controlling their distribution. Purchasers of guns were required to have permission from the Commissioner of Guns, but in fact the commissioner granted permits only to the government. Since the government bought very few, gun production virtually ended in Japan during the early seventeenth century, and the use of firearms faded from the scene.

Japan's experience from the seventeenth to the early nineteenth centuries shows that a superior military technology is not always destined to be universally accepted; here, as elsewhere, technological determinism shows its inadequacies. In the case of firearms in Japan at least, it was possible to "turn back the clock." At the same time, it must be remembered that the disappearance of firearms was the result of a conscious political decision, a decision that the government did not make through altruistic motives. These weapons vanished after the Tokugawa shoguns succeeded in bringing Japan under centralized control. Local power holders had been neutralized, and the shoguns wanted to maintain this state of affairs. The spread of firearms would have made it much easier to mount local rebellions. At the same time, these weapons would have allowed the common folk to pose an effective challenge to the martial class that formed the core of the shogun's military power. It was therefore obviously to the advantage of the ruling elite to reverse the course of technological development by eliminating firearms from their domain.

The case of Japan during this era leaves us with a certain sense of

optimism, for it shows that military technologies do not necessarily have an unstoppable momentum; the development and use of increasingly deadly weapons can be arrested. At the same time, however, it is necessary to temper this optimism with a dash of cynicism; this case also shows that disarmament is most likely to take place when it works to the advantage of a dominant group. Today's nuclear weapons make arms control advantageous to all. But can we effectively formulate and enact arms control programs that allow us to realize our own best interests? It is to this crucial issue that we will next turn.

The Control of Nuclear Weapons

There is widespread agreement among both civilian and military leaders that an all-out nuclear war would be unwinnable. Since no combatant could expect to profit from the use of nuclear weapons, it is to the advantage of all to prevent these weapons from being used. Effective arms control agreements are not generated by one nation's willingness to make one-sided sacrifices; they are the product of the realization that all parties would gain from them. Nor is it necessary that the parties to an agreement be friends; after all, the very need to come to an agreement implies that there are basic conflicts between the two parties. Nations enter into arms control agreements not because they are on the best of terms with the other parties, but because they have good reason to fear the consequences of unshackled military power. In sum, arms control treaties are signed when nations see them as being in their best interest, and as long as their interests are preserved, they have no reason to violate the agreements.³⁹

Deterrence, but No More

Despite a high level of tension between the United States and Soviet Union during the Cold War era, neither side was inclined to take on the other in a full-scale war. Much of the reason for this reluctance lay in the fact that both nations had the capacity to utterly ruin each other by launching a nuclear attack in retaliation for the other's attack. This policy is known as mutually assured destruction (MAD), and although not pleasant to contemplate, it has had some positive results. Despite all of the insecurity it engendered, the development of nuclear military technologies helped to keep the peace because neither nation dared attack the other for fear of retaliation.

Although the Soviet Union no longer exists, U.S. defense strategy continues to rest on this principle. However, deterrence through MAD has its obvious perils. To have a credible capacity to retaliate is similar to keeping a gun in your house for protection. A gun is of little use unless it is loaded and readily accessible. But at the same time, this availability increases the level of danger, for the gun could easily be used by a small child, a disturbed acquaintance, or an enraged spouse. In similar fashion, nuclear weapons must be kept ready for immediate use, but this readiness increases the chances that they will be launched as a result of an accident, miscalculation, or mechanical failure.⁴⁰ Military planners are thus confronted with the inherently conflicting demands of peace and war. In peacetime, an accidental or unauthorized use of nuclear weapons is a constant peril; at the same time, an effective deterrent requires the ability to launch retaliatory attacks without excessive delay or deliberation.⁴¹

The maintenance of a credible yet reasonably safe deterrent is difficult in its own right, and recent technological developments have made it even harder. If one country has the capacity to destroy an enemy's retaliatory forces in a first-strike attack the ability to deter is lost. Although it is impossible to make completely accurate predictions about the survivability of ICBMs, bombers, and missile-carrying submarines (the "strategic triad") in the event of a preemptive attack, there can be little doubt that advances in delivery systems, such as the use of multiple warheads known as MIRVs (multiple independently targeted reentry vehicles) on missiles, have increased the vulnerability of at least the land-based component of retaliatory forces.⁴²

Even if sufficient numbers of one's retaliatory weapons survived such an attack, the disruption of civil and military communications facilities might make the launching of a retaliatory strike difficult or even impossible.⁴³

This vulnerability to a first-strike attack creates a dangerous incentive for a nation to mount an attack on an enemy before damage is suffered, or indeed, before it is entirely certain that an attack is under way. Once a potential enemy possesses a first-strike capability it instills a "use 'em or lose 'em" mentality in other nations. If these nations' retaliatory weapons are vulnerable to a preemptive strike there will be a strong incentive to strike first in a crisis situation; otherwise, most of these weapons could be destroyed before they were launched.

No present nuclear power has deliberately sought a first-strike capability nor used it to achieve a position of military superiority. Rather, official policy has stressed maintaining parity with potential adversaries. Even so, devising mutually acceptable arms control agreements that preserve parity is very difficult. "Parity" is an elusive concept, more so now than at any time before. In the past, it might have been possible to maintain parity by ensuring that one nation did not get ahead of others by acquiring a numerical superiority in the quantity of weapons, soldiers, and war matériel. Today, the situation is different. In addition to considering sheer numbers, successful arms control agreements have to take into account the technological level of the respective military forces. These qualitative assessments are inherently more difficult than those that center on the mere counting of weapons. To cite one example, the first Strategic Arms Limitation Treaty (SALT I, which went into effect in 1971) between the United States and the Soviet Union resulted in restrictions on the number of missiles, but it failed to halt technological advances that produced missiles with greater accuracy. This produced a new kind of arms race, one that was qualitative instead of quantitative.⁴⁴ Further complicating matters, modern technologies are inherently dynamic, so changes in military technology can render an existing arms control agreement irrelevant. It also makes it even more difficult to negotiate a new one. As one group of scholars has pointed out, "The negotiation of arms control agreements takes time, and the development of technology can run ahead of the ability of arms control negotiators to come up with effective means of identifying, counting and limiting weapons."⁴⁵

This problem is illustrated by the case of cruise missiles. An arms control agreement requires the ability to verify how many weapons have been deployed; cruise missiles and their launching facilities are virtually unidentifiable by nonintrusive inspection measures. Additionally, it is difficult to determine through direct observation if a cruise missile is a tactical weapon with a conventional warhead or a strategic weapon with a nuclear one.

The Perils of Proliferation

During the Cold War, military planners were largely concerned with the prospect of a nuclear war between the United States and the Soviet Union. Much less attention was devoted to an issue that was taking on growing importance, the development of nuclear capabilities in other parts of the world. There are certainly no scientific obstacles to many nations “going nuclear,” as there are no real secrets about the construction of atomic weapons anymore. The present situation, where eight nations (the United States, Russia, Great Britain, France, China, Pakistan, India, and North Korea) have already tested nuclear weapons, is dangerous enough; the prospects of a world full of nuclear powers is frightening beyond description.

Still, some encouragement can be taken in other nations’ willingness to cooperate in limiting the spread of nuclear weapons. The most visible manifestation of this spirit has been the Nuclear Nonproliferation Treaty, which by 2016 had 190 signatories, including five nations with known nuclear capabilities. Its key provisions enjoin established nuclear powers from transferring nuclear weapons to other countries or aiding in their production. Nonnuclear signatories agree to refrain from acquiring or producing nuclear weapons.⁴⁶ In another effort at nonproliferation, all of the nations of Latin America except Cuba are signatories to the Treaty of Tlatelolco (in force since 1968), which mandates that their region be kept free of nuclear weapons.

Up to now, the spread of nuclear weapons has been kept in check, as the majority of the nations of the world have observed the Nonproliferation Treaty. At the same time, however, several nations have not signed the treaty, including two existing nuclear powers, India and Pakistan, as well as Israel, which almost certainly has a nuclear capability, even if it has not yet tested a nuclear device. North Korea, which has tested nuclear weapons on four occasions, withdrew from the treaty in 2003. The treaty’s signatories have the right to withdraw on three months’ notice; thus, they could easily produce nuclear weapons secretly and then begin to test them after withdrawing from the treaty. One thing that has prevented the nations that have signed the treaty

from actively flouting it has been the willingness of the nuclear nations to assist the nonnuclear ones in the development of nonmilitary applications of nuclear energy. As things have turned out, this may not have produced great benefits, for nuclear power is not well suited to the needs of many developing countries. And even “peaceful” applications of nuclear technology can be applied to warlike purposes. It is also likely that the nonnuclear countries may be less inclined to continue practicing self-restraint if the major powers make only halting progress in reducing their own nuclear arsenals.

QUESTIONS FOR DISCUSSION

1. In what ways have warfare and military preparation advanced technology? Can you think of any contemporary military technologies that might eventually have civilian applications? Do civilian “spinoffs” from the military sector partially justify today’s tremendous expenditures on military technology?
2. During World War I, high-ranking officers sent hundreds of thousands of men to their deaths in futile attempts to gain territory defended by machine guns, artillery, and barbed wire. Why did they do so? Could their social origins and past educational experiences have blinded them to the realities of modern warfare?
3. Firearms were suppressed in Tokugawa-era Japan because it was in the interests of the ruling elite to do so. Are the political elites of modern nations similarly motivated to prevent the development and use of new weapons? Do individual nations differ from one another in this regard?
4. Is mutually assured destruction (MAD) an inherently immoral policy? Can it continue to be the cornerstone of U.S. military policy? Are there any alternatives other than the forging of effective arms control treaties?
5. The history of arms control agreements presents, at best, a mixed record; a few successful agreements are more than balanced by many failures. But nuclear weapons have been held in check up to now. Is there anything about these weapons that makes them better subjects for successful arms control agreements? Is it reasonable to hope that we will succeed in controlling these weapons, or are we living on borrowed time?
6. The threat of retaliation has often prevented attacks from hostile countries. Today, however, an attack may come from an amorphous terrorist group with no significant territorial base. How can retaliation be a credible threat in such circumstances? Are there other ways to prevent terrorist attacks?

PART SEVEN

| The Shaping and Control of Technology

Technology is a human creation; as noted in Chapter 1, one of the distinguishing characteristics of the human race is that its members have consciously developed and used technologies to extend and surpass their natural capabilities. Yet, we as individual men and women seem to have little control over the technologies that affect our lives. Although crucial decisions about technology appear to be made anonymously, some individuals and groups are in fact making these decisions. Who are they, and how do they operate?

The final set of chapters extends and grapples with the question we asked in Chapter 1: Do we control technology or does technology control us? In these chapters, we look at the social forces that help to shape technology, and how they do so. Chapter 18 revisits the issue of technological determinism and then looks at the role of experts, the individuals who play a particularly important role in the creation and diffusion of new technologies. Chapter 19 considers how the aggregation of these individuals into organizations affects the process of technological change, and Chapter 20 looks into the governmental structures and processes that strongly influence the overall environment for the technological advances generated by individuals and private organizations alike.

CHAPTER EIGHTEEN

Technology and Its Creators: Who's in Charge of Whom?

Chapter 1 introduced the concept of technological determinism, the idea that technology acts as an independent force in human affairs. As we have seen, this perspective has a number of problems, one of them being that it simply takes technological change as a given and fails to consider how new technologies emerge and diffuse. In the first part of this chapter, we will revisit the concept of technological determinism by noting some of its corollaries and considering their strong and weak points. We will then assess the influence of some of the key actors who are directly involved with the process of technological change. To repeat an earlier assertion, technology is a human creation, but at the same time it should be evident that individual men and women have not participated equally in initiating and directing technological change.

Technological Advance and Cultural Lag

For all of its shortcomings, technological determinism still exerts a lot of influence. One of the places where it shows up is in the theory of “cultural lag.” Formulated by William F. Ogburn, whom we briefly met in Chapter 1, the theory of cultural lag is predicated on the belief that habits, thoughts, values, and social arrangements often fail to change at the same speed as technological innovation. Technology moves ahead, but many other things lag behind. On the face of it, this seems a reasonable concept, and we should have no difficulty in coming up with a number of examples. To take one, the expansion of public health services and modern medical technologies have lowered infant mortality, but people in some parts of the world continue to have large families, due in part to traditional expectations that many children will not survive infancy. Only after several generations, when expectations and practices have “caught up” with the level of technology, will birthrates begin to fall. To take another example—one that has been the source of considerable conflict, litigation, and governmental legislation—the ease of copying and transferring digitized books and music has profoundly undermined traditional notions of intellectual property and the proper means of accessing it. We can be confident that many years will go by before the legal system catches up.

Appealing as it is on the surface, the theory of cultural lag has its shortcomings. In the first place, technological changes are simply taken as givens, and no attempt is made to delineate how they came to be in the first place. Although traditional histories of technology have conveyed the impression that inventions are carried forward largely by their own internal logic and are little influenced by external factors, this perspective leaves a great deal out of the story. As earlier chapters of this book have indicated, many things that are not technical in nature strongly influence the course of technological change. At the risk of repetition, suffice it to say that technology should not be viewed as an independent source of social change.

Second, many attempts to demonstrate the connection between technological and social changes present us with the problem of measuring

and trying to connect different kinds of phenomena. Technological changes can often be more easily measured than sociocultural changes, making it hard to determine the precise connection between the two. We can easily tabulate the increase in the number of automobiles between 1900 and 1925, but to what extent did widespread car ownership contribute to changes in sexual activity during this period? In similar fashion, we can tabulate the number of television shows with violent programming, but, as we have seen in Chapter 13, determining the influence of these programs on individual behavior is fraught with difficulties.

Third, at what point can it be said that a society “catches up” with a given technological innovation? New productive technologies have allowed major alterations in the traditional divisions between “men’s work” and “women’s work,” but customs and social arrangements have not completely taken account of this fact. To be sure, there have been significant changes, but at what point can it be confidently said that a complete accommodation has occurred? Then, too, some technological innovations have been followed by rapid adjustments, while in other cases these adjustments occur slowly, if at all. In regard to the latter, the killing power of modern weaponry far exceeds the spears and stones of our Neolithic ancestors, yet we still engage in warfare as a means of resolving our disputes. Obviously, something other than technology itself is affecting the extent of and speed at which particular cultural lags are eradicated.

Fourth, the theory of cultural lag assumes a unified society and culture, and ignores the economic, political, and cultural divisions to be found in all complex societies. Describing a social phenomenon as an example of cultural lag may therefore be a reflection of the values and preferences of particular groups or individuals.¹ The unwillingness of Amish farmers to use electricity could be labeled an instance of cultural lag, but this assumes that saving labor is a benefit of unquestionable value; those convinced of the sanctity of physical work would not agree.

Finally, there is a hidden value judgment contained in the concept of cultural lag. Implicit in it is the notion that technology is a progressive, dynamic element in human history, and that social and cultural arrangements are intransigent sources of obstruction. But is it not possible that a cultural lag may demonstrate the danger or inappropriateness of a particular

technological innovation? Once again, it might be noted that just because something is technically possible, it does not necessarily follow that it should be done, or that people should submit to it and make the necessary alterations to their lives. We now have the capability to implant a fertilized ovum into a surrogate mother, who then carries and delivers the baby. Should we replace old-fashioned methods of reproduction with this “improved” technology?

Technology, Globalization, and Cultural Convergence

The interplay of technological and cultural changes is especially relevant in the globalized era in which we live. As was noted in Chapter 10, advances in transportation and communications have made individuals and the communities in which they live less insular by facilitating the movement of people, goods, cultural elements, and ideas all over the world. Globalization has brought tai chi to Iowa, Delta blues to Japan, and pad thai to Ireland. Cultural change as a result of globalization is not a new phenomenon; the music we listen to, the clothes that we wear, the language that we use, and the devices we employ have been strongly influenced by importations from other lands. What has made things different is the speed at which these transfusions occur. As was noted in Chapter 13, there was a time when major battles were fought by combatants who were unaware that an armistice had been declared weeks earlier. Today, even trivial news items are broadcast to the world at the speed of light. It is obvious that technological advances in transportation and communications have helped to create a more interconnected and fast-moving world, but is a truly globalized civilization emerging? Or to put it slightly differently, are all of the world's societies and cultures converging toward a common model?

The idea that the use of similar technologies results in cultural and social sameness has been around for a long while in the guise of an approach known as convergence theory. Closely associated with a belief in technological determinism, convergence theory argues that the nations of the world are becoming more similar to one another—that is, they are converging—as they make use of the same technologies. For example, running a steel mill or operating an airline does not allow substantial culturally based variations in the procedures employed. Many other examples of technologies requiring a certain kind of structure and mode of action can be cited, but the effects of modern technologies are not limited to particular industries; according to convergence theory, the process is demonstrated by commonalities in

educational systems, family patterns, organizational structures, and even preferences in food and clothing as they all move toward a universal pattern.²

In geometry, convergence means that several lines are all moving toward a single point. Convergence theory, however, usually assumes that countries with relatively low technological levels will move toward a point already occupied by technologically advanced countries, most of which have been in the orbit of European culture (Japan being the notable exception). Since most advanced technologies have originated in Europe and North America, other countries will have to adopt Western institutions and culture if they are to make effective use of modern technologies. In other words, convergence really means Westernization. This equation of modernity with Western culture is embodied in the remark of a U.S. senator who, early in the twentieth century, expressed the hope that “we will lift Shanghai up and up, ever up, until it is just like Kansas City.”³

This was a prospect that many Chinese did not view with pleasure. Throughout most of their history, the Chinese have been wary of foreign importations, and not even the adoption of Communist ideology altered this fundamental attitude. Especially when under the influence of Mao Zedong’s ideology, many Chinese had misgivings about the adoption of foreign technologies. The underlying hostility toward the use of foreign technologies strongly asserted itself during the second half of the 1960s, when China was racked by the internal struggles that went under the name of the Great Proletarian Cultural Revolution. Among the victims of the often bloody conflicts that occurred during this period were technical experts who were accused of being captivated by foreign technologies and opposed to the efforts of China’s workers and peasants to develop indigenous technologies. Opponents of the use of foreign technologies also feared that these technologies would be accompanied by unacceptable foreign cultural patterns. Imported technologies, it was feared, inevitably would be accompanied by “bourgeois” habits and “decadent” activities.⁴ Elements of this mentality remain today, as authorities have created “the Great Firewall of China” in the hope of blocking outside influences carried over the internet.

China’s concerns about foreign influences have not been unique; throughout the Third World today can be found the apprehension that technologies developed in modern countries will result in the disruption of

traditional social and cultural patterns. In some countries, these apprehensions have motivated a return to traditional cultural patterns. This has been most notable in Iran, where rapid economic modernization led by the Shah's authoritarian government produced cultural and social disruption that eventually resulted in the ouster of the Shah and a resurgence of Islamic fundamentalism.⁵ Even in places where the reaction has not been as strong, many have mourned the passing of traditional patterns of life and thought, and their replacement by a social order that rejects established ways in favor of the latest novelties, and where a cold rationality intrudes into all human relationships.

This has been the fear. But is it really true that technological modernization has to be obtained as a complete package, and that it destroys all existing cultural patterns that are not favorable to it? Although it has been widely accepted, much of the evidence for convergence theory is impressionistic and anecdotal. Rigorous empirical tests are not abundant, and they do not always come to the same conclusion. In support of convergence theory, one study of Korean automobile workers found that exposure to industrial technology produced patterns of behavior and belief that were similar to the patterns exhibited by Italian and Argentinean automobile workers when their countries were at similar levels of industrialization.⁶ On the other hand, another study found that the values of individual workers were much more affected by their nationality than the kind of work they did; Brazilian oil refinery workers held values and beliefs that more closely resembled those held by farmers in their country than those held by their occupational counterparts in India or Ghana.⁷



Getty Images News/Getty Images

China has embraced some cultural elements from beyond its borders, yet it is far from certain that it is converging toward a common world culture.

A study by Robert Marsh took up the issue by hypothesizing that economically developed societies would exhibit less variation in the key characteristics of their social structures (form of governance, composition of the labor force, educational institutions, communications media, and so on) than less developed countries.⁸ Economically developed countries have more specialization than less developed ones, making social interactions both essential and frequent. These interactions need to be mutually comprehensible and predictable, which necessitates more uniformity. To take a concrete example, a buyer and a seller of some commodity or service need to assume that their transaction will not be affected by differences in their gender, ethnicity, tribal membership, or other “particularistic” identities. This essential uniformity is made possible by similar institutional characteristics across developed countries, such as centralized governments, high levels of school enrollment for girls and women, and widespread consumption of newspapers, television, and other communications media. Marsh’s research found that a few less-developed countries resembled more advanced

countries in some of their characteristics, such as widespread educational opportunities for girls and women. But his essential finding was that, on the whole, these countries exhibited much more variation than was found in developed countries. In other words, many of the structural elements of a developed country undergo a process of convergence with other developed countries, resulting in a greater degree of uniformity in many key social, economic, and political categories than in less-developed countries. Equally important, the research demonstrated that the extent of uniformity in developed countries increased over time.



SHAH MARAI/Getty Images

Although combining the two may at times be difficult, societies can incorporate both traditional practices and modern technologies, as exemplified by these Afghan women.

Although the case for convergence theory is plausible on both theoretical and empirical grounds, the role of technological change in promoting the convergence of societies is less certain. It would certainly be a stretch to think of technological change as a universal solvent that dissolves all prior cultural

and social patterns so that they conform to the presumed dictates of modern technology. The effects of specific technologies or of technological change in the aggregate are complex in the extreme, and it is simplistic to expect that all of the features of a society will be summarily transformed in accordance with technology's requirements. In this matter, it is useful to consider the words of David Landes: "Clearly there are no rigid compulsory relationships between a modern industrial economy and the entirety of its complex, multifaceted environment. Rather there is a wide range of links, direct and indirect, tight and loose, exclusive and partial, and each industrializing society develops its own combination of elements to fit its traditions, possibilities, and circumstances."⁹

Every society has its distinctive characteristics, and a particular technology will not necessarily produce the same effects for all that employ it. The actual consequences of a particular technology depend on why people have developed or adopted it in the first place.¹⁰ Having invented gunpowder, the Chinese used it for rockets and primitive cannon, but fireworks became the main application. In contrast, in late medieval Europe, gunpowder was eagerly employed as the basis of increasingly destructive weaponry. The uses to which a technology is put depends on history, existing social arrangements, and the distribution of power.

Similarly, television in the United States as well as much of the world is primarily geared toward entertainment and the desire of advertisers to persuade the viewing public to buy their products. In contrast, authoritarian states have used television to trumpet the achievements of their regime, and a great deal of programming consists of stories that glorify the political leadership. Even when a diffused technology is used for the same goals as in its country of origin, the manner in which the technology is used may still reflect cultural differences. Consider baseball in Japan. The game uses the same equipment, bases are 90 feet apart, pitchers have the same repertoire of pitches, and an inning ends when both teams have made three outs. But Japanese baseball reflects some important cultural elements of that country. Players do not argue with umpires, base runners do not aggressively attempt to break up double plays, fans usually cheer primarily when cheerleaders (who are middle-aged men) tell them to do so, it is considered impolite for a pitcher to disagree with the catcher's pitch selection, and games can end in

ties after twelve innings.

To take another example of only partial convergence, cars throughout the world use the same set of technologies and are similar in the layout of their controls. But as anyone who has driven outside his or her native land will attest, driving styles can vary greatly from place to place. In other cases, imported technologies may be accompanied by parallel behavioral and cultural changes, but these will be confined to a few enclaves that exert little influence over their surrounding society. Medical procedures at elite hospitals in poor countries may be similar to those in the developed world, but these are not available to the bulk of the populace. In sum, the introduction of new technologies may play a significant role in transforming a society, but only in conjunction with organizational, cultural, and other changes, and these usually unfold over a much longer period of time, if at all.

Experts, Expertise, and the Shaping of Technology

At the end of the sixteenth century, the philosopher, essayist, and corrupt government official Francis Bacon formulated a famous maxim: “Knowledge is power.” Since technology is ultimately based on knowledge, it stands to reason that the power to control technology will be wielded by those with the greatest technical knowledge. But is it so simple? Is the possession of the appropriate knowledge a sufficient basis for the exercise of control over the course of technological change?

During Bacon’s time it might have been possible for a well-educated person to understand most of the basic principles underlying the science and technology of the era. The body of human knowledge was limited, and no intellectual barriers separated laypeople from scientists and technicians. Scientific inquiry was not the exclusive province of professional scientists, so amateurs could make significant contributions. Technological knowledge was more restricted, as many craft secrets were jealously guarded, but there were no intellectual reasons that these could not be comprehended by an outsider.

The situation today is vastly different. Knowledge has been growing at an accelerating rate of speed. Whereas a mere ten scientific journals existed in the middle of the eighteenth century, according to one tally, in 2014, there were about 28,100 peer-reviewed journals published in English and an additional 6,450 in other languages. Together, they account for around 2.5 million articles each year.¹¹ The great technological achievements of our time are to a significant degree a reflection of the enormous growth of knowledge that has taken place, but at the same time, this “knowledge explosion” has made all of us relative ignoramuses. Even well-trained scientists and technicians have to admit their own limitations when they leave their own field of specialization. In a world in which there is so much to know, nobody knows very much.

This ignorance can limit the ability of citizens and their representatives to control the course of technological change. Most technologies are built on a

base of specialized knowledge; if most people are incapable of comprehending that knowledge, there looms the danger that the direction of technology will be left to the small cadre who are. When public choices depend on expert information, experts and not the electorate will supply and evaluate this information.¹² If this happens on a widespread scale, democracy becomes an illusion as vital issues such as climate change, nuclear power, genetic modification, and missile defense systems are not subject to public debate and citizen oversight. People can do nothing but accept the judgments of experts and hope that they are right.

But what does it mean to be “right”? Technologies cannot be judged purely according to their technical merit. Their social consequences have to be considered, and when this happens, value judgments often have to be made. These judgments necessarily take the expert well outside the realm of his or her expertise. To illustrate, biologists might agree that a new medical technology is effective in allowing a couple to choose the sex of the child they intend to have. More crudely, in some countries sonograms can be used to identify the sex of a fetus, which may be aborted if it is of the “wrong” gender—that is, female. These may be effective technologies, but should they be used? If they are used, the likely result will be a lopsided sex ratio where boys and men substantially outnumber girls and women. This is already happening in some countries. For example, in China and India, births of males outnumber the births of females by ratios of 119 and 115 to 100, respectively. Over time, this will result in a very large cohort of men with no hope of ever getting married, and a host of problems for these countries.¹³

Even when an issue seems to revolve solely around technical matters, hidden value judgments have a way of sneaking in. Many sophisticated tools used by experts, such as cost–benefit analysis, achieve apparent precision because they are based on simplifying assumptions that may reveal the analyst’s own preferences. To take one straightforward example, some cost–benefit analyses require the determination of the value of a human life, which has some objective bases, such as expected future earning power, but also may be affected by a government’s interest in promoting lifesaving regulations. The Environmental Protection Agency under the presidency of George W. Bush set \$6.8 million as the value of a human life. When the Obama administration took over, the figure was raised to \$9.1 million. At the

same time, the Food and Drug Administration reckoned that a human life was worth \$7.9 million, \$2.9 million more than the number used at the end of the Bush administration. Meanwhile, the figure used by the Department of Transportation remained the same at \$6 million for each life.¹⁴

Public participation in the shaping of technology may also be compounded by the desire of some experts to keep their knowledge secret. An expert can bolster his or her importance by being the sole source of important knowledge. The arcane nature of scientific and technological knowledge makes this inevitable to a certain degree, but experts have been known to draw a veil of mystery over their work in order to enhance their positions. The organizations in which they work have done the same thing. As Max Weber pointed out many decades ago, organizations commonly seek to expand their power and insulate themselves from outside pressures by keeping their knowledge secret.¹⁵

In addition to undermining democratic participation, secrecy can also result in bad decisions because it promotes “groupthink.” The only people deemed to be fully qualified experts are those who have access to secrets, and these secrets are accessible only to people within the same tight circle. As a result, everyone involved in a new technological project is an enthusiastic supporter, while potential opponents are excluded from the action. Major decisions can thus be made by a cadre of self-interested enthusiasts who are unchallenged by an informed opposition. The decisions to support the Concorde supersonic airliner and an ambitious atomic energy program in Britain occurred under precisely these circumstances.¹⁶

At this point, it is important to note that the power of expertise is not always based on the ability to offer superior knowledge; there are times when expert opinion is used to bolster an organization’s self-interested claims.¹⁷ As an old joke has it, individuals and organizations use expertise the way a drunk uses a lamppost—more for support than for illumination.

The commercial value of knowledge has at times created such a close relationship between profit-making enterprises on the one hand and scientific and technical experts on the other that freestanding experts are almost nonexistent in some areas of research. To take one notable example, until the practice was banned in 2004, researchers at the National Institutes of Health could receive payments for acting as consultants for pharmaceutical firms.¹⁸

Close ties, financial and otherwise, between researchers and these firms have also motivated some medical journals to require that contributors divulge these connections when presenting the results of their research. Another example of independent technical expertise being undermined by the experts' entanglement with other organizations and programs is provided by a software systems analyst who was asked to serve on an advisory panel that was to make recommendations regarding the computer development program for the Strategic Defense Initiative (SDI; the "Star Wars" antiballistic weapon program):¹⁹

I have a project with the U.S. Navy that could profit from SDI funding and I suggested to the panel organizer that this might disqualify me. He assured me quite seriously that if I did not have such a conflict, they would not want me on the panel. He pointed out that the other panelists, employees of defense contractors and university professors dependent on Pentagon funds for their research, had similar conflicts. Citizens should think about such conflicts the next time they hear of a panel of "distinguished experts."

Of course, even if some experts are not inclined to challenge technological policies, there may be other persons who will. Ralph Nader, in calling attention to the shortcomings of automobiles in the 1960s, especially in regard to safety or the lack of it, probably has done more to affect their design than any single engineer. Nuclear power has been under assault from a variety of quarters, and it is not likely that the issue will be resolved on the basis of purely technical criteria. Decisions to develop new military technologies can be intensely political. Technical considerations are important but not preeminent, for the decision to develop and deploy a new weapons system usually has significant economic, political, and strategic ramifications.

When major policy decisions are at stake, freestanding experts will likely find that their technical knowledge cannot easily be converted into political influence. This has been particularly evident in the political battles that have been waged over climate change. There have been two aspects to this issue. The first centers on the likelihood of rising future temperatures, which has been challenged by some members of the U.S. Congress, who claim that experts are divided on this issue. There in fact have been some dissenters, but one extensive study found that belief in the reality of climate change is closely correlated with the knowledge and research accomplishments of the

respondents.²⁰

The second issue, the extent of human contributions to climate change through the burning of carbon-based fuels, has been affirmed by 200 worldwide scientific organizations, ranging from the American Academy for the Advancement of Science to the U.S. National Academy of Sciences and from the Chinese Academy of Science to Britain's Royal Chemical Society.²¹ Yet for all of this scientific firepower, large numbers of individuals refuse to believe in the reality of climate change and its causes; according to a survey conducted in 2015, although 72 percent of those polled believed in the reality of climate change, only 50 percent were of the opinion that human activity is a major source of climate change.²² Public opinion is important for the shaping of policy, but for the short term at least, what really matters are the beliefs of those holding positions of power. It is here where expert knowledge has met with the most resistance; in 2016, large numbers of Congressional officeholders, including the chairman of the Senate Committee on the Environment and Public Works, vehemently denied the existence of climate change and the human causes of it.²³ Facts do not always speak for themselves, and ideological stances coupled with the influence of special interests can be very difficult to overcome.

In sum, experts are in a position to influence the course of technological change, but at the same time they face many difficulties in converting their knowledge into power. Being free from outside influences and having the correct technical answers are not enough; wielding power requires the mobilization of a constituency and the ability to create a broad base of support.²⁴ Even outside government, technological decisions have the same political character, with the same need for gathering support for projects and policies. This means that except for fairly trivial matters, issues often are not settled on the basis of purely technical considerations.

Engineers and the Control of Technology

To further explore the connection between expertise and the shaping of technological change, we will consider the working lives of the people who are most closely involved with technological innovation: engineers. As we shall see, more is involved in their work than the exercise of purely technical skills. In a modern economy, the design and development of new technologies is largely the work of engineers and other technical specialists. It seems natural, then, to expect that a great deal of control over the direction of technological development should be exercised by members of these occupations. Moreover, since so much of our world is shaped by technology, technical experts might be expected to have a powerful influence on society as a whole.

As we have seen in Chapter Chapter 2, some have argued that technocracy, the exercise of political authority by engineers and other technical experts, was the soundest and most rational way to govern. One of the most systematic and influential statements of the virtues of technocracy was the work of a sociologist/economist named Thorstein Veblen, who expounded his ideas during the first two decades of the twentieth century. According to Veblen, engineers and other technical experts were the “indispensable factor in the everyday work of carrying on the country’s productive industry.”²⁵ But at the same time, “they have nothing to say in the planning and direction of this industrial system, except as employees in the pay of financiers.”²⁶ It was this contradiction between the technical acumen of the engineers and their subjugation to managerial control that Veblen saw as the greatest obstacle to continued economic progress. The only solution was a takeover of business enterprises by a “Soviet of Technicians” so that the economy would be continuously stimulated by technological advance instead of being retarded by the narrow financial interests of absentee owners and their delegated managers.²⁷

Veblen’s ideas provided inspiration for a technocratic political movement that flourished for a brief period during the 1930s and then expired.²⁸ But the

idea that technical expertise should be the proper basis of control did not die with it. Several decades later, a number of social scientists advanced the idea that Veblen's prescriptions had been achieved; the enterprises of advanced industrial economies were now under the control of engineers and other technologically oriented personnel. For sociologist Daniel Bell, the key personnel in modern corporations were the "corporate organizers," a "special breed, often engineers, whose self-conscious task was to build a new economic form."²⁹ A similar theme was sounded by economist John Kenneth Galbraith in his influential book *The New Industrial State*. Galbraith argued that the owners of large business firms no longer ran them, as had been the case in the days of the traditional entrepreneur. Instead, the management of modern enterprises was now in the hands of the "technostructure": managers and engineers with the specialized knowledge and talent essential to planning and decision making.³⁰

Many of the assertions presented in *The New Industrial State* have been largely refuted in the decades following the book's publication.³¹ But one concept is at least worthy of further inquiry. Galbraith's invocation of the "technostructure" has directed our attention to the role of engineers and other technical experts in the management of modern firms. As subsequent research has shown, engineers as a group are deeply involved in management, but they do not form a technocratic elite, nor, at the other end of the spectrum, are they simply hired hands.

In understanding the role played by engineers, it is important to note that, along with other skilled occupational groups, engineers expect to be recognized as professionals. At the most basic level, the work of a professional centers on the possession and application of specialized knowledge that is found only within the ranks of the profession. This means that someone outside the profession is not qualified to pass judgment on working professionals; only other professionals are able to do so. Consequently, the essence of professionalism is autonomy.³² This has been evident in the long-established professions, such as medicine and law, where doctors and attorneys have been accustomed to the insulation of their careers from outside forces. In part, this has been due to the fact that, until fairly recently at least, they have been in business for themselves as independent practitioners. But this has not been the case with engineers. Except for a

small number of private consultants, engineers have been the employees of an organization, usually some sort of business enterprise.

While serving as employees, engineers do enjoy a considerable amount of freedom as they go about their work. They are not subject to rigid supervision, and they have considerable discretion regarding how they plan their activities and schedule their work. They have to respond to the requests of management and deal with the problems presented to them, but they have wide latitude in determining how the job is done.³³ At the same time, however, the work of engineers is closely constrained by the expectations of their employers. While they have the freedom to decide how a job is to be done, engineers have little influence over the choice of what is to be done. And, in truth, few engineers are concerned about their lack of influence in the setting of company policies or the purposes to which their talents are being put. The engineer's training and on-the-job socialization do not produce ambitions of this sort. The work of engineers exemplifies the rational search for the best way of attaining particular ends. But engineers rarely have the privilege of selecting these ends. Indeed, once they do, they no longer act as engineers.³⁴

While engineers are subject to managerial authority, they often exert their own authority by joining the ranks of management. This is a common practice in the United States. According to a survey conducted in 1999, of the 1,300,000 employed engineering graduates, 306,000 occupied senior management positions, and another 66,000 held other administrative positions.³⁵ At the same time, however, engineers holding management positions paradoxically results in dilution of engineers' influence. For many engineers, career success means attaining a managerial position, not being an increasingly proficient engineer.³⁶

Engineering and management require different skills and orientations. As Samuel C. Florman summarizes, "The characteristics of a good manager—a feeling for people, politics and the bottom line—appear to conflict with those of a first rate creative engineer—an aptitude for numbers, theorems, materials, and spatial relationships."³⁷ But while orientations and even fundamental values may conflict, with the prospect of a managerial career dangled in front of him or her, a practicing engineer is not likely to challenge managerial values, even when they may conflict with the engineer's

professional values. Expert knowledge and a lifetime devotion to the acquisition and use of that knowledge are central to the professional's value system; in contrast, businesspersons and managers value loyalty and personal initiative. The prospect of moving from engineering into management can affect a person's values and undercut his or her identity as an engineer.³⁸

The problems of an engineer influencing company policy are illustrated by the dangers of "whistle-blowing." A whistle-blower is someone who detects some sort of wrongdoing within his or her organization and brings it to the attention of the public. An engineer can be put in this position when management makes a decision that is so technically unsound or otherwise defective that it poses a threat to the user or to society as a whole. Since an engineer knows the technical facts of a case better than anyone else, he or she is in the best position to reveal whatever problems have appeared.



The LIFE Picture Collection/Getty Images

An engineering office in the 1950s. Although computerization has reduced the need for paper documents, most engineering work is still

done in an organizational setting.

Engineers may be willing to call attention to serious problems because of their conviction that “the facts speak for themselves.”³⁹ In this, they are sadly naive. Most engineers work in organizational settings with strong hierarchical structures. Decisions are made in accordance with vertical relationships; those at the upper levels can countermand those at the lower level, even if the latter have the “facts” in their favor. This is dramatically illustrated by the experiences of some engineers who worked for a major defense contractor. After a chief engineer designed an aircraft disc brake that was woefully deficient in stopping power, he enlisted the support of his superiors in falsifying crucial test data. When a lower-level engineer and a technical writer objected, they were told to keep their mouths shut and participate in the falsification. Subsequent testing by the Air Force revealed the brake’s dangerous shortcomings. Deeply disturbed by the whole process, the dissenting engineer and the writer resigned from their positions. All of the conspirators retained their jobs, except for two who were promoted to higher positions.⁴⁰

The hierarchical structure of organizations also helps management to control communication; employees are expected to “go through channels.” Facts that pose a challenge to a superior can thus easily be suppressed. The only alternative is circumventing the hierarchy; a concerned employee can attempt to get the attention of officials at much higher levels of the organization, or he or she can reveal malfeasance to the media or some other outside agency. These are risky courses of action. Top-level officials do not like disturbances of conventional channels of authority, and they are also likely to have doubts about an employee who has gone behind the boss’s back. Revealing a problem to the media or an outside agency is an even worse breach of proper organizational behavior. Loyalty is much prized in organizations, and an employee who is perceived as being disloyal to his or her superior or to the organization as a whole is someone to be scorned.

The perils of whistle-blowing by an engineer were starkly revealed by the events following the breakup of the space shuttle *Challenger* 73 seconds after it was launched on January 28, 1986.⁴¹ A group of engineers from Morton-Thiokol, the manufacturer of the shuttle’s solid-fuel booster rockets, had warned the night before the launch that cold weather could cause a failure of

the O-rings that sealed the segments of the rockets. After the erosion of an O-ring resulted in the tragedy that many had feared, Roger Boisjoly, a specialist in seals who had worked on NASA projects for 20 years, provided the official government board of inquiry with an internal memo he had written six months earlier in which he had called attention to the danger of launching the shuttle in subfreezing weather. This soon led to his being ostracized and isolated at Morton-Thiokol. Suffering from depression, headaches, and double vision, he left his secure and remunerative job, sold his house, and moved out of the community in which he had lived for many years. Afterwards, he spoke to more than 300 universities and civic groups about corporate ethics and was awarded the American Academy for the Advancement of Science's Prize for Scientific Freedom and Responsibility, but he had paid a heavy price for calling attention to the reckless irresponsibility of some of his colleagues.⁴²

The battle of an engineer against his or her organization is likely to be a lonely one. Especially unfortunate is the fact that the professional engineering associations usually are not very helpful to the whistle-blower. These associations have often been dominated by businessmen who are more likely to be concerned with their industry than they are with the career concerns of individual engineers.⁴³ This is illustrated by the case of Ernest Fitzgerald, who was summarily fired after he had called attention to the huge cost overruns on the Lockheed C5A transport plane. His professional association, the American Institute of Industrial Engineers, spurned Fitzgerald's request to "investigate the professional and ethical questions involved." It refused on the grounds that it was a "technical organization," and not a "professional society." The inclusion of military contractors as members of the Institute made this a likely outcome.⁴⁴



N.A.S.A./SIPA/Newscom/Sipa Press/KENNEDY SPACE CENTERFLORIDA USA

The ill-fated crew of the *Challenger*.

From this brief survey, it should be apparent that engineers do not exercise commanding influence over the course of technological change. Their work, while essential to technological development, is constrained by the economic, political, and organizational environment in which engineering operates. The crucial decisions are made by management, and even if engineers are often recruited into its ranks, when this happens they necessarily change their orientations. Managers must be primarily concerned with profit or some other organizational goal; technical virtuosity cannot be an end in itself. If we are looking for a major source of control over technology, we therefore need to look beyond engineers to the organizations that employ them. This will be done in the next chapter.

QUESTIONS FOR DISCUSSION

1. Which twentieth-century technology has produced more changes in our lives, television or the automobile? What have their social consequences been? Are these consequences solely due to these technologies, or have these technologies interacted with other sources of change?
2. Which technologies seem to confront the greatest amount of cultural lag? Why is this so? Are these lags necessarily bad, or do they serve some useful purposes?
3. Globalization has enriched our cultural lives, and has brought a number of economic benefits. At the same time, it has been the source of a fair number of disruptions, some of them, like lost jobs, quite serious. Should anything be done to restrain globalization? Is it even possible?
4. From its origin in San Bernardino, California, the McDonald's fast-food chain has spread to Europe, Asia, Africa, Latin America, and Australia. The food, decor, and general ambience of a McDonald's restaurant are about the same wherever you go. Is McDonald's a harbinger of a U.S.-based universal world culture? Is the "McDonaldization" of the world a good thing? What sort of forces stand in opposition to it?
5. Some scientific and technological experts claim that nuclear power is safe and economical, and that catastrophes like Chernobyl and Fukushima were anomalies caused by highly unusual events. Other experts say just the opposite. How can a nonexpert choose between the two? What sort of procedures might be used in order to determine which group's claims are more valid?
6. In this chapter, the assertion is made that engineers cease to act as engineers when they are involved in the selection of the goals to be pursued by their organization. Do you agree? How might the professional abilities of engineers make them effective participants in the goal-selection process? How might these abilities hinder them?

CHAPTER NINETEEN

Organizations and Technological Change

Organizations are a dominant part of modern life. Most of us are born in organizations, are educated in them, spend our working lives in them, and, when we finally depart from this world, one organization takes care of our mortal remains while another attempts to ease our passage into the hereafter. The pervasive influence of organizations has stimulated a considerable amount of research on their relationship to technological change. We will first consider how organizations are affected by technology. After that, we will turn things around and look at how organizational structures and processes can influence the course of technological change.

Technology as a Cause of Organizational Structure

Much of the research on the interaction between organizations and technology has been concerned with the influence of technology on organizational structures and processes. Many of these studies have come to the conclusion that an organization's structure—the extent to which authority is centralized, the extent of worker specialization, and the number and importance of formal rules—is strongly influenced by the principal technology that the organization uses.

“Organizational structure” is an abstract term that may seem remote from actual working lives. In fact, organizational structures can be of supreme importance; some promote workplaces that are challenging, involving, and sources of satisfaction, while work performed under different structural conditions is “just a job” that provides a paycheck and little else. The same can be said about the kinds of technologies found in different work environments. Some workplace technologies have the potential to empower workers and make their work a meaningful activity, while other technologies have the opposite effect.

Empirical Studies of Organizations and the Technologies They Use

Quite a lot of research on the relationship between technologies and organizational structures was conducted in the 1960s and 1970s, while more recent research has built upon the insights generated by these studies. One early study was conducted by Robert Blauner.¹ His research focused on a number of different industries that exemplified particular types of technologies and how these affected organizations and their employees. His examples were drawn from the industrial sector at a time when making things constituted a larger part of the economy than it does today. Nevertheless, his research has provided some useful ways of considering the relationship between production technologies and organizational patterns. His first example, printing, was characterized by a set of activities reminiscent of traditional craft occupations that required a high degree of worker skill and involvement. Conducting his research at a time before the invention of computerized typesetting equipment, Blauner found that the absence of specialized machinery resulted in a work environment that allowed a great deal of worker autonomy. In contrast, textile mill operatives were little more than machine-minders. Their activities had to be closely attuned to the demands of the equipment, so there was little room for individual initiative. The third industry studied was the automobile industry, which used assembly-line operations that forced the worker to submit to a rigid scheduling of activities that was dictated by the inexorable movement of the line. Finally, and in sharp contrast to the last two, continuous process industries, such as chemical manufacture or oil refining, made use of highly sophisticated technologies, but unlike textile production or automobile manufacture, they required considerable worker involvement and initiative. Workers had to carefully monitor production processes and take decisive action when the inevitable problems occurred. Their work could not be precisely scheduled or regulated, and they enjoyed a considerable amount of on-the-job freedom.

Whereas Blauner's study focused on the relationship between the technology used by an industry and its effects on workers, Joan Woodward's

inquiries centered on how different technologies affected organizational structures.² Of particular concern to her were such structural variables as the number of levels in the managerial hierarchy, the ratio of managers to other personnel, the number of people supervised by first-line managers, and the flexibility of the managerial system. Woodward was not concerned with individual technologies, but with general manufacturing processes. Her mode of analysis made use of three broad categories: unit and small-batch production (such as shipbuilding or the manufacture of large transformers), large-batch and mass production (as exemplified by automobile manufacture), and process production (such as making chemical or petroleum products).

According to Woodward, each of these categories was distinguished by differences in technological complexity and the extent to which uncertainty could be reduced through the application of routine procedures. These differences, in turn, resulted in different types of organizational structures each with their distinctive processes. Mass-production technologies required routinized processes, narrowly defined job duties, and a clear hierarchy of authority that kept a firm grip on things. In contrast, the two other methods of production—unit production and continuous process production—were much less rigid in their operations and had a regular flow of worker–management communication that was not filtered according to hierarchical position. In similar fashion, the span of control—the number of workers under a single supervisor—was greatest in firms using mass-production technologies. Other kinds of organizational differences also seemed to reflect production technologies. Managerial specialization occurred more frequently in mass-production firms, and process production technologies required a higher ratio of managers to other personnel than was the case in organizations using different productive technologies. More relationships could be cited, but Woodward’s essential point is that organizational forms must be matched to production technologies. In practical terms, an effective organization is one that uses structures and procedures that are appropriate to the productive technology employed.³



William Taufic/Getty Images

Industries using continuous-process technologies like this chemical plant typically require more worker involvement and initiative than factories using mass-production technologies.

Woodward's study was an early contribution to a mode of organizational analysis known as "contingency theory," which postulated that there is no optimal mode of organization that can be applied to every type of activity. This insight is even more relevant after the passage of five decades; organizations today deal with products and processes that barely existed when Woodward was conducting her research. Current and future researchers will have no lack of topics when considering the organizational correlates of postindustrial technologies such as software, biomedicine, and material technology.⁴

Another example of an organizational theory guided by a consideration of technology has been provided by the work of Charles Perrow. Perrow's theory is pitched at a more general level than that of Blauner or Woodward. Instead of considering specific types of production technologies, Perrow considers two basic aspects of the work undertaken within an organization: the degree of variability of the raw materials processed by the organization, and the extent to which problem-solving procedures can be routinized. By raw materials, Perrow does not mean just inanimate objects; iron ore is a basic raw material for a steel mill, but for an employment agency, people are its major raw material. In "processing" its raw materials, an organization will confront different degrees of difficulty. Perrow's analysis of the problem-solving process centers on the number of exceptional cases that must be confronted and the extent to which the problem-solving procedures are "analyzable"—that is, the extent to which they can be reduced to a routine. Different kinds of organizations are characterized by different combinations of these elements.⁵

1. Few exceptions and analyzable problem-solving procedures, as exemplified by:
 - mass-production manufacture
 - custodial mental institutions
 - prisons
2. Few exceptions and unanalyzable procedures, as exemplified by:
 - craft manufacture
 - custom-made products
 - most schools
3. Many exceptions and analyzable procedures, as exemplified by:
 - engineering
 - heavy machinery manufacture
 - a large portion of medical practice
 - building construction
4. Many exceptions and unanalyzable procedures, as exemplified by:
 - cutting-edge scientific research

- much of the aerospace industry
- painting, sculpture, and other fine arts

Perrow's implicit definition of technology is quite general and abstract. Technology is simply viewed as a way of doing things, and no attention is paid to the material artifacts that are part of these technologies. What is important is the nature of the raw material and methods used to convert it into the organization's products. Above all, Perrow is concerned with organizational effectiveness. A major conclusion of his analysis is that the organizational structure should reflect the particular qualities of the raw materials being used and the technologies used for their transformation. To be effective, an organization must use technologies appropriate to its tasks. His conclusions are thus similar to Woodward's: There is no such thing as an optimal organizational form that is universally valid. Everything depends on how things are produced and the materials from which they are made.

These studies, and others like them, have sensitized organizational theorists to the influence of technology on organizational structures and processes, albeit at the risk of drifting toward technological determinism. In general, research into organizations has shown that their structures and processes are influenced by the technologies that they use, although the relationship is not particularly strong.⁶ This lack of a definitive relationship between technology and organizational structure is understandable, given the numerous variables that shape organizations. The way that an organization gets its work done will likely affect its structure, but technology is not the only factor involved. As many students of organizations have pointed out, an organization's size will also affect how it is structured.⁷ The same can be said about complexity; rather than making use of a single technology, organizations employ a variety of technologies, especially when they have numerous functional divisions. A research and development (R&D) laboratory and an accounting office may be components of the same organization, but their technologies will differ substantially. Accordingly, the linkage between technology and organizational structure is likely to be more evident when the basic element of analysis is the work unit rather than the organization as a whole.

What does seem clear is that a crucial variable connecting technology and organizational structure is the degree to which an organization's operations

consist of routine activities. What is meant by “routine” in this context is the kind of activities that can be done by following standardized procedures.⁸ The job of a cook in a fast-food restaurant is mostly a matter of cooking a few items according to a preset timer and doling out portions of ketchup from a dispenser that always supplies the same quantity. Contrast this with the work of a chef in a high-end restaurant, who uses a variety of cooking techniques, develops new dishes, and makes use of seasonally available fruits and vegetables. Technologies that reduce work to preset routines are a good fit with formalized organizational structures and their well-articulated rules, clearly defined responsibilities, and fixed lines of authority. In contrast, forcing routinization on the employees of an organization that requires creativity is likely to be counterproductive.

Although size, the extent that its activities can be routinized, and the technologies they use influence the way that organizations are structured, this is not the end of the story. Organizational structures are created by individual men and women, and as such they reflect the cultural traits that these individuals bring to the organization.⁹ These, in turn, will affect the relationship between technology and organizational structure. One study of manufacturing plants in Britain, France, and Germany found that the relationship between technology and organizational structure found by Woodward did not hold when a cross-national analysis was undertaken. No matter what the level of technological complexity, German firms had higher levels of worker expertise, autonomy, and flexibility than French firms, while British firms were in an intermediate position. In similar fashion, a study of American and Japanese factories found that there was less specialization and taller hierarchies in the Japanese firms even when the technologies used were substantially identical to the ones employed in the American factories.¹⁰

The influence of national cultures on organizational structures and processes illustrates an enduring problem in ascertaining the relationship between technology and organizational structure. Although many questions remain unanswered regarding this relationship, the studies that have been conducted have led to a significant rethinking of the nature of organizations and their management. As has been previously noted, what works with one production technology will not necessarily work with another. In order to be successful, an organization needs to develop and use organizational structures

and processes that are appropriate for the technologies it employs. As a result, many different kinds of organizational structures have been developed and used—matrix organizations, “ad-hocracies,” task forces, project teams, loose aggregations of professionals, and “skunk works.”¹¹ And all the while, plain old bureaucratic organization is alive and well in places where it is still appropriate (and sometimes where it is not).

Technology as a Consequence of Organizational Structure

Up to now, we have considered how technology affects organizations. Yet the reverse can also be true. Organizations can shape technological change through their ability to affect the supply and demand for a particular technology. We are a long way from a perfectly competitive market, where no individual firm is able to significantly influence the supply of a product or the demand for it. In regard to supply, an organization that accounts for a significant portion of an industry can strongly influence the technological development of the industry as a whole when it creates (or refrains from creating) new products. The choices of a few firms thus determine the kinds of cars we drive, the way steel is made, the operating systems used by our computers, and the links we get when we do a Web search. In similar fashion, when a few organizations are the major purchasers of particular products (as when a few aerospace firms buy highly specialized machine tools), their requirements will determine the nature of the product and the technology it embodies.

On what basis do organizations make technological choices? This is an important question, given the importance of organizational decisions for the course of technological change. Unfortunately, researchers have not paid much attention to this issue. Most of the studies centering on the connection between technology and organizational structures and processes simply take technology as a given. In the studies just summarized, the technologies used by organizations appeared as independent entities. These studies tacitly imply that organizations and their personnel react passively to the presumed dictates of technology, and in so doing they fall prey to technological determinism.

It is possible, however, that the technologies employed by an organization are themselves the product of an organization's own structure and processes, and, in particular, the configurations of power within the organization. Such a view would be in general accord with the perspective presented earlier in this book that technologies can be, and often are, employed by individuals or groups in order to advance their own interests. Charles Perrow, whose ideas

were described a few pages ago, has recognized this, and in so doing, has expressed some disenchantment with his earlier work in which he took technology to be an independent influence on an organization's structure. Perrow forcefully makes the point that, after all is said and done, organizations are powerful tools for achieving goals. Much therefore depends on who controls the tools, and for what purposes.¹² A technology might be selected not because of its innate superiority but because it meets the needs of the power holders within that organization.

One example of this process can be found in the early history of electrical power in the United States.¹³ Until 1915, the most common sources of electrical power were small-scale generating plants that had been set up to serve individual homes, apartment buildings, or business enterprises. In the years that followed, these facilities went into decline as large generating stations serving a wide area came to be the dominant mode of generating electrical power. Some of the success of these stations can be attributed to more efficient operation through economies of scale, but more was involved than the pursuit of efficiency. Of considerable importance to the shaping of the American electrical power industry were two industry-wide organizations, the National Electric Light Association (NELA) and the Association of Edison Illuminating Companies (AEIC). These organizations were, in turn, strongly influenced by a few men who had close personal and organizational ties to Samuel Insull, the entrepreneur who played the leading role in the construction and operation of large-scale urban generating plants. Insull's associates used their strategic position within NELA and AEIC to determine the kinds of topics discussed at meetings of the two associations and the papers they published, and to take the lead in prescribing the equipment and procedures deemed best for the industry. Most importantly, the group was able to strongly influence the drafting of government regulations that worked to the advantage of privately owned, centralized generating plants and to the detriment of local, small-scale facilities. In sum, the basic technological configuration of electricity generation was not solely the result of technical and economic requirements, but it also reflected the use of organizational power to advance the interests of particular individuals and firms.

Another noteworthy example of the choice of technology being affected

by the exercise of power in an organizational setting is provided by David Noble's study of the development of numerically controlled machine tools.¹⁴ During the early 1950s, the Servomechanism Laboratory at the Massachusetts Institute of Technology, with the financial support of the U.S. Air Force, produced the first numerically controlled (NC) machine tools. Instead of being manipulated by skilled machinists, these devices were guided by programs stored on magnetic tape. NC technology increased productivity and allowed the precise machining of the complex shapes used in modern aircraft. At the same time, NC machine tools significantly reduced the amount of skilled labor required and removed a great deal of decision-making power from the machinists. These consequences could be taken as an unavoidable by-product of technological advance; that is, the technology determined the skills, work patterns, and hierarchical relationships found in a machine shop using NC machine tools.



amriphoto/Getty Images

For some managers, the appeal of numerical control lay in its ability to diminish the power of skilled workers like this machinist.

The actual story is quite a bit more complicated. Most importantly, the use of numerical control was not the only way to make machine tools run automatically. During the late 1940s, a “record-playback” method for machine-tool guidance was developed. This technology recorded the motions of a machinist making a part. These motions were recorded on magnetic tape, which was then used to run the machine tool. The machinist, and not a programmer removed from the workplace, was thus the source of the machine’s instructions. As it turned out, this was the greatest drawback of this technology. Numerical control was far more appealing to managers because it allowed them to gain more control over the work process. NC tools promised a reduction of the decision-making powers of workers and vested it with managers, engineers, and programmers. In the words of one manager: “Look, with record-playback the control of the machine rests with the machinist—control of feeds, speeds, number of cuts, output; with NC there is a shift of control to management. Management is no longer dependent upon the operator and can thus optimize the use of their machines. With NC, control over the process is placed firmly in the hands of management—and why shouldn’t we have it?”¹⁵

As things turned out, NC did not completely fulfill management’s hopes for greater control. As we have seen in Chapter 10, computer-controlled production systems have their drawbacks, and the fully automated factory is still a long way off, even with today’s generation of computer numerical control (CNC) machines. Although the growth in the number of jobs for machinists is only about average when compared with all other occupations,¹⁶ their services are still vital; a worker lacking the necessary skills can do tens of thousands of dollars of damage in a few seconds.

The relationship between technology, worker skills, and organizational authority has become especially salient as a result of the incorporation of computers and automated systems into production processes. Modern information systems can be used to enhance the power and responsibilities of shop floor workers. At the same time, however, they can produce the opposite effect by giving management a greater capacity to centralize operations and restrict the discretion of the workers. As one manager asserted, “The more we can control with the computer, the less dependence we will have on operators with in-depth knowledge. When there is a problem,

we will have computer programs, logic, electronic sensors. We will be able to understand the problems.”¹⁷

A certain degree of computer-based centralization may be justified in terms of its supposed contribution to coordination and efficiency. But this is hardly its only rationale. Many managers worry that computerized information systems can just as easily dilute managerial authority by making information more readily available to ordinary workers. A top executive from the same firm as the manager quoted above described the potential erosion of managerial authority:¹⁸

The classic managerial role has been that of the handler, manipulator, dealer, and withholder of information. An issue that the technology is forcing us to face involves the loss of managerial control.... Suddenly you are vesting in folks at the control station, folks who are interfacing with a tremendous technology power—power to see all the functions of the operation. That is kind of scary to some managers.

Managers realize that the control of information has been an essential element of their authority. Consequently, in the words of one line manager, “Managers perceive workers who have information as a threat. They are afraid of not being the ‘expert.’ They are used to having everyone come to them and ask what to do.”¹⁹ This use of information was duly noted by a worker in the same firm: “[Managers] can’t share information with us, because only by holding on to knowledge that we don’t have can they maintain their superiority and their ability to order us around.”²⁰

In this setting, computer-based information systems are not neutral instruments; rather, they are likely to be used in ways that are congenial to those occupying positions of authority within organizations. As with CNC machine tools, a technology may be employed because managers see it as a way of extending their own power. Conversely, computerized information systems may be used to empower workers, enhance their responsibilities, and give them a claim to higher wages and salaries. There is no simple technological logic governing the use of these systems. The use of an existing technology may reflect the existing distribution of power in an organization, while the installation of a new technology may become an occasion for conflict over how it will be wielded in the future.

Organizational Size and Technological Innovation

Technological innovation requires the commitment of personnel, money, and equipment if it is to be successful. It therefore seems logical to expect that large organizations, which are well endowed with these resources, should be the prime sources of technological changes. This expectation has been clearly articulated by John Kenneth Galbraith: “A benign Providence ... has made the modern industry of a few large firms an excellent instrument for inducing technical change. It is admirably equipped for financing technical development. Its organization provides strong incentives for undertaking development and for putting it to use.”²¹ For Galbraith and others who hold to this view, the day has long passed when independent inventors and small firms were the prime source of important new technologies. Their place has been taken by the well-financed laboratories and workshops of large corporations and government agencies.

On the face of it, this seems reasonable. It is hard to imagine how jumbo jets and mainframe computers could be produced in basement workshops. But the large-scale production of an innovation is not the same thing as its original conception and creation. In point of fact, many important inventions were first conceived and produced by small firms. Only when their technical feasibility had been demonstrated did they become products of large enterprises. Key patents on the turbojet were held by Frank Whittle, an Englishman who produced some of the world’s first jet engines in a small workshop that was chronically short of funds and personnel. The first digital computer, the ENIAC, was put together at the University of Pennsylvania’s Moore School of Electrical Engineering by John Mauchly and J. Presper Eckert with the assistance of ten engineers. Hewlett-Packard’s startup in a garage and Apple’s modest financial underpinnings during its early years are the stuff of Silicon Valley legend.

Examples like these are interesting but hardly definitive, and in fact efforts to determine with some precision the connection between organizational size and inventive activity have had mixed results. The

assertion that large organizations play a preeminent role in the process of technological advance has not been supported, but neither has it been completely repudiated.²² Attempts to find a simple correlation (either positive or negative) between firm size and inventive activity are doomed to failure because factors other than size have to be taken into account. Of at least equal importance is the perceived developmental potential of the technologies relevant to an industry's products and operations. R&D efforts will be extensive in industries where key technologies are judged to have high potential for further development, and less so when technological prospects appear to be limited. To take two examples, in 2007 the communications equipment industry spent 14.9 percent of net sales revenues on R&D, while the finance, insurance, and real estate industries collectively allocated only 0.4 percent of their net revenues for this purpose.²³ Even if a correlation between size and inventive activity existed, it would tell us nothing about how effective the research efforts of large firms have been. Much of the research conducted by large organizations with secure markets is not oriented toward the production of radically new things but is directed at the creation of modest, incremental improvements. Large firms that control a substantial share of their market are more likely to produce inventions that maintain the status quo and to avoid engaging in research that might radically alter the industry in which they already have a comfortable niche. Conversely, small firms or independent units of larger firms have been more successful in creating, developing, and marketing inventions that disrupt the technological status quo.²⁴



DB Apple/Newscom/Picture Alliance/Mountain_View California United States of America

Steve Jobs and Steve Wozniak with their first commercial computer, the Apple II.

To be sure, invention is not the same thing as innovation. To actually bring an invention successfully into the marketplace may require the resources of a large organization. As we have already seen, the development of new technologies can be a lengthy and expensive process. Large organizations are often better equipped to do development work, where scaling up and making relatively small but nonetheless important improvements are the key tasks. This may be their most important contribution to technological innovation.

These generalizations of course do not apply to all industries. In some industries, such as nuclear power, the bulk of both the research and development work has been done by large firms and government agencies. In other industries, such as smartphone and tablet apps, a great amount of innovative effort has come from individuals and small firms. About the safest statement that can be made is that technological advance requires the efforts of a wide variety of organizational types and sizes. The initiation and

development of some technologies require the massive efforts that only large organizations can provide. At the same time, many technologies have been—and will continue to be—brought forth by people working in small organizations or just by themselves.

Organizations and New Information Technologies

Some of the issues surrounding the relationship between technological change and the evolution of organizational structures appear in sharper focus when we take a look at digital information technologies. Numerous scholars have pointed out that the essential work of organizations centers on the manipulation of information, broadly construed. Whether it is within an employment office, a bank, or a school, members of an organization spend a great deal of their time gathering information, analyzing it, deciding what to do in the light of what they have learned, communicating with others, and evaluating and reporting what has been done.

During the second half of the nineteenth century, organizations were able to expand, improve their operations, and operate at higher levels of efficiency and effectiveness through the use of what were then novel technologies for gathering, recording, analyzing, distributing, and storing information—typewriters, telegraphs, dictating machines, telephones, pneumatic tubes, standardized forms, carbon paper, and filing systems.²⁵ Recent decades have seen more revolutionary changes in information technology, and few of today's organizations can get along without computers, database management programs, word processing, spreadsheets, the internet, email, copy machines, and voice mail, while growing numbers of organizations are making extensive use of more recently introduced technologies like smartphones, intranets for internal communications, and videoconferencing for linking participants from all over the globe in real time.

The nearly universal use of electronic information technologies has motivated a substantial number of researchers to conduct inquiries into how these technologies have affected the structure and functioning of contemporary organizations. In general, this research has indicated that advanced information technologies have sped up operations, reduced costs, increased the amount and accessibility of information, and more extensively linked members of organizations.²⁶ Less certain, however, are the effects of new information technologies on organizational structures and procedures.

As with all significant technological advances, there is rarely a simple, straightforward connection between technological and organizational changes. A new information technology, no matter how radical, is only one of many influences on a particular organization, and not necessarily the most important one; other organizational features, such as size, the composition of the work force, and the nature of the clientele, may be more significant than the information technologies used.



Corbis

A clerical worker demonstrates two state-of-the-art communication technologies from the early 1930s, a typewriter and a Dictaphone.

One much-discussed issue has to do with the role of new information technologies in promoting organizational decentralization. As some students of organizations have argued, a primary reason for the concentration of organizational authority in times past was the difficulty of obtaining and

analyzing information. Information was a scarce resource, something that could be provided for only a few members of an organization, those at the top of the managerial pyramid. In similar fashion, only those at the summit of the organization were deemed capable of intelligently acting on the information made available to them. In contrast, today's digital technologies make information and the ability to analyze it readily available at low cost, allowing more decentralized and participatory modes of decision making. This does seem to be happening; one study of 400 large firms found that greater levels of information technology were in fact associated with more delegation of authority to individuals and teams.²⁷

The easy availability of information makes it possible to decentralize organizational authority and to empower workers, but as has been noted before, the way that a technology is used is not entirely determined by the technology itself. Whether a powerful information technology promotes centralization or decentralization may have more to do with existing distributions of power and authority than with presumed technological imperatives. Instead of democratizing the workplace, today's information technologies may be used to enhance managerial control. As we have seen in Chapter 11, some new workplace technologies, far from empowering workers, may enhance top-down control through the use of electronic monitoring.²⁸ To take another example, it has sometimes been stated that the use of email has eroded organizational hierarchies by allowing direct communications between the upper and lower ranks. This may come to pass when the top organizational echelons value and encourage bottom-up communications, but many managers would prefer to avoid such "distractions." Even when managers are receptive to communications from employees lower down in the organization's hierarchy, there is always the likelihood that these messages will be lost in the blizzard of email communications that plague most organizations. In any event, a lot depends on what the members of the organization, especially the managerial cadre, want to do with new communications technologies.



Cultura/Getty Images

Today's communication technology allows the separation of work and workplace.

As a final point, it should be kept in mind that new communications technologies do not necessarily supplant existing ones. For example, it might be expected that the growing use of the telephone in the early twentieth century reduced the need for traditional forms of communication, but in fact the opposite occurred, as telephone use seems to have stimulated the desire for more face-to-face communication, not less.²⁹ The same thing may be happening today. New electronic media such as email and videoconferencing certainly have their place, but they fail to provide some crucial elements of communication, such as body language and indications of whose turn it is to speak. Old-fashioned, face-to-face communication may not be of much importance for many organizational tasks, but it is usually essential for activities that have an important social-psychological component, such as negotiating, maintaining relationships, and building trust.³⁰

Interorganizational Relations and Technological Development

No business firm, no matter how large, develops all of the technologies that are embodied in its products. Every firm depends on a network of suppliers for the new materials, components, and even the ideas that are incorporated into its own products. This is especially true of mature industries, where supplier firms are likely to be the principal source of substantial technological breakthroughs.³¹ Without the efforts of outside suppliers to develop and sell innovative products, it is likely that the technological level of many established industries' products would stagnate. Technological changes are therefore shaped not only by the structure and dynamics of individual organizations but also by the pattern of relationships between organizations.

The automobile industry exemplifies the transfer of technology from supplier organizations to the automobile manufacturers themselves. It also demonstrates that poor interorganizational relationships may act as obstacles to technological advance within the industry. From its earliest years, the automobile industry has depended on thousands of outside suppliers for many of its components—everything from nuts and bolts to complete engines. These suppliers have provided some of the most important technological innovations for the automobile: disc brakes, radial tires, fuel injection, electronic ignition, and digital engine management systems, to name but a few.

These innovations did not sell themselves, however. Before they appeared in automobiles, they had to be bought by the automobile manufacturers (also known as “OEMs,” or original equipment manufacturers). Throughout most of the history of the industry, the relationship between suppliers and OEMs was that of independent buyers and sellers; cooperative approaches were generally absent. Suppliers were often left in the dark about the actual application of their products; a supplier might not even know which cars used its products or that they were about to be replaced by something totally different. The OEMs did not inform their suppliers about long-range intentions, and, as a result, suppliers could not effectively plan for the future.

Research done by suppliers usually took place without direct consultation with the OEMs, and the job of application came only after the component had been developed. There were few attempts to foster joint efforts between OEM and supplier in order to devise and develop new technologies.

The lack of supplier involvement in the design process was a major reason why in the 1970s and 1980s American automobiles fared poorly in competition with those made in Japan, where there was a greater inclination to incorporate suppliers in the design process at an early stage of a car's development.³² But faced with stiff competition from automakers in Japan and other countries, in recent years American car manufacturers have begun to initiate joint activities with their suppliers. This is a logical and necessary step for an industry that needs to constantly upgrade the technological level of its products.

These cooperative activities stand in sharp contrast to traditional buyer-seller relationships, where both parties are only concerned with their own narrow interests. These relationships work well enough when standard commodities are bought and sold, and price is the paramount concern of the parties to the transaction. In contrast, the development and transfer of new technologies involve unique products and are fraught with many uncertainties. These uncertainties make it difficult to evaluate transactions on a precise cost-benefit basis. Moreover, marketplace exchanges by their nature do not foster the long-term vision necessary for the development and application of modern, sophisticated technologies. As the Japanese experience has indicated, the creation of effective working relationships between separate organizations is an essential element of technological and economic vitality.

Entrepreneurs and Organizations

Organizations are essential for the operation of established technological systems like airlines or oil refineries. Their fundamental purpose is to coordinate the efforts of individuals in order to accomplish essential tasks. When routine tasks are involved, this coordination is usually accomplished through the application of basic bureaucratic principles: specialization, formalization (the use of rules, regulations, and standard operating procedures), and hierarchical authority. Although bureaucracies are sometimes thought to be inherently inefficient, there is no reason that they should be. In fact, when it works as it should, a bureaucracy is like a well-oiled machine that faithfully does the job for which it was intended.

But bureaucratic organization has its limitations. As has been noted earlier, bureaucracies thrive on routine, working best in stable environments where nothing new comes along to disturb their machinelike operations. At the same time, however, these bureaucratic routines are difficult or impossible to reconcile with the inherent uncertainty of creating something new. Furthermore, many unresolved issues surround not just the technology itself but also all of the ancillary changes that may be required to use it effectively. All sorts of uncertainties may be involved in such matters as the acceptance of the technology by customers, the retraining of personnel, legal liabilities, performance of component suppliers, and changing government regulations.³³

Bureaucracies rely on rules, regulations, and formal managerial practices to get their employees to do what needs to be done. In most cases, activities and projects are closely scheduled and subject to careful financial scrutiny. But innovators usually need a lot of elbow room and have an indefinite time horizon, which puts them at odds with bureaucratic procedures. A large corporation that is organized according to bureaucratic principles can be a difficult environment for inventors. As Jack Kilby, the co-inventor of the integrated circuit, has noted: “There is a basic incompatibility of the inventor and the large corporation. Large companies have well-developed planning mechanisms which need to know at the beginning of a new project how much

it will cost, how long it will take, and above all what it's going to do. None of these answers may be apparent to the inventor."³⁴

As we have seen in Chapter 3, technological innovation is often the work of entrepreneurs. By definition, entrepreneurs are people who disrupt normal activities and procedures by vigorously pushing new ways of doing things. Promoting innovation is risky business, and routine-seeking bureaucratic organizations are generally disinclined to take risks. Not only is a bureaucracy's structure attuned to routine activities, its personnel usually seek to protect their positions and maintain their customary modes of operation. Under these circumstances, an entrepreneur's efforts to promote innovation within an organization may encounter a fair amount of resistance and even hostility.

Although entrepreneurial activities are usually associated with the private sector, entrepreneurship may emerge as a force for change in government agencies, charitable organizations, schools, and religious institutions. The transformative power of an entrepreneur in the face of stiff opposition is well illustrated by an episode in the history of one of the most hidebound institutions in nineteenth-century America, the U.S. Navy.³⁵ At that time, gunnery was highly inaccurate; of the 9,500 shots fired from American naval vessels during the Spanish–American War, only 121 found their target. No attempt was made to follow a target; gunners used their cannons' elevating gear to give the shell the proper trajectory, fired after the roll of the ship brought the target into their sights, and hoped for the best. Then, during the last years of the nineteenth century, a British naval officer modified the elevating gear of his ship's guns so that they could be rapidly moved, allowing them to continuously track their target. He also modified the gun's telescopic sight so that it would not poke the gunner in the eye when the gun recoiled.

The improvements in accuracy were spectacular, and before long an American officer named William S. Sims embarked on a personal mission to bring these improvements to American ships. Sims was the quintessential entrepreneur; although he had not invented the new system, he was utterly convinced of its value and passionately devoted to seeing it installed. And he was willing to rattle a lot of cages in the course of promoting it. For its part, the Navy acted as a bureaucracy might be expected to act. At first, it ignored

Sims' reports on the inadequacies of American gunnery technology and what could be done to improve it. The reports were simply filed away, where they provided a few good meals for the cockroaches that inhabited the file cabinets. When Sims became too insistent to be ignored, the Navy arranged a series of inappropriate tests that "proved" the inadequacy of the new system. Sims finally prevailed only after he succeeded in getting the attention of President Theodore Roosevelt, who installed him in a position that allowed him ultimately to become "the man who taught the Navy to shoot."

The case of Sims versus the United States Navy is an admittedly extreme example of conflict between an entrepreneur and an entrenched bureaucracy. There are, after all, many examples of successful working relationships between innovative individuals and the organizations that employ them. Not every organization is structured along classic bureaucratic lines, and as we have already seen, an organization committed to innovation will likely have different structural characteristics than one pursuing routine activities. Still, there is no getting around the fact that organizations may find it hard to accommodate employees who take on the role of entrepreneur. These individuals can be arrogant, stubborn, and single-minded to the point of fanaticism. But at the same time, their vision and energy may be the most important element in their organization's success. To take a recent example, Steve Jobs embodied the positive and negative qualities of the classic entrepreneur. He was an exceedingly difficult person in many ways, but without his vision and guidance, Apple Computer would lie buried along with the dozens of defunct personal computer firms barely remembered today.³⁶

For many organizations, technological dynamism has required continual efforts to find a balance between the needs of would-be entrepreneurs and established organizational structures and processes. We cannot discard bureaucratic organizations, but we need to find ways that allow them to continue doing what they do best, while at the same time preventing them from obstructing the individuals whose efforts are a major source of technological advance.

Complex societies could not exist without organizations, bureaucratic or otherwise. Organizations are no less important for the initiation, development, and application of most technologies. At the same time,

however, inappropriate organizational structures can stifle technological advance. Equally important, the controllers of powerful organizations can select and cultivate technologies that serve only their own interests. This problem is not confined to business organizations; it can also manifest itself in the public sector. Accordingly, we will turn our attention to the biggest and potentially most powerful organization of all: the federal government of the United States.

QUESTIONS FOR DISCUSSION

1. How would you organize work if you were the director of a research laboratory? How would you create a climate that would stimulate the creativity of your personnel and at the same time prevent them from going off on unproductive tangents?
2. How might you design a research project that investigates the extent of managerial control over the selection of a firm's technologies? What sort of industries would be particularly suitable for such a project?
3. Many key industries are dominated by a handful of large firms. This tendency has been increasingly evident in recent years, as many separate firms have merged into larger ones. How might this trend affect technological innovation? Could it pose a threat to the overall development of the economy?
4. Why have many organizational analysts fastened on information as an organization's key resource? To what extent do your experiences with organizations reflect this idea? How does the ability to control the flow of information reflect and reinforce power relations within an organization?
5. Who comes to mind when you think of present-day entrepreneurs? To what extent are they similar to the classic entrepreneurs of the past who propelled industrial innovation? Does today's economic and political environment promote or retard entrepreneurial efforts?

CHAPTER TWENTY

Governing Technology

The last chapter put forth the claim that organizations play a major role in determining the kind of technologies we get. To be sure, these organizations are not all-powerful. When business firms are involved, consumers can affect technological change by deciding whether or not to buy their products. As employees, we might be able to exert some influence through our acceptance or rejection of new workplace technologies. But not all of the major decisions affecting the trajectory of technological change are made in the private sector. To a large extent, government organizations influence technological choices. In a democratic society, this should expand the power of citizens to get the technologies they want. But do they? Does governmental involvement in the development of technology necessarily result in more beneficial technologies? Are democratic ideals realized in the operation of government policies and processes? These are some of the issues that will be addressed in the following survey of the government's role in shaping technological change.

Government Actions and the Shaping of Technology

The involvement of the federal government in technological change is as old as the Republic. The United States of America emerged during an era when technological change was beginning to accelerate, and the framers of the Constitution believed that the government should encourage technological advance through the granting of patents and copyrights to those who had produced new things. Accordingly, Article I, Section 8, of the Constitution stipulates that Congress is to “promote the Progress of Science and Useful Arts by securing for limited Times to Authors and Inventors the Exclusive Rights to their respective Writings and Discoveries.”

The government’s granting of patent rights provides the legal framework for the monopolistic control of technological advances generated by individuals and private organizations. The government also supports other types of infrastructure that are essential to the creation, development, and use of modern technologies. Since the ultimate basis of technological advance is the growth of knowledge, governments at all levels do much to indirectly sponsor technological advance through their support of education. Federal aid to individual students has supported the education of large numbers of scientists, engineers, and technicians. Moreover, in recent decades, institutions of higher learning have been major sources of technological advance through their research activities. These activities were strongly encouraged by the passage of P.L. 96-517, commonly known as the Bayh-Dole Act, in 1980. Under its provisions, universities receiving federal research funds that aid in the creation of innovative products and processes can obtain patents on them.¹ Universities are involved with more than 4,000 patent licensing agreements annually, accounting for about \$2 billion in licensing fees. A few patents have been spectacularly successful from a financial standpoint; the gene-splicing technology developed by Herbert Boyer and Stanley Cohen brought \$200 million in revenues to Stanford University and the University of California, San Francisco. But patenting has not produced financial windfalls for most institutions; most of the revenues

have gone to a small number of institutions.² Moreover, critics have voiced concerns that the pursuit of these revenues has undermined some of the basic values of the university, such as the pursuit of knowledge for its own sake and the free transmission of knowledge.

In addition to maintaining the patent system and supporting education and university research, government programs also provide the auxiliary goods and services that are essential for the use of particular technologies. For example, high-speed air travel requires more than just jet aircraft; equally important are government-supported airports, air traffic controllers, navigation aids, weather forecasts, and safety inspections. To take another obvious example, the effective use of automobiles is dependent on a network of roads and highways, as well as driver training in the schools, the enactment and enforcement of traffic laws, and so on.

The case of the automobile brings up another reason for government involvement in technological matters. To repeat a theme briefly noted in Chapter 6, every significant technological change brings with it an assortment of auxiliary consequences, some of them pernicious. The private automobile has generated many benefits, but it has also created a number of problems. These problems are not borne exclusively by individual car owners, and for this reason they are known as “negative externalities.” That is, they are costs that are not directly taken into account when a person buys a car and puts it on the road; they are external to the market exchange between the buyer and the seller of the car. In operating a car, the owner incurs a number of personal costs: gas, insurance, repairs, and monthly payments that seem to go on forever. But at the same time, the operation of the car results in costs for the society as a whole: increased pollution, congestion, and so on. Since these costs are not included in the market transaction, governmental action is necessary. To take a notable example, the negative externality of automobile-generated air pollution is commonly addressed by regulations that require the installation of emission-control devices. Alternatively, the government could assess an emission tax, thereby making it financially advantageous to own a car equipped with these devices.

Some government policies and activities are not aimed directly at technological change, but they can strongly influence its scope and direction nonetheless. Tax policies can affect technological change by encouraging

capital investments that often embody new technologies. One element of current tax policy is based on the idea (which is not universally held by economists) that capital investment can be stimulated by taxing the income derived from investments at a lower rate than other sources of income. As a result, individuals and firms supposedly are motivated to invest their money in new machines and other productive goods. Capital investment can also be encouraged by allowing the accelerated depreciation of capital equipment. This means that the cost of a machine or other piece of equipment with a useful life of, say, 20 years can be used to offset taxes during a much shorter period. As a result, a firm's immediate profits are increased. Since business executives tend to be primarily concerned with short-term performance, accelerated depreciation can stimulate capital investments that embody new technologies.

The government can also encourage the development and use of specific technologies by offering tax credits or deductions to those willing to invest in them. For many years, the federal tax code provided an important benefit for oil producers by granting a depletion allowance that was used to offset corporate taxes. One result was the expansion of petroleum-based energy technologies. A different approach was taken when the energy crises of the 1970s generated a strong interest in alternative sources of energy. One governmental response was the sponsorship of alternative energy technologies; in the past decade, the federal government provided \$100 billion in tax credits to individuals and institutions investing in wind-powered electrical generators, the economic viability of which has been closely tied to government subsidies.³

As we have seen, innovation does not always respect existing social and legal arrangements, and the courts may be called upon to resolve issues generated by technological change. To take one example, until fairly recently, biological parenthood was not a problematic concept; every child had a father and mother who jointly contributed to his or her conception. Since 1978, however, it has been possible to use in-vitro fertilization for this purpose. This practice has led to a number of legal conundrums centering on the definition of parenthood. One such issue has arisen as hundreds of men have had their sperm frozen for future artificial insemination because they suffered from a terminal disease, were soldiers about to be deployed to a combat zone,

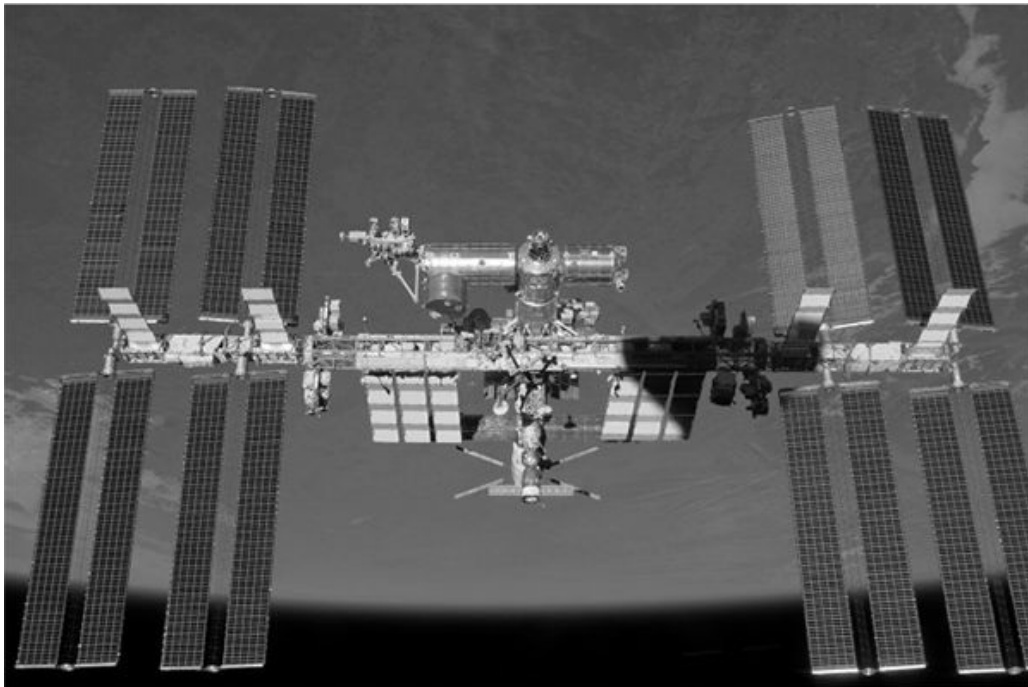
or simply did it as a precautionary measure. Some of these men did in fact die prior to a successful insemination and birth, giving rise to this question: Were their children entitled to the Social Security benefits that are paid to children whose father has died? In Florida, one man's widow filed for benefits on behalf of twins that had been conceived after her husband's death. The agency denied her claim, only to have the decision overturned by an appeals court. But in 2012, the United States Supreme Court unanimously overturned the lower court's decision because Florida barred inheritance for posthumously conceived children. But this is not the end of the matter, as the laws in individual states take different approaches to the inheritance rights of posthumously conceived children.⁴ What is fair and proper in cases such as these? This situation will, if anything, become more common in the years to come; children can be born decades after the death of their biological father, given that frozen sperm can retain viability for up to 100 years. It is also possible for embryos to be implanted in a surrogate mother long after the death of the woman who was the source of the eggs that had been fertilized. Issues such as these will become even more prominent in the future as advances in reproductive technologies have the potential to alter the essential nature of parenthood and family. Judges and legislators will confront many issues and challenges regarding child custody, inheritances, and government benefits.

Paying for Science and Technology

In addition to dealing with the consequences of emerging technologies, the federal government is directly involved in the generation of some of these technologies through its support of research and development (R&D). The scope of government involvement in R&D has grown massively in the postwar era. In 1940, the federal government spent only \$67 million on the direct support of science and technology, the equivalent of about \$1.03 billion today.⁵ In 2014, the federal government budgeted \$69.4 billion for R&D, which included \$30.8 billion for the National Institutes of Health and \$11.5 billion for NASA.⁶ Over the years, the space program has absorbed an impressive amount of federal funds. Since its creation in 1958, NASA has been a major recipient of federal R&D funds. By the time of the last lunar landing, in late 1972, the Apollo program had absorbed \$19.4 billion, about \$115 billion in today's dollars.⁷ More recently, the cost of the construction of the International Space Station has made major claims on the government's science and technology budget; from the beginning of construction in 1998 until late 2013, the tab for the International Space Station came to \$160 billion, of which the United States contributed \$100 billion, making it perhaps the most expensive human project of all time.⁸

Government expenditures on military R&D have waxed and waned as different governments have come to power and as perceptions of military threats have oscillated. In the 1984 fiscal year, a massive peacetime military buildup resulted in military R&D expenditures of \$31.8 billion, almost 70 percent of the total federal R&D budget.⁹ The waning of the Cold War resulted in a significant reduction in the proportion of R&D funds allocated to defense. Even so, the military R&D budget for 2014 came to more than \$66 billion, close to half of the total federal R&D budget.¹⁰ Since 9/11, the federal government has greatly increased antiterrorism research and development. Support for technologies aimed at foiling terrorist attacks has increased significantly, as has R&D for code breaking. The extent of funding for the latter is classified, but it is known that the National Security Agency, the highly secretive organization that oversees this research, possessed the

world's fastest computer in 2009 and is sponsoring the construction of an even faster one today. The raw data for these supercomputers will come from everything from personal emails and telephone records to bookstore purchases and travel itineraries, all of it intercepted and aggregated in a complex being built in Utah that will be five times the size of the U.S. Capitol.¹¹



NASA

The International Space Station has generated major expenses for the sponsoring countries.

Although the military sector absorbs a large portion of federal R&D resources, the funds allocated for other purposes are still considerable. In sum, by supplying about half of the funds used for the nation's R&D efforts, the federal government plays a very large role in the sponsorship of scientific and technological advance. Consequently, the allocation of federal R&D funds can significantly influence the direction of technological advance. To take a notable example, from fiscal year 2003 to 2012, the federal government spent a total of nearly \$40 billion on energy R&D. Of that sum, 25.4 percent went for fossil fuel R&D, and another 25.9 percent went to

nuclear R&D, while R&D funds for energy efficiency and renewable energy accounted for 16.4 and 17.1 percent, respectively.¹²

But Is It Really Necessary?

Why has government involvement in technological development increased to such a marked degree in the postwar era? In part, it is due to the recognition that our prosperity is tied to our ability to advance technologically. Given the fierce competition within the international economy, the failure to maintain high technological levels can have severe consequences. Japan recognized this fact, and its Ministry of International Trade and Industry (MITI, now METI, the Ministry of Economy, Trade, and Industry) aggressively sponsored the development of selected high-technology industries such as semiconductors, genetic engineering, robots, and composite materials. Not only had it provided research funds, MITI also organized cooperative joint research efforts between firms in the same industry so that they could do collectively what they could not do individually.¹³

The government of the United States has been less explicit in its sponsorship of technological advance, but it still has played a major role. The development of computers and semiconductors during the early 1950s was extensively supported by federal funds for research and development. Equally important, government procurement of the resulting products created a market at a time when sales within the private sector did not seem promising.¹⁴ In similar fashion, government procurement of aircraft engines and other components provided a strong stimulus for technological advances that spilled over into commercial aviation.¹⁵ Military needs were of course the main source of these efforts. Accordingly, it can be argued that during the postwar era the United States has had a de facto policy of supporting technological development, but unlike Japan, much of it has been driven by military rather than commercial considerations.

Important though they are, military requirements are not the sole justification for government support of technological advance. Although the market system has served as midwife to an abundance of innovative technologies, it cannot be expected to stimulate every type of technological innovation. Certain kinds of technological advances have little appeal to individual entrepreneurs, for they cannot be easily sold to individual

consumers. Moreover, once these technologies are in place, they presumably benefit everyone, whether they pay for them or not. This is the so-called free rider problem. For example, some people may be ardent supporters of a cleaner environment, but if they were to individually pay for a power plant's smokestack scrubbers, everyone in the community would benefit equally, even though most of them made no financial contributions to the installation of the scrubbers. Under these circumstances, the government has to take the lead by mandating the development and installation of emission-control equipment or assessing a pollution tax that stimulates their installation. The costs would be borne by the operators of the power plant, who would likely pass them along to consumers in the form of higher utility bills. Alternatively, the government could subsidize the installation of scrubbers, and offset the subsidy by levying a tax.

Some activities produce benefits that are considerably greater than the returns that accrue to the individuals or firms that engage in them. In contrast to negative externalities, these can be labeled "positive externalities." In some cases, the potential social benefits may be great, but the private rate of return may be so small that no private party is willing to undertake them. This is frequently the case with basic research that has no direct payoff but provides a foundation for subsequent technological applications. Moreover, once the research has been done, the knowledge gained can be made available to everyone at little additional cost, thereby increasing its benefits to society as a whole. Under these circumstances, it makes sense for the government to sponsor basic research, paying for it through taxation. This is precisely what has happened: about half of the "pure" or "basic" scientific research conducted in the United States is financed by the federal government, while the remainder is funded by colleges, universities, and private industry.¹⁶

Government Institutions for the Guidance of Technology

A modern nation's economic and military security is closely tied to its ability to generate and absorb new technologies. At the same time, simply coping with all of the consequences of technological change can require the leadership and organization that only government can provide. For these reasons, many governments have established special departments and ministries charged with the promotion, control, and governance of technology. But this has not been the case in the United States. There is no cabinet-level Department of Technology, only a collection of congressional committees and government agencies that involve themselves in a plethora of separate issues and decisions. Some of these agencies reside within the executive branch as parts of cabinet-level departments (such as the Department of Energy's Nuclear Regulatory Commission), while others (such as NASA and the National Science Foundation) are quasi-independent agencies directly under the president.

The executive branch is best situated to bring some degree of coherence to technology policy, and in fact the president and his staff have on occasion played significant roles in determining the course of a particular technology by influencing legislation, designating agency heads, impounding funds, and using the other tools available to the president. The importance of having the president well advised on scientific and technological matters was recognized in 1957 with the formation of the Presidential Science Advisory Committee (PSAC) within the Eisenhower administration. PSAC was largely concerned with matters relating to defense and space, and when its members failed to support President Nixon's policies on missile defense and the construction of a supersonic airliner, PSAC was abolished in 1973 and some of its functions were transferred to the National Science Foundation.

A formal structure for providing scientific and technical advice for the president was reconstituted in 1976 with the formation of the Office of Science and Technology Policy (OSTP).¹⁷ The director of OSTP also serves as a member of the National Science and Technology Council, which was

established by a 1993 executive order of President Clinton. In addition to the OSTP director, the council includes the president, vice president, and several cabinet-level officials and high-level administrators. Among its responsibilities are providing the president and senior staff with technical advice, ensuring that policies of the executive branch are based on sound science, and coordinating the science and technology policy-making process within the executive branch of the OSTP.¹⁸ It is also the domain of the chief technology officer, a position created by President Obama in 2009 and whose efforts have been directed toward making the government more effective and accessible through the use of current technologies.

Some presidents have had more interest in science and technology policies than others, but direct presidential involvement in the shaping of these policies has been infrequent in all administrations. On a few occasions, however, it has been highly significant. President Reagan's Strategic Defense Initiative (the "Star Wars" ballistic missile defense system) represented a major redirection of American defense policy, yet it began as an idiosyncratic effort. The president publicly announced the program only five days after informing his science adviser, while the joint chiefs of staff, the secretary of state, and the secretary of defense got only two days' notice. The chief scientist for the Pentagon learned of the proposal only nine hours before the speech that presented the program to the nation.¹⁹

With presidential involvement in the setting of technology policy largely confined to a few major policy decisions, the day-to-day shaping of technological policy tends to be the business of Congress and various government agencies. Here, the disjointed nature of American technology policy is apparent. There is no unified approach to the budgeting of funds for research and development: over a dozen appropriation subcommittees in each house of Congress take a hand in determining the budgets of the agencies they oversee. These committees and subcommittees often have to address issues directly connected to technological matters. Congressional involvement with technological issues was recognized in 1972 by the creation of the Office of Technology Assessment (OTA), which had as its purpose the provision of information to Congress to help guide its decisions about technological policy, and to give it more leverage over the president in science and technology matters.²⁰ OTA investigated a wide selection of

topics that ranged from an examination of the physiological basis of drug addiction to an evaluation of the Social Security Administration's plans to upgrade its computer facilities. In its early years, OTA was criticized for not taking on highly controversial topics, but it eventually became involved in contentious matters like the effectiveness of a proposed antimissile defense system. In the latter case, the publication of its report was delayed by a lengthy classification review, and in the end several key chapters were deleted due to the objections of the Defense Department.²¹ It is likely that the Defense Department's opposition had more to do with the negative tone of the report than with concerns about its revelation of military secrets.

As the past example indicates, OTA sometimes found it difficult to achieve a balance between the goals of its overseers in the federal government and the objectivity and neutrality characteristic of scholarly inquiry. Given the contentiousness of many technological issues and the frequent difficulty of separating facts from values, OTA was in an inherently precarious situation. Being on the "wrong side" in some controversial issues undercut OTA's support in Congress, especially after Republicans gained control of both houses in 1994. Despite strong bipartisan agreement on the value of OTA outside Congress, the office was dismantled one year later. As far as the actual working of Congress is concerned, policies relating to technology emerge from the many committees and subcommittees of the two legislative branches. Legislation affecting the development and use of technology is forged in bodies as disparate in their concerns as the House Armed Services Subcommittee and the Senate Agriculture Committee. These committees and subcommittees often work in conjunction with federal agencies and departments, such as NASA or the Department of Defense, that administer a particular technological sector.

How Government Policies Shape Technological Change

The most direct way that Congress determines the course of technological development is through passing laws that either forbid the use of a particular technology or regulate the way it is used. Indeed, the very notion that the government has a legitimate right to regulate private industry originated with the need to address a problem presented by a new technology—the explosion of riverboat steam boilers in the first half of the nineteenth century.²² The Franklin Institute in Philadelphia was given the task of investigating the construction and operation of boilers. Its report provided a wealth of information about boilers and their components, as well as a set of recommendations regarding their operation and maintenance, many of which were subsequently written into law by Congress. Today, government regulations cover a vast number of technological concerns, everything from the siting of nuclear power plants to the length of trucks.

Along with the passage of laws and regulations, the federal government affects the course of technological development through the budgetary process; that is, by deciding to pay for certain kinds of technologies and not others. In some important cases, government financial support can be crucial. The supersonic transport (SST) plane literally never got off the ground because in 1971, Congress voted not to appropriate any more funds for its development. Also, as we have seen in Chapter 8, the George W. Bush administration severely restricted stem-cell research that used human embryos. Conversely, some technologies, such as civilian nuclear power, have received a large amount of financial and legal support from the federal government that has been crucial to their development and use.

Governmental decisions that affect technological development do not take place in a political vacuum. It often happens that technologies are sponsored because they have substantial outside support. Gaining government interest in addressing a technological issue is a crucial first step, and one that cannot be taken for granted. Here again, the piecemeal approach to governing technological change is evident. There is no clear and

comprehensive approach to deciding what technological goals should (and should not) be pursued so that a governmental agenda can be set. Instead of being the product of calm deliberation, an issue is often put on the agenda because of some “focusing event”; an oil embargo forces a consideration of the energy technologies we use; the launch of *Sputnik* by the Soviet Union demonstrates the apparent need for an accelerated U.S. space program; a serious accident reveals material and organizational defects in the operation of nuclear power plants.

A sense of crisis and the need for decisive action also emerge when a social movement is directed at a particular technology. Some of these have taken on well-established technologies that had remained under the radar until they became the subject of media exposés, notably hydraulic fracturing, or “fracking,” for the extraction of oil and gas. But large-scale protests are more likely to emerge when a new technological possibility lies just over the horizon. Technologies that have already been established, whatever their unfortunate consequences, simply do not generate the kind of concerns that new ones do.²³ Cars, along with giving us our prized freedom of mobility, also befoul our environment, encourage ugly sprawl, and in 2014, killed 33,675 people in the United States, the equivalent of a major commercial airline crash every two days. Yet few people consider bringing them under tighter governmental regulation or even abolishing them altogether.



DOD Photo/Alamy

It is likely that some natural disasters, such as severe flooding in Texas, may be the result of climate change.

Only a few technologies have generated much popular opposition. Such diverse technologies as the chlorination of water, the extensive use of medical X-rays, microwave ovens, and birth-control pills have received, at best, passing attention, and no sustained effort to subject them to governmental control.²⁴ In fact, it is not entirely clear why some technologies and not others become the focus of widespread concern. But it is certainly true that a technology that produces large-scale failures, such as a nuclear reactor accident, is more likely to evince opposition than one that produces a series of small-scale failures, even though in aggregate their consequences may be great, as has been the case with automobile accidents. And it is also the case that media exposure can greatly heighten opposition to a technology with evident problems.²⁵ Again, this sort of exposure is more likely when the failure is large and spectacular rather than diffuse and significant only in the aggregate.

Examples of widespread public debate over new technologies are infrequent; most innovations emerge with little public attention. But this does not mean that politics has been irrelevant. As noted earlier, many new

technologies owe their development and diffusion to sponsorship by particular governmental agencies. Since there is no centralized approach to the governance of technology, many key decisions are made at the middle levels of government, that is, by government agencies and congressional committees. It is here that decisions are made to sponsor a particular technology and to create the conditions necessary for its success. Technology policy is the sum of many separate policy actions undertaken at this level. Under these circumstances, the ambitions of individual governmental agencies and their administrators can determine the course of technological development, for an agency has a strong interest in pushing technologies that are in accordance with its own goals, and having them adopted as national policy.²⁶ This is often achieved with little fanfare. Most decisions about technological policy do not generate much political heat, and a government agency may successfully promote a particular technology with little or no public discussion or debate.

The importance of government sponsorship can be seen in the history of nuclear power in the United States. In the mid-1950s, the electrical utilities, the greatest potential users of nuclear power, had little reason to make use of the new technology. According to one utility company president, “We weren’t anxious to get into nuclear power, and I don’t think any other company in its right mind wanted to get into it either.”²⁷ To overcome this reticence, the key government agency, the Atomic Energy Commission, engaged in a large-scale selling job. A demonstration plant was built at Shippingport, Pennsylvania, in 1954, and technical assistance was offered to the industry, along with subsidized prices for nuclear fuel.²⁸ This is not to say that the Atomic Energy Commission’s actions were illegitimate or that civilian nuclear power owes its existence solely to government support, but it does show how national policy can be shaped by the interests of a particular government agency.

Since some government agencies are more powerful than others, their programs forge ahead while other agencies’ projects languish. As a result, potentially significant programs are not enacted, or if enacted they are chronically underfunded, while more dubious ones move ahead. A few agencies are more influential than others because of the greater technical abilities of their staff and their greater interest in science and technology. But

in many cases, what really matters is who their clients are. Government agencies do not operate in splendid isolation; they are often closely tied to a particular set of clients. As we have seen with the Federal Communications Commission in Chapter 13, even when the task of the agency is regulation, it may be “captured” by the industry that it is supposed to regulate. This happens because the agency needs the support of the industry it oversees in order to maintain its legitimacy and resources. An agency may even delegate to the industry some of the regulatory tasks that it is charged with performing. For example, much of the inspection work performed before the Federal Aviation Administration certifies the airworthiness of a new airplane is actually done by engineers and technicians in the employ of the plane’s manufacturer.

If an industry has a strong interest in a particular technology, it may exert a great deal of influence, and Congress and the relevant government agencies will lend their support to that technology. In turn, members of Congress may find a particular technology to be politically attractive because it offers “pork barrel” benefits to their constituents. Some technologies, especially those in the military sector, have forged ahead because a project has contractors and subcontractors in a large number of congressional districts. Members of Congress quite naturally are likely to support programs that provide jobs and other economic benefits for their states and districts, and are willing to support projects that benefit the constituents of other representatives in return for support of projects that benefit their own.

In sum, as with many other government policies, the direction of technological policy often results from the interaction of an “iron triangle” of congressional committees, government agencies, and the key groups whose interests are closely affected by governmental decisions. The decision to sponsor a new technology, along with the shape that it takes as it is developed, is often determined by these triangles. This means that the government usually does not sponsor the development of new technologies as part of a general effort to find solutions to public problems. Rather, a technology is sponsored because a coalition can be formed from the members of the triangle, who see to it that the selected technologies develop in accordance with their own needs and interests.

It also happens that once under way, the development of a new technology builds up momentum. The personnel and agencies charged with

its development have a strong interest in its continuation, as do potential users. As a result, a technological policy gets locked in place and options are closed off. In the absence of outside pressures, projects are destined to move ahead.²⁹ Even when a technology has manifest problems of considerable magnitude, the sponsors of the technology will tend to “throw good money after bad,” for once the commitment has been made and the program is under way, it often is far more difficult to terminate a program than to continue with it.

This is one of the greatest defects of our system of governing technology. Technological change is an uncertain process, with many unforeseeable consequences. Efforts to forecast the precise consequences of a new technology so that policies can be constructed in advance to deal with them are doomed to failure. The best that can be hoped is that technologies can be stopped or modified if this should prove necessary. This is easier said than done. The effective governance of technology is faced with a fundamental paradox: change is easiest at the beginning, but this is when the need for it cannot be foreseen. As Ernest Fitzgerald, the whistle-blower we briefly met in Chapter 18, has said of military projects, “There are only two phases to a major program. The first phase: ‘It’s too early to tell.’ The second phase: ‘It’s too late to stop.’ ”³⁰

In this way, technology appears to be out of control, as many technologies seem to be driven by their own momentum. But this is not really what is happening; seemingly out-of-control technologies move ahead because they suit the real interests of individuals and organizations. Were these to be taken away, there would be far less reason to continue with the development or deployment of the technology. Technologies do not simply stand or fall on their own merits; their success or failure can often be attributed to the political support that they receive. And this political support will likely be a reflection of the distribution of power both inside and outside the corridors of government. Under these circumstances, is there any hope that an unorganized citizenry can have any influence over the way technology develops? It is to this, our last topic, that we will next turn.

The Democratic Control of Technology

The decisions and activities of experts, enterprise managers, and government officials have powerfully affected the kinds of technologies that have been developed, where they have been applied, and how their costs have been met. Most of us have been little more than the consumers of technologies that have been developed by people and organizations largely unknown to us. This process has produced spectacular successes and spectacular problems. Technology has extended our lives, lightened some of our burdens, increased our wealth, and kept us amused. At the same time, the advance of technology has left us with some very unpleasant by-products. This is not the place to attempt to determine if the good has outweighed the bad, for so much depends on what we value. Which way of living is preferable, that of the !Kung San with its relaxed work patterns but material impoverishment and limited control of the environment, or our own with its abundance of goods and knowledge but frantic work schedules? In any event, for most of us the choice is moot; unless we decide to become nomadic hunter-gatherers or subsistence farmers, our lives will be lived in a world shaped by modern technology. At issue is not the acceptance or rejection of technology; what matters is how much individual influence we have over the choice of technologies that we use now and will use in the future.

As individuals, are we doomed to the passive acceptance of technological changes that have been decreed by others? Even if technological development has produced more good than bad, it has proceeded in a fashion that has put it beyond our individual control. It seems as though we have struck a bargain whereby we consume the fruits of technological advance in return for delegating to others the power to determine the technologies that shape the basic contours of our lives—everything from what we eat, to how we work, to the way we are entertained.

Most people seem to believe that this is a fair bargain. As we have seen in the first chapter of this book, there is not a great deal of anguish about our reliance on modern technology. Then, too, it must be remembered that democratic participation has its costs. Above all, the expansion of the number

of people engaging in technological decision making can disrupt the orderly processes favored by managers, engineers, and bureaucrats. This follows from the simple arithmetic of participation; the more parties there are to a decision, the harder it is to decide. The result is often a stalemate—"my vote cancels yours." Everybody ends up with veto power, but no one is able to act in a positive fashion. At best, the result is compromise, which may be a reasonable conclusion in some cases, such as the modification of nutritional standards; but in matters that require decisive action, such as stopping the spread of weapons of mass destruction or significantly mitigating climate change, a compromise decision may be worthless or even dangerous.

Does this mean that there is no middle ground between an apathetic acceptance of technological change decreed by others and a paralyzing stalemate? Can democratic participation be reconciled with technological advance? Before these questions can be answered, it is obviously necessary to have some workable definition of democracy. A vast amount of thinking and writing has gone into this issue, and we cannot presume to break any new ground here. But most of us could agree that a democratic process is one in which the people as a whole are able to participate in making meaningful choices about the things that affect their lives. The capitalist economic system does contain some democratic elements, for consumers can choose to buy or not buy particular products, and in so doing they affect the course of technological change. There has been a "democratic" affirmation of hybrid cars, but not of battery-powered ones. And certainly consumer choice has dictated the shift to smaller cars whenever gasoline prices shoot up. But these are choices made after the fact. Consumers can choose only between existing alternatives; they cannot determine which alternatives will be made available to them. This is a bit like voting in a referendum; the electorate can decide an issue, but it does not determine which issues are put on the ballot in the first place.

In similar fashion, democratic choice can be exercised by voting for or against candidates because of their stance on a key technological issue. There have been local elections that have hinged on a candidate's position on the fluoridation of water or on nuclear power, but these have been rare. Elections are usually fought over a variety of issues; technological policy has been but one, and usually a minor one at that. And even where a technological issue is at the center of a campaign, the voters' voices are heard only after a

technology is already in place, as with referenda on nuclear power. There is virtually no popular input into whether or not completely new technologies should be developed. In this sense, democratic controls are at best reactive.

Is it possible to have democratic control of technology that goes beyond these after-the-fact votes? In some ways, the advance of technology has increased the potential for democratic participation in government. Most importantly, the electronic media have heightened our awareness of political issues. It has often been remarked, for example, that the widespread protests against the Vietnam War were stimulated by the horrible realities of warfare appearing on television day after day. At the same time, however, exposure does not guarantee an enlightened response. As we have seen, the expansion of newspaper reading that was triggered by the invention of the steam-powered rotary press stimulated a great outpouring of jingoist sentiment and the fanning of imperialist ambitions in the United States. More recently, the rise of the internet, cable TV, and social media have exacerbated political divisions by allowing us to live in our own “echo chambers” where we only hear what we want to hear. Making matters worse is the mode of discourse often found in these media: uninformed, hyperbolic, and at times downright vile. Finally, many critics have decried the present-day debasement of the political process by slickly produced advertisements for candidates and ballot initiatives. It thus seems that advances in communication technologies have had mixed consequences for the democratic process. The electronic media in general and the internet in particular hold out the prospect of a more informed electorate, but the positive contributions of these media are often overwhelmed by the negative ones, just as happened with the rise of the popular press generations earlier.



David McNew/Getty Images

The rise of the internet and fragmentation of media have contributed to a high degree of political polarization.

Advances in electronic media have also presented the possibility of direct democracy through a kind of electronic town hall. Instead of delegating decisions to elected officials, every citizen could use an internet site to vote on the pressing issues of the day. Such a system is certainly technologically feasible, but is it a practical possibility? Security questions aside, could voters be expected to be sufficiently well informed to pass judgment on everything from levels of farm price supports to the wisdom of supplying arms to a revolutionary movement in some far-off land? And even if such a system were implemented, would it really result in a truly democratic order? It is obvious that people could not vote on every single issue, so some kind of rationing would have to be instituted. Some agency would have to determine what got on the “ballot” in the first place, and this would be a source of power in itself. The ability to set governmental agendas—the determination of which issues make it into the political arena—is a crucial political decision, and this system would do nothing to democratize this process. All voters could do would be to make choices according to a preplanned agenda.

Given the limitations of direct democracy, we necessarily have to rely on

some form of representative democracy. Unfortunately, the established institutions of representative democracy in the United States have not always guided technological development in ways that serve the public interest. The key political actors have been especially responsive to large, well-organized bodies, such as industries, labor unions, and other special interests. All too often the common good is lost to the special pleadings of these groups. Compounding the problem is the fact that the political process is fragmented, which allows government agencies and officials to cut deals with special interests while no one looks after the needs and concerns of the nation as a whole. Under these circumstances, government officials end up representing themselves and their powerful constituents rather than the people who voted them into office.

Does this mean that there is no hope that individual citizens can affect the course of technological change? Despite what has just been said, there is some room for optimism, and there are numerous occasions when democracy can assert itself in technological affairs. Democracy may work best when issues are close to home. To note two recent examples, concerns about their effects on local environments have motivated well-organized protests over fracking and the construction of an oil pipeline passing through the Midwest. In contrast, many pressing but seemingly far-off technological issues do not engage the interest of people distracted by their individual problems of raising a family, meeting mortgage payments, or studying for exams. Burdened with mundane daily problems, it is all too easy for us to deny that there is an urgent need to do something about nuclear proliferation or climate change. The perception that immediate, local concerns are being affected by technological change can therefore energize greater levels of public perception than is the case when the issues seem too large and remote to concern us. There is considerable wisdom in the slogan that enjoins us to “think globally and act locally.”

It must be admitted that local politics is uninteresting to many people, as the usually low levels of voter turnout for local elections attest. Moreover, participation at the grassroots level faces the same limits as other kinds of political participation; involvement can be time-consuming and stressful, and people would prefer to leave the tasks of governance to local officials. But at the same time, involvement in technological policies that have a direct impact on one’s own community can reduce apathy and lethargy. And it might also

be the case that expanding democratic participation and tying technological issues to local concerns would result in the emergence of technologies significantly different from those produced by our present system.³¹

Finally, while our governmental structures and processes have produced some technologies of very questionable value, we should also realize that no system of guiding technology will guarantee a utopia. No matter how advanced or benign our technologies, human life will always have its insecurities, disappointments, frustrations, and tragedies. It can even be argued that it is dangerous to seek perfection in both our technological and political systems. There is something inhuman about a society that cannot tolerate the fact that life does not always go according to plan. The invention and development of new technologies have been characterized as ongoing searches for the “best way,” and elegantly satisfactory solutions to technological problems do emerge on a regular basis. But most of life is not like that. We will always have to reconcile ourselves to the fact that even the most advanced and responsive technologies will not solve many of our basic problems. As we have seen, the spectacular advances of many individual technologies should not blind us to the fact that some of the inherent difficulties of life are simply not amenable to technological solutions.

The Challenges of the Future

In considering the years ahead, it is well to recall the waggish statement that it is dangerous to make predictions, especially about the future. The course of technological development has produced many surprises, and it will continue to do so. Fifty years ago, few would have foreseen the emergence of smartphones with the power of existing mainframes. Yet at about the same time, it was predicted that in the future electricity would be so inexpensive to produce that it would be “too cheap to meter.”³²

Forecasting is a highly inexact art, and although it can be safely said that our lives will be strongly influenced by technological change, predictions beyond this general statement are fraught with hazards.³³

Even so, the general contours of future technological developments can be discerned. Advances in transportation and electronic communication will bring the people of the world even closer together. The internet will be the basis for ever-increasing amounts of information, media presentations, and social interaction. Advances in nanotechnology, materials, and microprocessors will produce fundamental changes in the design and operation of many objects. The application of artificial intelligence could affect every aspect of work, play, and learning. And genetic engineering might allow nothing less than the redesign of human beings. Profound social changes will be necessary if we choose to make use of these technologies.

And yet, just because these things are possible does not mean that they should be done. We do not have to resign ourselves to the inexorable advance of technology while passively hoping that it produces more good than harm. Technology remains a human creation, and we have it in our power to determine its future course. Unfortunately, the power to make this determination is very unevenly distributed through society. A major reason for this unequal distribution of power is the unequal distribution of knowledge. This is especially unfortunate because a knowledgeable citizenry has always been essential to the functioning of democracy. In the words of Thomas Jefferson, “If we think [the people] not enlightened enough to exercise their control with a wholesome discretion, the remedy is not to take

it from them, but to inform their discretion.”³⁴ The expansion of citizens’ knowledge is even more crucial than it was in the days of Jefferson, when most adults worked as farmers, and humans had never traveled faster than the speed of a horse. The relentless advance of technology has produced a dizzying pace of change that at times leaves us gasping. Even so, it bears repeating that technology is our own creation and that its ultimate source is knowledge. But for technology to be truly beneficial, more than technical knowledge is required. Our challenge will be to develop and apply many different kinds of knowledge—ethical, philosophical, sociological, political, and economic—so that we can do a better job of defining our real needs and creating the technologies that serve them.

I hope that this book has given you some of the knowledge necessary to participate in shaping a future that will be strongly influenced by the technological decisions we make. But acquiring knowledge is not enough; it is also necessary to apply that knowledge. And that will be up to you.

QUESTIONS FOR DISCUSSION

1. Do you think that the government should establish an agency similar to Japan's Ministry of External Trade and Industry as a way of stimulating technological advance? What obstacles would such an agency confront in the American political climate?
2. Very few elected officials in America have professional training in science or technology. Does this inhibit the effective governance of science and technology? Do you think that American government would be substantially different if most senators and representatives previously worked as scientists or engineers instead of as lawyers, as is the case today?
3. Can you think of any potentially important technologies that have languished because they have lacked political support? How could they gain this support?
4. What is your definition of democracy? On the whole, has technological advance increased or decreased the amount of democratic participation in modern society?
5. In the text, it is argued that citizen involvement in local issues will aid in the democratic shaping of technology. But local concerns have at times blocked technologies such as wind power installations that may contribute to the general good. Is it possible to address local concerns when pursuing projects that may benefit the nation as a whole?
6. Which emerging technologies will have the greatest impact on life during the opening decades of this century? Will they have any unfortunate consequences? Should the government restrict or prevent any of them? Do you intend to exert any influence over these decisions? How will you do it?

NOTES

Chapter 1 Notes

1. National Science Foundation, "Science and Engineering Indicators: 2014," accessed on October 21, 2015, at www.nsf.gov/statistics/seind14/index.cfm/chapter-7/c7h.htm.
2. This paragraph is derived from Carl Mitcham, *Thinking through Technology: The Path between Engineering and Technology* (Chicago: University of Chicago Press, 1994), pp. 117–34.
3. Jacob Bronowski, "Technology and Culture in Evolution," *Philosophy of the Social Sciences* 1, 3 (1971): 199.
4. Lewis Mumford, "Technics and the Nature of Man," *Technology and Culture* 7, 3 (July 1966): 303–17.
5. The Thomas Edison Papers, "Electric Light and Power System" (March 16, 2015), accessed on October 21, 2015, at <http://edison.rutgers.edu/power.htm>.
6. John B. Rae, *Climb to Greatness: The American Aircraft Industry, 1920–1960* (Cambridge, MA: MIT Press, 1968), p. 74; Edward Constant, *Origins of the Turbojet Revolution* (Baltimore: Johns Hopkins University Press, 1980).
7. Lewis Mumford, *Technics and Civilization* (New York: Harcourt, Brace and World, 1934), p. 110.
8. Edwin Kiester, Jr., "A Little Fever Is Good for You," *Science* 84, 5, 9 (November 1984): 172.
9. Robert C. Post, "Technological Enthusiasm," in Rudi Volti (Ed.), *The Encyclopedia of Science, Technology, and Society*, vol. 3 (New York: Facts on File, 1999), pp. 999–1001.
10. Quoted in Jonathan Hughes, *The Vital Few: The Entrepreneur and American Economic Progress* (New York and Oxford: Oxford University Press, 1986), p. 327.
11. Michael Adas, *Machines as the Measure of Man: Science, Technology, and Ideologies of Western Domination* (Ithaca and London: Cornell University Press, 1989).
12. Norbert Wiener, *The Human Use of Human Beings: Cybernetics and Society* (New York: DaCapo, 1988; originally published in 1954), p. 61.
13. Otto Mayr, "Adam Smith and the Concept of the Feedback System," *Technology and Culture* 12, 1 (1971).
14. Albert Speer, *Inside the Third Reich* (New York: Macmillan, 1970), p. 212.
15. This concept is explored by Weber in "Science as a Vocation," in H. H. Gerth and C. Wright Mills (Eds.), *From Max Weber: Essays in Sociology* (New York: Oxford University Press, 1958), pp. 129–56.
16. Julian Freund, *The Sociology of Max Weber* (New York: Pantheon, 1968), p. 24.
17. Edmund Burke, *Reflections on the Revolution in France* (New York: Holt, Rinehart and Winston, 1959; originally published in 1790), p. 91.
18. Richard Schlegel, "Why Can Science Lead to a Malevolent Technology?" *Centennial Review* 21, 1 (Winter 1977): 14.

19. For a narrative of the historical processes that have led to the perception that technology is “men’s work,” see Ruth Oldenziel, *Making Technology Masculine: Men, Women, and Machines in America, 1870–1945* (Amsterdam: University of Amsterdam Press, 1999).
20. Jennifer Light, “Programming,” in Nina E. Lehrman, Ruth Oldenziel, and Arwin Mohun (Eds.), *Gender and Technology: A Reader* (Baltimore and London: Johns Hopkins University Press, 2003).
21. Sherry Turkle, *The Second Self: Computers and the Human Spirit* (New York: Simon and Schuster, 1984); Paul N. Edwards, “Industrial Genders: Hard/Soft,” in Nina E. Lerman, Ruth Oldenziel, and Arwen Mohun, (Eds.), *Gender and Technology: A Reader* (Baltimore: Johns Hopkins University Press, 2003).
22. One of the most influential explorations of this idea is Langdon Winner, *Autonomous Technology: Technics-Out-of-Control as a Theme in Political Thought* (Cambridge, MA, and London: MIT Press, 1977).
23. William F. Ogburn, “Technology and Governmental Change,” in Otis Dudley Duncan (Ed.), *On Culture and Social Change: Selected Papers* (Chicago: University of Chicago Press, 1964), pp. 132–33. Quoted in Rudi Volti, “Classics Revisited: William F. Ogburn, Social Change with Respect to Culture and Original Nature,” *Technology and Culture*, 45, 2 (April 2004): 399.
24. C. S. Lewis, *The Complete C. S. Lewis Signature Classics* (San Francisco: HarperCollins, 2002), p. 719.

Chapter 2 Notes

1. Moses Abramowitz, "Resource and Output Trends in the United States Since 1870," *American Economic Review*, Papers and Proceedings 56 (May 1956): 5–23; John W. Kendrick, "Productivity Trends, Capital and Labor," *Review of Economics and Statistics* 37 (August 1956): 248–57; R. M. Solow, "Technical Change and the Aggregate Production Function," *Review of Economics and Statistics* 39 (August 1957): 312–20.
2. Jeffrey D. Sachs and John W. McArthur, "Technological Advancement and Long-Term Economic Growth in Asia," in Chong-En Bai and Chi-Wa Yuen (Eds.), *Technology and the New Economy* (Cambridge, MA: MIT Press, 2002): 157–85, accessed on October 26, 2015, at www.earthinstitute.columbia.edu/sitefiles/file/about/director/pubs/tech_new_ecc
3. See Howard P. Segal, *Technological Utopianism in American Culture 1830–1940* (Chicago: University of Chicago Press, 1985).
4. Quoted in Herbert J. Muller, "Human Values and Modern Technology," in Edwin T. Layton, Jr. (Ed.), *Technology and Social Change in America* (New York: Harper & Row, 1973), p. 159.
5. MIT "Real-Time" Rideshare Research, "Rideshare History and Statistics" (January 24, 2015), accessed on October 23, 2015, at <http://ridesharechoices.scripts.mit.edu/home/histstats/>.
6. *Business Insider*, "Here's How Uber Got Its Start and Grew to Become the Most Valuable Startup in the World" (September 13, 2015), accessed on October 23, 2015, at www.businessinsider.com/history-of-uber-and-its-rise-to-become-the-most-valuable-startup-in-the-world-2015-9.
7. See for example BBC News, "France Cracks Down on Uber Service After Protests" (June 26, 2015), accessed on October 23, 2015, at www.bbc.com/news/world-europe-33267581.
8. Sarah McBride and Dan Levine, "In California, Uber Driver Is Employee, Not Contractor: Agency," Reuters (June 18, 2015), accessed on October 23, 2015, at www.reuters.com/article/2015/06/18/us-uber-california-idUSKBN0OX1TE20150618.
9. Davey Alba, "Florida Says Uber Driver Isn't an Employee After All," *Wired* (October 1, 2015), accessed on October 25, 2015, at www.wired.com/2015/10/florida-uber-decision-reversal/.
10. W. F. Cottrell, "Death by Dieselization: A Case Study in the Reaction to Technological Change," *American Sociological Review* 16 (June 1951): 358–65.
11. *Ibid.*, p. 362.
12. Langdon Winner, "Do Artifacts Have Politics?" *Daedalus* 109, 1 (Winter 1980): 123–25.
13. Peter Blake, *Form Follows Fiasco: Why Modern Architecture Hasn't Worked* (Boston: Little, Brown, 1974), p. 59.

14. George Rude, *The Crowd in History: A Study of Popular Disturbances in France and England, 1730–1848* (New York: John Wiley & Sons, 1965), pp. 66–92; Malcolm I. Thomis, *The Luddites: Machine-Breaking in Regency England* (New York: Schocken Books, 1972).
15. Paragraph 128 of “The Unabomber Manifesto.” This document is available on numerous internet sites.
16. Lori Osterberg, “7 Unexpected Benefits of a Digital Detox,” *Huffington Post* (October 22, 2015), accessed on October 26, 2015, at www.huffingtonpost.com/lori-osterberg/digital-detox_b_8361700.html.
17. James C. Williams, “The Trolley: Technology and Values in Retrospect,” *San Jose Studies* 3, 3 (November 1977): 74–90.
18. James J. Flink, *The Car Culture* (Cambridge, MA: MIT Press, 1975), p. 39.
19. William F. Dix, “The Automobile as a Vacation Agent,” *Independent* 56 (June 2, 1904): 1259–1260, quoted in *ibid.*, pp. 39–40.
20. Daniel Sarewitz and Richard Nelson, “Three Rules for Technological Fixes,” *Nature*, 456 (December 18, 2008), accessed on October 27, 2015, at www.nature.com/nature/journal/v456/n7224/full/456871a.html.
21. “The Age of Unreason,” *The Economist*, 416, 8946 (July 11, 2015), Special Report, p. 6.
22. National Institute of Mental Health, “Attention Deficit Hyperactivity Disorder (ADHD),” accessed on January 4, 2012, at www.nimh.nih.gov/health/publications/attention-deficit-hyperactivity-disorder/complete-index.shtml.
23. For a biography of Taylor, see Robert Kanigel, *The One Best Way: Frederick Winslow Taylor and the Enigma of Efficiency* (New York: Viking, 1997).
24. Quoted in Samuel Florman, *The Existential Pleasures of Engineering* (New York: St. Martin’s Press, 1976), p. 8.
25. V. I. Lenin, “The Immediate Tasks of the Soviet Government,” *Izvestia* (April 28, 1918), accessed on October 26, 2015, at www.marxists.org/archive/lenin/works/1918/mar/x03.htm.
26. Daniel Nelson, *Managers and Workers: Origins of the New Factory System in the United States, 1880–1920* (Madison: University of Wisconsin Press, 1975): 75–76.

Chapter 3 Notes

1. Wiebe Bijker, Trevor Pinch, and Thomas P. Hughes (Eds.), *The Social Construction of Technological Systems* (Cambridge, MA, and London: MIT Press, 2012).
2. Wiebe E. Bijker, "Understanding Technological Culture through a Constructivist View of Science, Technology, and Society," in Stephen H. Cutcliffe and Carl Mitcham (Eds.), *Visions of STS: Counterpoints in Science, Technology, and Society Studies* (Albany: State University of New York Press, 2001), p. 27.
3. Thomas P. Hughes, "Technological Momentum," in Merritt Roe Smith and Leo Marx (Eds.), *Does Technology Drive History? The Dilemma of Technological Determinism* (Cambridge, MA, and London: MIT Press, 1994), pp. 99–113.
4. Rudi Volti, *Cars and Culture: The Life Story of a Technology* (Baltimore: Johns Hopkins University Press, 2006), pp. 7–9; Gijs Mom, *Atlantic Automobilmism: Emergence and Persistence of the Car 1895–1940* (New York and Oxford: Berghan Books, 2015), pp. 62–63.
5. Nathan Rosenberg, *Inside the Black Box: Technology and Economics* (Cambridge, England: Cambridge University Press, 1982), pp. 62–70.
6. Louis Hunter, *Steamboats on the Western Rivers* (Cambridge, MA: Harvard University Press, 1949), pp. 121–122. Quoted in Rosenberg, *Black Box*, p. 64.
7. Albert Fishlow, "Productivity and Technological Change in the Railroad Sector, 1840–1910," in *Studies in Income and Wealth No. 30: Output, Employment, and Productivity in the United States after 1800* (New York: National Bureau of Economic Research, 1966), pp. 635, 641.
8. Center for Climate and Energy Solutions, "Freight Transportation," accessed on October 29, 2015, at <http://www.c2es.org/technology/factsheet/FreightTransportation>.
9. Richard Tanner Pascale and Anthony G. Athos, *The Art of Japanese Management: Applications for American Executives* (New York: Warner Books, 1981), p. 306.
10. The following is based on John A. Heitman and David J. Rhees, *Scaling Up: Science, Engineering, and the American Chemical Industry* (Philadelphia: Center for the History of Chemistry, 1984), pp. 17–21.
11. Paul E. Ceruzzi, *Computing: A Concise History* (Cambridge, MA and London: MIT Press, 2012), pp. 5–6.
12. Peter George, *The Emergence of Industrial America: Strategic Factors in American Economic Growth since 1870* (Albany: State University of New York Press, 1982), p. 51.
13. David A. Hounshell, *From the American System to Mass Production, 1800–1932: The Development of Manufacturing Technology in the United States* (Baltimore: Johns Hopkins University Press, 1984), pp. 189–215.
14. Edward Constant, *The Origins of the Turbojet Revolution* (Baltimore: Johns

- Hopkins University Press, 1980), p. 82.
15. Christopher Freeman, "The Determinants of Innovation: Market Demand, Technology, and the Response to Social Problems," *Futures* 11, 3 (June 1979): 211.
 16. Jacob Schmookler, *Inventions and Economic Growth* (Cambridge, MA: Harvard University Press, 1966).
 17. *Ibid.*, p. 93.
 18. Daron Acemoglu, *Introduction to Modern Economic Growth* (Princeton and Oxford: Princeton University Press, 2009), pp. 415, 430.
 19. W. G. L. De Haas, "Technology as a Subject of Comparative Studies: The Case of Photography," *Comparative Studies in Society and History* 21, 3 (July 1979): 367–70.
 20. Christopher Freeman, *The Economics of Industrial Innovation*, 2nd ed. (New York: Cambridge University Press, 1982), p. 124.
 21. Invention Statistics.com, "Invention Success Rates," accessed on October 28, 2015, at www.inventionstatistics.com/Innovation_Risk_Taking_Inventors.html.
 22. Freeman, *Economics*, p. 127.
 23. Wilson Dizard, *The Coming Information Age: An Overview of Technology, Economics, and Politics* (New York: Longman, 1982), p. 33. See also Paul Ceruzzi, "An Unforeseen Revolution: Computers and Expectations, 1935–1985," in Joseph J. Corn (Ed.), *Imagining Tomorrow: History, Technology of the American Future* (Cambridge, MA: MIT Press, 1986).
 24. Hugh G. J. Aitken, *Syntony and Spark: The Origins of Radio* (Princeton, NJ: Princeton University Press, 1985).
 25. Robert Heilbroner, *Between Capitalism and Socialism: Essays in Political Economics* (New York: Random House, 1970), p. 162.
 26. Karl Marx and Frederick Engels, *Manifesto of the Communist Party*, (1848), accessed on October 28, 2015, at www.marxists.org/archive/marx/works/1848/communist-manifesto/ch01.htm.
 27. Elting E. Morison, *From Know-How to Nowhere: The Development of American Technology* (New York: New American Library, 1977), p. 126.
 28. Quoted in Roger Burlingame, *March of the Iron Men: A Social History of Union through Invention* (New York: Grosset & Dunlap, 1938), p. 77.
 29. *Ibid.*, p. 77.
 30. Barton C. Hacker, "Robert H. Goddard and the Origins of Space Flight," in Carroll W. Pursell, Jr. (Ed.), *Technology in America: A History of Individuals and Ideas* (Cambridge, MA: MIT Press, 1981), p. 233.
 31. R. Jeffrey Smith, "High-Priced F-22 Fighter Has Major Shortcomings," *Washington Post*, July 10, 2009, accessed on September 3, 2012, at www.washingtonpost.com/wp-dyn/content/article/2009/07/09/AR2009070903020.html.
 32. Daniel Callahan, "Health Care Costs and Medical Technology," *The Hastings Center* (2015), accessed on November 2, 2015, at www.thehastingscenter.org/Publications/BriefingBook/Detail.aspx?id=2178.

Chapter 4 Notes

1. John D. Verhoeven, "The Mystery of Damascus Blades," *Scientific American* 284, 1 (January 2001), pp. 74–79.
2. Pamela O. Long, *Artisans/Practitioners and the Rise of the New Sciences, 1400–1600* (Corvallis: Oregon State University Press, 2011).
3. Thomas S. Kuhn, *The Rate and Direction of Inventive Activity* (Princeton, NJ: Princeton University Press, 1963), pp. 450ff.
4. Thomas S. Kuhn, "Comment on the Principle of Acceleration," *Comparative Studies in History and Society* 11, 4 (1969): 428. See also Thomas S. Kuhn, *The Essential Tension: Selected Studies of Scientific Tradition and Change* (Chicago: University of Chicago Press, 1977).
5. Chalmers W. Sherwin and Raymond S. Isenson, "Project Hindsight," *Science* 156, 3782 (June 23, 1967): 1571–1577.
6. Richard Chait et al., *Enhancing Army S&T: Lessons from Project Hindsight Revisited* (Washington, DC: National Defense University, Center for Technology and National Security Policy, 2007) pp. 23–24, accessed on June 18, 2008, at <http://stinet.dtic.mil/cgi-bin/GetTRDoc?AD=ADA466795&Location=U2&doc=GetTRDoc.pdf>.
7. Sherwin and Isenson, "Project Hindsight," p. 1575. See also Wendy Faulkner, "Conceptualizing Knowledge Used in Innovation: A Second Look at the Science-Technology Distinction and Industrial Innovation," *Science, Technology, and Human Values* 19, 4 (Autumn 1994): 435, 454.
8. J. E. S. Parker, *The Economics of Innovation: The National and Multinational Enterprise in Technological Change*, 2nd ed. (London: Longman, 1978), p. 30.
9. Edwin Layton, "Mirror-Image Twins: The Communities of Science and Technology in 19th-Century America," *Technology and Culture* 12, 4 (October 1971): 564–65.
10. Otto Mayr, "The Science–Technology Relationship as a Historiographic Problem," *Technology and Culture* 17, 4 (October 1976): 668.
11. See, for example, Bruno Latour, *Science in Action: How to Follow Scientists and Engineers through Society* (Cambridge, MA: Harvard University Press, 1987).
12. F. R. Jevons, "The Interaction of Science and Technology Today, or, Is Science the Mother of Invention?" *Technology and Culture* 17, 4 (October 1976): 731.
13. Robert Cardil, "Kepler: The Volume of a Wine Barrel," Mathematical Association of America, (2015), accessed on November 26, 2015, at www.matematicasvisuales.com/loci/kepler/doliometry.html.
14. Ashish Arora and Alfonso Gambardella, "The Changing Technology of Technological Change: General and Abstract Knowledge and the Division of Innovative Labour," *Research Policy*, 23, 5 (September 1994), accessed on November 26, 2015, at www.sciencedirect.com/science/article/pii/004873339401003X.

15. Eugene S. Ferguson, "The Mind's Eye: Nonverbal Thought in Technology," *Science* 197, 4306 (August 26, 1977): 827.
16. Philip H. Abelson, "Instrumentation and Computers," *American Scientist*, 1 (1986). Quoted in Paul DeHart Hurd, "Technology and the Advancement of Knowledge in Science," *Bulletin of Science, Technology, and Society*, 14, 3 (1994): 126.
17. Eda Fowlks Kranakis, "The French Connection: Giffard's Injector and the Nature of Heat," *Technology and Culture* 23, 1 (January 1982): 3–38.
18. Nathan Rosenberg, *Inside the Black Box: Technology and Economics* (Cambridge: Cambridge University Press, 1982), pp. 146–47.
19. Frederik Nebeker, "Charles Townes, the Maser, and the Relationship between Engineering and Science," *Engineering Science and Education Journal* 4, 6 (December 1995): S41–S46.
20. Edwin T. Layton, Jr., "American Ideologies of Science and Engineering," *Technology and Culture* 17, 4 (October 1976): 688.
21. Eric Drexler, "The Nobel Prize for Technology" (January 8, 2009), accessed on January 12, 2012, at <http://metamodern.com/2009/01/08/the-nobel-prize-for-technology/>.
22. Langdon Winner, *Autonomous Technology: Technics-out-of-Control as a Theme in Political Thought* (Cambridge, MA: MIT Press, 1977), pp. 24–25.
23. Hugh G. J. Aitken, *Syntony and Spark: The Origins of Radio* (Princeton, NJ: Princeton University Press, 1985), p. 316.
24. Edward Constant, *The Origins of the Turbojet Revolution* (Baltimore: Johns Hopkins University Press, 1980), pp. 15–16.
25. James M. Utterback, "Innovation in Industry and the Diffusion of Technology," *Science* 183, 4125 (February 15, 1974): 622.
26. Faulkner, "Conceptualizing Knowledge," p. 427.
27. John Rae and Rudi Volti, *The Engineer in History*, 2nd ed. (New York: Peter Lang, 2001), pp. 190–192.
28. Aitken, *Syntony and Spark*, pp. 335–36.
29. George Shiers, "The First Electron Tube," *Scientific American* 220, 3 (March 1969): 104–12.
30. Peter Mathias, "Resources and Technology," in Peter Mathias and John A. Davis (Eds.), *Innovation and Technology in Europe: From the Eighteenth Century to the Present Day* (Oxford, England, and Cambridge, MA: Basil Blackwell, 1991), p. 37.
31. Peter Mathias, "Who Unbound Prometheus? Science and Technical Change, 1600–1800," in Peter Mathias (Ed.), *Science and Society 1600–1900* (Cambridge: Cambridge University Press, 1972), p. 79.
32. Robert M. Pirsig, *Zen and the Art of Motorcycle Maintenance* (New York: Bantam Books, 1974), pp. 99–103.
33. John Ziman, *An Introduction to Science Studies: The Philosophical and Social Aspects of Science and Technology* (Cambridge: Cambridge University Press, 1984), p. 104.
34. Ann Johnson, *Hitting the Brakes. Engineering Design and the Production of*

- Knowledge* (Durham, London: Duke University Press, 2009).
35. Rebecca S. Eisenberg and Richard R. Nelson, "Public vs. Proprietary Science: A Fruitful Tension?" *Daedalus* 131, 2 (Spring 2002): 91.
 36. See Henry Petroski, *To Engineer Is Human: The Role of Failure in Successful Design* (New York: St. Martin's Press, 1985).
 37. Melvin Kranzberg, "Let's Not Get Wrought up about It," *Technology and Culture* 25, 4 (October 1984): 742.

Chapter 5 Notes

1. See Robert Temple, *The Genius of China: 3,000 Years of Science, Discovery, and Invention* (New York: Simon and Schuster, 1989).
2. Charles Till, "The Diffusion of the Stirrup into Medieval Western Europe," accessed on November 30, 2015, at <http://steventill.com/2008/06/18/the-diffusion-of-the-stirrup-into-medieval-western-europe/>.
3. Frances and Joseph Gies, *Cathedral, Forge, and Waterwheel: Technology and Invention in the Middle Ages* (New York: HarperCollins, 1994), pp. 45–47.
4. Gilbert Rozman (Ed.), *The Modernization of China* (New York: The Free Press, 1981), pp. 22–23.
5. Xin Xiangrong, "Open Policy, Import of Culture," *Beijing Review* 29, 46 (November 17, 1986): 4.
6. Elting E. Morison, *From Know-How to Nowhere: The Development of American Technology* (New York: New American Library, 1977), pp. 21–36.
7. "Immigrants Lead Many Tech Start-Ups, Study Says," *Los Angeles Times* (January 4, 2007), accessed on September 4, 2012, at <http://articles.latimes.com/2007/jan/04/business/fi-execs4>.
8. Angus Maddison, *Economic Growth in Japan and the USSR* (New York: W.W. Norton, 1969), pp. 16–17.
9. Japan Patent Office, "Sakichi Toyoda Wooden Hand Loom, Automatic Loom," (October 7, 2002), accessed on November 30, 2015, at www.jpo.go.jp/seido_e/rekishi_e/sakichi_toyoda.htm.
10. Henry S. Rowen, Marguerite Gong Hancock, and William F. Miller (Eds.), *Making IT: The Rise of Asia in High Tech* (Stanford: Stanford University Press, 2007), p. 10.
11. Global Security.org, "Y-10," accessed on November 30, 2015, at www.globalsecurity.org/military/world/china/y-10.
12. Paul Stoneman, *The Economics of Technological Diffusion* (Oxford and Malden, MA: Blackwell, 2002), p. 75.
13. Richard G. Lipsey, Kenneth I. Carlaw, and Clifford T. Bakar, *Economic Transformations: General Purpose Technologies and Economic Growth* (Oxford: Oxford University Press, 2005), p. 87.
14. Vernon W. Ruttan, "Towards a Global Agricultural Research System: A Personal View," *Research Policy* 15, quoted in Edward J. Malecki, *Technology and Economic Development: The Dynamics of Local, Regional, and National Change* (New York: John Wiley & Sons, 1991), p. 142.
15. Tuvia Blumenthal, "A Note on the Relationship between Domestic Research and Development and Imports of Technology," *Economic Development and Cultural Change* 27, 2 (January 1979): 303–06.
16. Christopher Freeman, *The Economics of Industrial Innovation*, 2nd ed. (Cambridge, MA: MIT Press, 1982), p. 61.
17. Zhou Jiahua, "Gunpowder and Firearms," in *Ancient China's Technology and*

- Science* (Beijing: Foreign Languages Press, 1983), pp. 184–191; Arnold Pacey, *Technology in World Civilization: A Thousand-Year History* (Cambridge, MA: MIT Press, 1991), pp. 44–50.
18. Keijiro Otsuka, Gustav Ranis, and Gary Saxenhouse, *Comparative Technology Choice in Development: The Indian and Japanese Cotton Textile Industries* (London: Macmillan, 1988), pp. 23–24, in Morris-Suzuki, op. cit., p. 87.
 19. The narrative is based on Nakaoka Tetsuo, “Imitation or Self-Reliance: A Lesson from the Early History of Modern Japanese Iron Manufacturing,” in *Japanese Foundation Newsletter* 8, 4 (October–November 1979): 1–6.
 20. U.N. Office for the Coordination of Humanitarian Affairs, “In-Depth: Youth in Crisis: Coming of Age in the 21st Century,” accessed on August 27, 2012, at www.irinnews.org/InDepthMain.aspx?InDepthID=28&ReportID=69977.
 21. Trading Economics, “Passenger Cars (per 1,000 persons) in India,” accessed on December 1, 2015, at www.tradingeconomics.com/india/passenger-cars-per-1-000-people-wb-data.html.
 22. Robert C. Toth, “Fitting Technology to Need Held Critical in Third World,” *Los Angeles Times* (June 18, 1978), part 1: 1, 32.
 23. The most influential book on this subject is E. F. Schumacher, *Small Is Beautiful: Economics as If People Mattered* (New York: Harper & Row, 1973). For some examples of current appropriate technologies, see “10 Cases of Appropriate Technology,” at <http://listverse.com/2010/06/12/10-cases-of-appropriate-technology/> (accessed on February 7, 2012).
 24. “10 Cases of Appropriate Technology,” (June, 12, 2010), accessed on August 7, 2012, at <http://listverse.com/2010/06/12/10-cases-of-appropriate-technology/>.
 25. Louis T. Wells, Jr., “Economic Man and Engineering Man: Choice and Technology in a Low-Wage Country,” *Public Policy* 21, 3 (Summer 1973): 319–42.
 26. National Science Foundation, “International Comparisons of R&D Performance,” accessed on December 1, 2015, at www.nsf.gov/statistics/seind14/index.cfm/chapter-4#s2.
 27. Everett M. Rogers, *Diffusion of Innovations*, 5th ed. (New York: The Free Press, 2003), pp. 15–16.
 28. Hugh G. J. Aitken, *Syntony and Spark: The Origins of Radio* (Princeton, NJ: Princeton University Press, 1985), pp. 329–35.
 29. *Ibid.*, p. 335.
 30. Lipsey et al., op. cit. pp. 86–87.
 31. See John Enos, “Invention and Innovation in the Petroleum Refining Industry,” in Richard Nelson (Ed.), *The Rate and Direction of Inventive Activity* (Princeton, NJ: Princeton University Press, 1962).
 32. John Thomson, “What We Should Know about Tires: A Historical Background,” accessed on December 2, 2015, at www.jags.org/TechInfo/2001/05May01/tires/historyoftires.htm.
 33. Donald A. Schon, *Technology and Change: The New Heraclitus* (New York: Dell, 1967), pp. 24–25.
 34. Richard R. Wilk, *Economies and Cultures: Foundations of Economic*

- Anthropology* (Boulder, CO: Westview, 1996), p. 63.
35. Pablo A. Guerron-Quintana, "Risk and Uncertainty," Federal Reserve Bank of Philadelphia (2012), accessed on December 2, 2015, at www.phil.frb.org/research.
 36. Freeman, *Economics of Industrial Innovation*, p. 154.
 37. Henry Ford II, quoted in James C. Jones, "Dr. Schweitzer's Dilemma: Not Invented Here," *Ward's Auto World* (November 1974): 41.
 38. Rogers, *Diffusion of Innovations*, pp. 414–17.
 39. Miroslav N. Jovanovic, *The Economics of European Integration* 2nd ed. (Cheltenham, England: Edward Elgar, 2013), p. 211.
 40. Dan Vergano, "Scientists Engineer Bioterror Fears," *USA Today* (January 26, 2012), pp. 1A–2A.
 41. FindLaw, "United States vs. Dubilier Condenser Corp.," accessed on December 4, 2015, at <http://caselaw.findlaw.com/us-supreme-court/289/178.html>.
 42. J. E. S. Parker, *The Economics of Innovation: The National and Multinational Enterprise in Technological Change*, 2nd ed. (London: Longman, 1978), p. 310.
 43. *Ibid.*, p. 327.
 44. Freeman, *Economics of Industrial Innovation*, p. 61.
 45. Leonard S. Reich, "Lighting the Path to Profit: GE's Control of the Electric Lamp Industry, 1892–1941," *Business History Review* 66 (Summer 1992): 310, 312.
 46. Stuart Macdonald, "When Means Become Ends: Considering the Impact of Patent Strategy on Innovation," *Information Economics and Policy* 16 (2004): 135–58.
 47. Adam B. Jaffe and Josh Lerner, *Innovation and Its Discontents: How Our Broken Patent System Is Endangering Innovation and Progress, and What to Do about It* (Princeton and Oxford: Princeton University Press, 2004).
 48. "Intellectual Property: A Question of Utility," *The Economist*, 416, 8950 (August 8, 2015): 50–52.
 49. James Flink, *America Adopts the Automobile, 1895–1910* (Cambridge, MA: MIT Press, 1970), pp. 318–28.

Chapter 6 Notes

1. U.S. Energy Information Agency, “EIA Projects World Energy Consumption Will Increase 56% by 2040” (July 25, 2013), accessed on December 8, 2015, at www.eia.gov/todayinenergy/detail.cfm?id=12251.
2. Worldwatch Institute, *Vital Signs: The Trends That Are Shaping Our Future* (Washington, DC: Island Press, 2013), p. 36.
3. Newton H. Copp and Andrew W. Zanella, *Discovery, Innovation and Risk: Case Studies in Science and Technology* (Cambridge, MA, and London: MIT Press, 1993), p. 299.
4. T. J. Blasing, “Recent Greenhouse Gas Concentrations,” U.S. Department of Energy, Carbon Dioxide Information Analysis Center (February 2014), accessed on December 8, 2015, at http://cdiac.ornl.gov/pns/current_ghg.html#.
5. University Corporation for Atmospheric Research, “How Much Has the Global Temperature Risen in the Last 100 Years?” (2015), accessed on December 8, 2015, at www2.ucar.edu/climate/faq/how-much-has-global-temperature-risen-last-100-years.
6. Anuj Chopra, “How Global Warming Threatens Millions in Bangladesh,” *U.S. News and World Report* (March 26, 2009), accessed on August 8, 2012, at www.usnews.com/news/energy/articles/2009/03/26/how-global-warming-threatens-millions-in-bangladesh.
7. Food and Agriculture Organization of the United Nations, “State of the World’s Forests 2007” (Rome: FAO, 2007), accessed on October 20, 2008, at www.fao.org/docrep/009/a0773a/a0773e00.htm.
8. Ross W. Gorte and Pervaze A. Sheikh, “Deforestation and Climate Change,” Congressional Research Service (March 24, 2010), accessed on December 8, 2015, at <http://forestindustries.eu/sites/default/files/userfiles/1file/R41144.pdf>.
9. U.S. Environmental Protection Agency, “Municipal Solid Waste” (June 25, 2015), accessed on December 8, 2015, at www3.epa.gov/epawaste/nonhaz/municipal/.
10. Laurel Adams, “EPA Superfund Cleanup Costs Outstrip Funding,” The Center for Public Integrity (May 19, 2014), accessed on December 8, 2015, at www.publicintegrity.org/2011/02/22/2121/epa-superfund-cleanup-costs-outstrip-funding. On Superfund, see U.S. Environmental Protection Agency, “EPA’s Superfund Program,” accessed on May 18, 2016, at www.epa.gov/superfund.
11. Kenneth S. Deffeyes, *Hubbert’s Peak: The Impending World Oil Shortage* (Princeton, NJ: Princeton University Press, 2001).
12. Michael T. Klare, “Peak Oil Is Dead ... Long Live Peak Oil,” *Huffington Post* (January 9, 2014), accessed on December 8, 2015, at www.huffingtonpost.com/michael-t-klare/peak-oil-is-dead_b_4567978.html.
13. David R. Montgomery, *Dirt: The Erosion of Civilizations* (Berkeley, Los Angeles, and London: University of California Press, 2007), pp. 4, 171–74.

14. Carlo M. Cipolla, *Before the Industrial Revolution: European Society and Economy, 1000–1700*, 2nd ed. (New York: W.W. Norton, 1980), p. 138.
15. Quoted in *ibid.*, p. 288.
16. W. Stanley Jevons, *The Coal Question: An Inquiry Concerning the Progress of the Nation, and the Probable Exhaustion of Our Coal-Mines*, 3rd ed. (London: Macmillan and Co., 1906), p. 9.
17. *Ibid.*, p. 187.
18. *Ibid.*, pp. 184–85.
19. *Ibid.*, p. 185.
20. James R. Chiles, “Spindletop,” *American Heritage of Invention and Technology* 3, 1 (Summer 1987): 34.
21. “Too Cheap to Meter?” (February 20, 2009), accessed on December 8, 2015, at <http://media.cns-snc.ca/media/toocheap/toocheap.html>.
22. Mycle Schneider et al., “The World Nuclear Industry Status Report 2013 (July 30, 2013), accessed on December 10, 2015, at www.worldnuclearreport.org/2013.html#annex_6_status_of_nuclear_power_in_
23. Adam Piore, “Planning for the Black Swan,” *Scientific American* 304, 6 (June 2011): 50.
24. Calculated from figures in John M. Deutch and Ernest Muniz, “The Nuclear Option,” *Scientific American* 295, 3 (September 2006): 78.
25. Matthew L. Wald, “What Now for Nuclear Waste?” *Scientific American* 301, 2 (August 2009): 46–53.
26. Deutch and Muniz, “The Nuclear Option,” pp. 82–83.
27. Matthew L. Wald, “The Power of Renewables,” *Scientific American* 300, 3 (March 2009): 56–61.
28. Natural Resources Defense Council, “Renewable Energy for America,” accessed on December 6, 2015, at www.nrdc.org/energy/renewables/solar.asp.
29. U.S. Department of Energy, “2014 Wind Technologies Market Report Highlights” (August 2015), accessed on December 8, 2015, at www.energy.gov/sites/prod/files/2015/08/f25/2014-Wind-Technologies-Market-Report-Highlights.pdf.
30. Natural Resources Defense Council, “Renewable Energy for America,” accessed on December 6, 2015, at www.nrdc.org/energy/renewables/solar.asp.
31. James J. Flink, *The Car Culture* (Cambridge, MA: MIT Press, 1975), p. 34.
32. “Power Slide,” *The Economist Online* (January 11, 2009), accessed on February 21, 2012, at www.economist.com/blogs/dailychart/2011/01/energy_use.
33. Chris Nelder, “The Worst Way to Measure Energy Efficiency,” *Slate* (March 13, 2013), accessed on December 9, 2015, at www.slate.com/articles/technology/the_efficient_planet/2013/03/energy_intensi
34. Arthur H. Rosenfeld and David Hafemeister, “Energy-Efficient Buildings,” *Scientific American* 258, 4 (April 1988): 78.
35. Eberhard K. Jochem, “An Efficient Solution,” *Scientific American* 295, 3 (September 2006): 66.
36. U.S. Department of Energy, “LED Lighting,” accessed on December 9, 2015, at <http://energy.gov/energysaver/led-lighting>.

37. Rosenfeld and Hafemeister, "Energy Efficient Buildings," p. 81.
38. Rick Bevington and Arthur H. Rosenfeld, "Energy for Buildings and Homes," *Scientific American* 263, 3 (September 1990): 78.
39. Jessica Lyons Hardcastle, "Aluminum Can Recycling Rate Hits 67% in 2012" (October 30, 2013), accessed on December 9, 2015, at www.environmentalleader.com/2013/10/30/aluminum-can-recycling-rate-hit-67-in-2012/.
40. U.S. Energy Information Administration, "Gasoline Explained" (October 29, 2015), accessed on December 10, 2015, at www.eia.gov/energyexplained/index.cfm?page=gasoline_home.
41. John DeCicco, Rod Griffin, and Steve Eertel "Putting the Brakes on U.S. Oil Demand" (Environmental Defense, 2003), accessed on June 24, 2008, at www.edf.org/documents/3115_OilDemand.pdf, p. 3.
42. U.S. Environmental Protection Agency, "Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 through 2013" (2013), accessed on December 9, 2015, at www.fueleconomy.gov/feg/pdfs/420r13011_EPA_LD_FE_2013_TRENDS.pdf.
43. Ben Knight, "Better Mileage Now," *Scientific American* 302, 2 (February 2010): 50–55.
44. James J. Flink, "The Path of Least Resistance," *American Heritage of Invention and Technology* 5, 2 (Fall 1989): 42.
45. EcoModder Wiki, "Vehicle Coefficient of Drag List" (July 16, 2012), accessed on August 8, 2012, at http://ecomodder.com/wiki/index.php/Vehicle_Coefficient_of_Drag_List.
46. Deborah L. Bleviss, "Saving Fuel: Time to Get Back on Track," *Technology Review* 91, 8 (November–December 1988): 50.
47. Toyota Motor Corporation, "Worldwide Sales of Toyota Hybrids Top 8 Million Units," accessed on December 9, 2015, at www.toyota-global.com/innovation/environmental_technology/hv-record/.
48. Robert L. Heilbroner, *An Inquiry into the Human Prospect* (New York: W.W. Norton, 1974), p. 110.
49. Judith Shapiro, *Mao's War against Nature: Politics and the Environment in Revolutionary China* (Cambridge and New York: Cambridge University Press, 2001).
50. Kimon Valaskakis et al., *The Conserver Society: A Workable Alternative for the Future* (New York: Harper & Row, 1979), p. 166.
51. Doug Koplow, "Nuclear Power: Still Not Viable without Subsidies," Union of Concerned Scientists (February 2011), accessed on February 21, 2012, at www.ucsusa.org/assets/documents/nuclear_power/nuclear_subsidies_report.pdf. See also Union of Concerned Scientists, "Production Tax Credit for Renewable Energy" accessed on December 9, 2015, at www.ucsusa.org/clean_energy/smart-energy-solutions/increase-renewables/production-tax-credit-for.html#.VmieJqRIjcs.
52. Diane Cardwell, "Energy Tax Breaks Proposed Despite Waning Support for Subsidies," *New York Times* (January 26, 2012), accessed on February 21,

2012, at www.nytimes.com/2012/01/27/business/energy-environment/clean-energy-projects-face-waning-subsidies.html?_r=2&pagewanted=1&ref=windpower.

53. Seth Hanlon, “Big Oil’s Misbegotten Tax Gusher,” Center for American Progress (May 5, 2011), accessed on February 21, 2012, at www.americanprogress.org/issues/2011/05/big_oil_tax_breaks.html. It should be pointed out that many of these quasi-subsidies are also collected by firms in other sectors of the economy.
54. Government Accountability Office, “Budget Trends and Challenges for DOE’s Energy R&D Program” (2008), accessed on June 28, 2008, at www.gao.gov/new.items/d08556t.pdf, p. 6.
55. U.S. Energy Information Administration, “Direct Federal Financial Interventions and Subsidies in Energy in Fiscal Year 2013,” accessed on December 9, 2015, at www.eia.gov/analysis/requests/subsidy/.
56. “Federal R&D Funding, by Budget Function: Fiscal Years 2013–15,” Table 1, accessed on December 9, 2015, at www.nsf.gov/statistics/2015/nsf15306/pdf/tab1.pdf.

Chapter 7 Notes

1. Lewis Thomas, *The Medusa and the Snail: More Notes of a Biology Watcher* (New York: Bantam Books, 1980), p. 133.
2. Thomas McKeown, *The Role of Medicine: Dream, Mirage, or Nemesis?* (Princeton, NJ: Princeton University Press, 1979).
3. John E. Wennberg et al., "Tracking the Care of Patients with Severe Chronic Illness" (April 2008), accessed on July 8, 2008, at www.dartmouthatlas.org/atlas/2008_Atlas_Exec_Summ.pdf.
4. U.S. Department of Health and Human Services, "Health, United States, 2014" (May 2015) p. 306, accessed on December 14, 2015 at www.cdc.gov/nchs/data/abus/abus14.pdf#103.
5. Louise B. Russell, *Technology in Hospitals: Medical Advances and Their Diffusion* (Washington, DC: The Brookings Institution, 1979), p. 3.
6. Daniel Callahan, "Health Care Costs and Medical Technology," *The Hastings Center* (2015), accessed on December 14, 2015, at www.thehastingscenter.org/Publications/BriefingBook/Detail.aspx?id=2178.
7. Adapted from Bryan Jennett, *High-Technology Medicine: Burdens and Benefits* (Oxford: Oxford University Press, 1986), p. 174.
8. Renee C. Fox and Judith P. Swazey, *The Courage to Fail: A Social View of Organ Transplants and Dialysis* (Chicago: University of Chicago Press, 1978), p. 230.
9. Shana Alexander, "They Decide Who Lives, Who Dies," *Life* 53 (November 9, 1962), quoted in *ibid.*, p. 231.
10. Fox and Swazey, *The Courage to Fail*, p. 233.
11. *Ibid.*, p. 348.
12. *Ibid.*, p. 349.
13. University of California, San Francisco, Schools of Pharmacy and Medicine, "The Kidney Project: Statistics" (2014), accessed on December 14, 2015, at <https://pharm.ucsf.edu/kidney/need/statistics>.
14. *Ibid.*
15. Henry J. Aaron and William B. Schwartz, *The Painful Prescription: Rationing Health Care* (Washington, DC: The Brookings Institution, 1984), p. 35.
16. Adnan Sherif and Keshwar Baboolal, "Update on Dialysis Economics in the UK," *Peritoneal Dialysis International*, accessed on December 14, 2015, at www.pdiconnect.com/content/31/Supplement_2/S58.full.
17. Centers for Disease Control and Prevention, *Health, United States, 2013*, Table 116 "Cost of Hospital Discharges with Common Hospital Operating Room Procedures in Nonfederal Community Hospitals by Age and Selected Principal Procedure: United States, Selected Years 2000–2011," accessed on December 12, 2015 at www.cdc.gov/nchs/data/abus/abus13.pdf#116.
18. *Ibid.*
19. Shannon Brownlee, "The Perils of Prevention," *New York Times Magazine*

- (March 16, 2003), accessed on July 7, 2008, at www.nytimes.com/2003/03/16/magazine/the-perils-of-prevention.html.
20. Thomas H. Maugh II, "Cardiologists Rush to Angioplasty despite Evidence for Value of Drugs," *Los Angeles Times* (May 11, 2011), accessed on December 15, 2015, at <http://articles.latimes.com/2011/may/11/news/la-heb-angioplasty-medical-therapy-05112011>.
 21. *Ibid.*
 22. Diana B. Dutton, *Worse than the Disease: Pitfalls of Medical Progress* (Cambridge: Cambridge University Press, 1988), p. 99.
 23. *Ibid.*, p. 118.
 24. Gideon Gil, "The Artificial Heart Juggernaut," *Hastings Center Report* 19, 2 (March/April 1989): 24.
 25. Syncardia Systems, Inc., "Patients Supported for More than 1 Year by the SynCardia Total Artificial Heart Experienced Acceptable Outcomes, Concludes International Study" (February 17, 2015), accessed on December 15, 2015, at www.syncardia.com/2015-multimedia-releases/patients-supported-for-more-than-1-year-by-the-syncardia-total-artificial-heart-experienced-acceptable-outcomes-concludes-international-study/itemid-1745.html.
 26. Dutton, *Worse than the Disease*, p. 300.
 27. Henry J. Kaiser Family Foundation, "10 FAQs: Medicare's Role in End-of-Life Care," accessed on December 11, 2015, at <http://kff.org/medicare/fact-sheet/10-faqs-medicares-role-in-end-of-life-care/>.
 28. U.S. Congress, Office of Technology Assessment, "The Changing Health Care System," in Schwartz, *Dominant Issues*, op cit., p. 286.
 29. Alexander Friedman, "Why Do Doctors Cling to Continuous Fetal Heart Monitoring?" (2011), accessed on February 23, 2012, at www.ncbi.nlm.nih.gov/pmc/articles/PMC1464043/.
 30. David E. Rogers, "On Technologic Restraint," *Archives of Internal Medicine* 135 (1975), p. 1395, cited in Stanley Joel Reiser, *Medicine and the Reign of Technology* (Cambridge: Cambridge University Press, 1978), p. 161.
 31. *Ibid.*, p. 38.
 32. Hughes Evans, "Losing Touch: The Controversy over the Introduction of Blood Pressure Instruments into Medicine," *Technology and Culture* 34, 4 (October 1993): 803.
 33. Reiser, *Medicine and the Reign of Technology*, p. 231.
 34. Richard Sherlock, "Medical Ethics," in Carl Mitcham (Ed.), *The Encyclopedia of Science, Technology, and Ethics* (Detroit: Thomson Gale, 2005), p. 1184.
 35. Carla K. Spivack, "The Law of Surrogate Motherhood in the United States," *The American Journal of Comparative Law* (2010), p. 114, accessed on December 15, 2010, at http://works.bepress.com/cgi/viewcontent.cgi?article=1014&context=carla_spivack.

Chapter 8 Notes

1. Information on the project, both current and historical, can be found at Human Genome Project Information, “History of the Human Genome Project,” accessed on February 29, 2012, at www.ornl.gov/sci/techresources/Human_Genome/project/hgp.shtml.
2. The majority ruling and the minority’s dissent in the case, *Diamond v. Chakrabarty*, can be found at <http://caselaw.lp.findlaw.com/cgi-bin/getcase.pl?court=us&vol=447&invol=303> (accessed February 29, 2012).
3. Human Genome Project Information, “Genetics and Patenting,” accessed on March 2, 2012, at www.ornl.gov/sci/techresources/Human_Genome/elsi/patents.shtml. This site has many useful links pertaining to the patenting of genes.
4. Elliot Marshall and Michael Price, “Supreme Court Strikes Down Human Genome Patents,” *Science Insider* (June 13, 2013), accessed on December 21, 2015, at <http://news.sciencemag.org/people-events/2013/06/u.s.-supreme-court-strikes-down-human-gene-patents>.
5. Food and Agriculture Organization of the United Nations, “World Food Situation,” accessed on December 25, 2015, at www.fao.org/worldfoodsituation/foodpricesindex/en/.
6. World Health Organization, “Twenty Questions on Genetically Modified Foods,” accessed on February 29, 2012, at www.who.int/foodsafety/publications/biotech/20questions/en/.
7. David Despain, “Farming the Future: GM Crops Recommended as Key Part of Obama’s Evergreen Revolution” (December 9, 2010), accessed on March 5, 2012, at www.scientificamerican.com/article.cfm?id=farming-the-future-gm-crops.
8. International Service for the Acquisition of Agri-Biotech Applications (ISAAA), “Global Status of Commercialized Biotech/GM Crops in 2014” (January 2015), accessed on December 26, 2015, at www.isaaa.org/resources/publications/pocketk/16/.
9. “Brazil GMO Planting to Increase by 6.8 Percent This Season” (December 18, 2013), accessed on December 21, 2015, at www.reuters.com/article/brazil-biotech-idUSL2N0JX0SF20131218.
10. Jorge Fernandez-Cornejo, Seth Wechsler, Mike Livingston, and Lorraine Mitchell, “Genetically Engineered Crops in the United States,” United States Department of Agriculture (February 2014), accessed on December 21, 2015, at www.ers.usda.gov/media/1282246/err162.pdf.
11. Ibid.
12. Matt Kallman, “Genetically Modified Crops and the Future of World Agriculture,” World Resources Institute (June 17, 2008), accessed on July 17, 2008, at <http://earthtrends.wri.org/updates/node/313>, p. 3.
13. ISAAA, “Global Status,” op. cit.

14. GM Watch, "The World's Top Ten Seed Companies: Who Owns Nature?" accessed on December 26, 2015, at www.gmwatch.org/gm-firms/10558-the-worlds-top-ten-seed-companies-who-owns-nature.
15. World Health Organization, "Twenty Questions," op. cit.
16. Dan Charles, "Top Five Myths of Genetically Modified Seeds, Busted," National Public Radio (October 18, 2012), accessed on December 22, 2015, at www.npr.org/sections/thesalt/2012/10/18/163034053/top-five-myths-of-genetically-modified-seeds-busted.
17. David Suzuki and Peter Knudtson, *Genethics: The Clash between the New Genetics and Human Values* (Cambridge, MA: Harvard University Press, 1989), p. 205.
18. The Innocence Project, "DNA Exonerations Nationwide" (December 18, 2015), accessed on December 22, 2015, at www.innocenceproject.org/free-innocent/improve-the-law/fact-sheets/dna-exonerations-nationwide.
19. Mark A. Rothstein, "Keeping Your Genes Private," *Scientific American*, 299, 3 (September 2008): 64–69.
20. "GINA and You: Understanding GINA, The Genetic Information Nondiscrimination Act of 2008" (May 21, 2008), accessed on May 3, 2016, at http://ginahelp.org/GINA_you.pdf.
21. Gina Kolata, *The Road to Dolly, and the Path Ahead* (New York: Morrow, 1998).
22. Rachel Dowty, "Clones and Cloning," in Sal Restivo (Ed.), *Science, Technology, and Society: An Encyclopedia* (Oxford and New York: Oxford University Press, 2005), p. 54.
23. David S. Moore, *The Developing Gene: An Introduction to Behavioral Epigenetics* (New York: Oxford University Press, 2015).
24. Andrea L. Bonnicksen, "Embryonic Stem Cells," in Carl Mitcham (Ed.), *Encyclopedia of Science, Technology, and Ethics* (Detroit: Thomson Gale, 2005), p. 609.
25. Eryn Brown, "Stem Cells: Research Funding and the 2012 Elections," *Los Angeles Times* (November 21, 2011), accessed on March 1, 2012, at <http://articles.latimes.com/2011/nov/21/news/la-heb-stem-cell-funding-2012-elections-20111121>.
26. National Institutes of Health, "Stem Cell Information" (February 9, 2015), accessed on December 22, 2015, at <http://stemcells.nih.gov/info/pages/faqs.aspx>.
27. Stephen S. Hall, "Revolution Postponed," *Scientific American* 303, 4 (October 2010): 60–67.
28. Suzuki and Knudtson, *Genethics*, op. cit., p. 205.
29. Ibid.
30. Ibid.
31. Daniel J. Kevles, *In the Name of Eugenics: Genetics and the Uses of Human Heredity* (Berkeley: University of California Press, 1985).
32. Philip Reilly, *The Surgical Solution: A History of Involuntary Sterilization in the U.S.* (Baltimore: Johns Hopkins University Press), pp. 94–95. Quoted in

- Joan Rothschild, *The Dream of the Perfect Child* (Bloomington and Indianapolis: Indiana University Press, 2005), p. 45.
33. Richard Weikart, "Eugenics," in *Encyclopedia of Science, Technology, and Ethics*, op. cit., pp. 708–09.
 34. Theodosius Dobzhansky, *Heredity and the Nature of Man* (New York: Harcourt, Brace, and World, 1964), pp. 14–15.
 35. Rothschild, *The Dream of the Perfect Child*, op. cit., pp. 52–131.
 36. Hall, "Revolution Postponed," op. cit.
 37. David S. Moore, *The Dependent Gene: The Fallacy of "Nature" vs. "Nurture"* (New York: Henry Holt, 2001), p. 140.
 38. Edward O. Wilson, *Consilience: The Unity of Knowledge* (New York: Vintage Books, 1999), p. 299.
 39. Amy Maxman, "The Genesis Engine," *Wired*, August 2015.
 40. Wilson, *Consilience*, op. cit.

Chapter 9 Notes

1. Chris Stringer and Peter Andrews, *The Complete World of Human Evolution* (London: Thames and Hudson, 2005) pp. 130–39.
2. Manning Nash, “The Organization of Economic Life,” in George Dalton (Ed.), *Tribal and Peasant Economies: Readings in Economic Anthropology* (Garden City, NY: The Natural History Press, 1967), pp. 4–6.
3. Ibid, p. 4.
4. Melville J. Herskovits, *Economic Anthropology: The Economic Life of Primitive People* (New York: W.W. Norton, 1965), pp. 124–52.
5. For a series of videos demonstrating the making of stone tools, see “Techniques for Flintknapping,” accessed on March 7, 2012, at www.ehow.com/videos-on_4514_techniques-flintknapping.html.
6. Frank R. Wilson, *The Hand: How Its Use Shapes the Brain, Language, and Human Culture* (New York: Pantheon, 1998), pp. 15–34; Dietrich Stout, “Tales of a Stone Age Neuroscientist,” *Scientific American*, 314, 4 (April 2016): 28–35.
7. Gerhard Lenski and Patrick Nolan, *Human Societies: An Introduction to Macrosociology* (Boulder, CO: Paradigm, 2004), p. 83.
8. Richard B. Lee, “What Hunters Do for a Living, or How to Make Out on Scarce Resources,” in Richard B. Lee and Irven DeVore (Eds.), *Man the Hunter* (Chicago: Aldine-Atherton, 1968).
9. “Hunter-Gatherers: Noble or Savage?” *The Economist* (December 19, 2007), accessed on December 30, 2015, at www.economist.com/node/10278703.
10. Marshall Sahlins, “Notes on the Original Affluent Society,” in Lee, *What Hunters Do*, p. 85.
11. Ibid, p. 86.
12. For a comprehensive discussion of the theories, controversies, and empirical findings bearing on the transition to agriculture, see Graeme Barker, *The Agricultural Revolution in Prehistory: Why Did Foragers Become Farmers?* (Oxford: Oxford University Press, 2006).
13. T. Douglas Price and Anne Birgitte Gebauer (Eds.), *Last Hunters, First Farmers: New Perspectives on the Prehistoric Transition to Agriculture* (Santa Fe, NM: School of American Research Press, 1995).
14. Ester Boserup, *Population and Technological Change: A Study of Long-Term Trends* (Chicago: University of Chicago Press, 1981), p. 17.
15. Roy A. Rappaport, “The Flow of Energy in an Agricultural Society,” in *Energy and Power* (San Francisco: W. H. Freeman, 1971).
16. Robert McC. Netting, *Cultural Ecology* (Menlo Park, Calif.: Cummings, 1977), p. 62.
17. Boserup, *Population and Technological Change*, p. 46.
18. Netting, *Cultural Ecology*, p. 68.
19. R. H. Tawney, *Land and Labor in China* (London: George Allen & Unwin,

- 1932), p. 24.
20. Boserup, *Population and Technological Change*, p. 52.
 21. Ibid., p. 39.
 22. *Genesis* 3:19.
 23. Boserup, *Population and Technological Change*, pp. 71–72.
 24. Quoted in Claude Mosse, *The Ancient World at Work* (New York: W.W. Norton, 1969), p. 79.
 25. Ibid., p. 104.
 26. Adam Smith, *An Inquiry into the Nature and Causes of the Wealth of Nations*, originally published in 1776, available at www.ifaarchive.com/pdf/smith_-_an_inquiry_into_the_nature_and_causes_of_the_wealth_of_nations%5B1%5D pp. 13–14.
 27. Stanley Udy, Jr., *Work in Traditional and Modern Society* (Englewood Cliffs, NJ: Prentice-Hall, 1970), p. 66.
 28. Horace Miner, *The Primitive City of Timbuctoo* (Garden City, NY: Doubleday, 1965), pp. 53–55.
 29. Ibid, p. 57.
 30. Gideon Sjoberg, *The Preindustrial City: Past and Present* (New York: Free Press, 1960), p. 187.
 31. Stephan R. Epstein, “Transferring Technical Knowledge and Innovating in Europe, c. 1200–c.1800,” in Stephan R. Epstein, Maarten Roy Prak, and J. L. van Zanden, *Technology, Skills and the Pre-Modern Economy in the East and the West: Essays Dedicated to the Memory of S. R. Epstein* (Leiden and Boston: Brill, 2013), p. 29.
 32. Pamela O. Long, “Invention, Secrecy, Theft: Meaning and Context in Late Medieval Technical Transmission,” *History and Technology* 16 (2000): 223–41.
 33. Steven A. Epstein, *Wage Labor and Guilds in Medieval Europe* (Chapel Hill, NC: University of North Carolina Press, 1991), pp. 66–67.
 34. Mack Walker, “Hometowns and Guilds in Early Modern Germany,” in Edward Shorter (Ed.), *Work and Community in the West* (New York: Harper & Row, 1973), pp. 40–41.
 35. Maarten Roy Prak and Jan Luiten van Zanden, “Introduction,” in Epstein, Prak, and van Zanden, *Technology, Skills and the Pre-modern Economy*, pp. 13–14.
 36. Claude Mosse, *The Ancient World at Work*, trans. Janet Lloyd (London: Chatto and Windus, 1969), pp. 106–7.
 37. Ibid., p. 45.
 38. *Politics* 1278. Quoted in Alison Burford, *Craftsmen in Greek and Roman Society* (Ithaca, NY: Cornell University Press, 1972), p. 34.
 39. Jacques Le Goff, *Time, Work, and Culture in the Middle Ages*, trans. Arthur Goldhammer (Chicago: University of Chicago Press, 1980), p. 44 (author’s emphasis).
 40. Sjoberg, *The Preindustrial City*, p. 209.
 41. Max Weber, *The Protestant Ethic and the Spirit of Capitalism*, trans. Stephen Kalberg (Los Angeles: Roxbury, 2002). (Originally published in 1905.)

42. Lewis Mumford, *Technics and Civilization* (New York: Harcourt, Brace and World, 1934), pp. 12–18.
43. Arnold Pacey, *The Maze of Ingenuity: Ideas and Idealism in the Development of Technology* (Cambridge, MA: MIT Press, 1976), p. 63.
44. David S. Landes, *Revolution in Time: Clocks and the Making of the Modern World* (Cambridge, MA: Harvard University Press, 1983), pp. 53–82.
45. Le Goff, *Time, Work, and Culture in the Middle Ages*, pp. 45–46.
46. *Ibid.*, p. 46.
47. Mumford, *Technics and Civilization*, pp. 14–16.

Chapter 10 Notes

1. John H. White, Jr., "Oh, to Be a Locomotive Engineer," *Railroad History*, no 190 (Spring/Summer 2004), p. 74.
2. Allan Jalon, "Synthesizers: Sour Sound to Musicians," *Los Angeles Times*, December 6, 1985, p. 1.
3. Ian Reinecke, *Electronic Illusions: A Skeptic's View of Our High-Tech Future* (Harmondsworth, England: Penguin, 1984), p. 49.
4. Peter G. Gosselin, "What's Old Is New Again in the U.S. Economy," *Los Angeles Times*, May 25, 2008, p. A29.
5. Malcolm I. Thomis, *The Town Labourer and the Industrial Revolution* (New York: Barnes and Noble, 1974), pp. 88–105.
6. Withold Rybczynski, *Taming the Tiger: The Struggle to Control Technology* (New York: Viking/Penguin, 1985), p. 103
7. Ibid.
8. T. A. Heppenheimer, "The Machine That Killed King Cotton," *American Heritage of Invention and Technology* 20, 1 (Summer 2004): 39.
9. Bureau of Labor Statistics, "Industry Employment and Output Statistics to 2024," *Monthly Labor Review* (December 2015), accessed on January 8, 2016, at www.bls.gov/opub/mlr/2015/article/industry-employment-and-output-projections-to-2024.htm.
10. For a review of how economists have viewed the relationship between employment and technological change, see Gregory R. Woirol, *The Technological Unemployment and Structural Unemployment Debates* (Westport, CT: Greenwood Press, 1996).
11. Ernest Braun and Stuart McDonald, *Revolution in Miniature: The History and Impact of Semiconductor Electronics* (Cambridge: Cambridge University Press, 1978), p. 57.
12. James Fallows, "America's Changing Economic Landscape," *The Atlantic* 255, 3 (March 1985): 54.
13. Robert Greenhill, "Preface," in Jennifer Blank and Thea Chiesa (Eds.), *The Travel and Tourism Competitiveness Report 2011*, Geneva, Switzerland, World Economic Forum (2011), accessed on March 16, 2012, at http://www3.weforum.org/docs/WEF_TravelTourismCompetitiveness_Report_2011.pdf.
14. International Federation of Robotics, "Industrial Robot Statistics," accessed on January 8, 2016, at www.ifr.org/industrial-robots/statistics/.
15. Micheline Maynard, "Yes, Assembly Lines Can Mix Apples and Oranges," *New York Times*, August 17, 2003, p. 5.
16. Harley Shaiken, "The Automated Factory: The Review from the Shop Floor," *Technology Review* 88, 1 (January 1985): 18.
17. Peter Whoriskey, "U.S. Manufacturing Sees a Shortage of Skilled Factory Workers," *Washington Post* (February 19, 2012), accessed on March 20, 2012, at [www.washingtonpost.com/business/economy/us-manufacturing-sees-](http://www.washingtonpost.com/business/economy/us-manufacturing-sees-shortage-of-skilled-factory-workers/2012/02/19/)

- shortage-of-skilled-factory-workers/2012/02/17/gIQAo0MLOR_story.html.
18. The figures for 1950 can be found in United States Census Bureau, *Statistical Abstract of the United States 1951*, Table 207 “Employees in Nonagricultural Establishments by Industry Division, 1919–1950,” accessed on September 25, 2012, at www2.census.gov/prod2/statcomp/documents/1951-03.pdf. The figures for 2012 appear in United States Bureau of Labor Statistics, Table B-1 “Employees on Nonfarm Payrolls by Industry Sector and Selected Industry Detail” (January 8, 2016), accessed on January 12, 2016, at www.bls.gov/news.release/empsit.t17.htm.
 19. Calculated from *ibid*.
 20. “Software as a Career Threat,” *Forbes* 155, 11 (May 22, 1995).
 21. Clive Thompson, “How Khan Academy Is Changing the Rules of Education,” *Wired* (August 2011).
 22. U.S. Census Bureau, *Statistical Abstract of the United States: 2012*, Table 694 “Share of Aggregate Income Received by Each Fifth and Top 5 Percent of Households: 1970–2009,” accessed on March 13, 2012, at www.census.gov/compendia/statab/2012/tables/12s0694.pdf.
 23. Florence Jaumotte, Subir Lall, and Chris Papageorgiou, *Rising Income Inequality: Technology, or Trade and Financial Globalization?* (Washington, DC: International Monetary Fund, 2008), p. 15.
 24. James Sherk, “Technology Explains Drop in Manufacturing Jobs” (October 12, 2010), accessed on May 13, 2016, at www.heritage.org/research/reports/2010/10/technology-explains-drop-in-manufacturing-jobs.
 25. David L. Kay and James E. Pratt, “Jobs, Good Paying Jobs, and Services,” *Research and Policy Brief Series*, Cornell University (May 2009), accessed on March 20, 2012, at devsoc.cals.cornell.edu/cals/devsoc/outreach/cardi/publications/loader.cfm?csModule=security/getfile&PageID=574410.
 26. David Rotman, “Technology and Inequality,” *MIT Technology Review* (October 21, 2014), accessed on January 12, 2016, at www.technologyreview.com/featured_story/531726/technology-and-inequality/.
 27. Eric Brynjolfsson and Andrew McAfee, *Race against the Machine: How the Digital Revolution Is Accelerating Innovation, Driving Productivity, and Irreversibly Transforming Employment and the Economy* (Lexington, MA: Digital Frontier Press, 2011), pp. 41–42.
 28. David Card and John E. DeNardo, “Skill-Based Technological Change and Rising Inequality: Some Problems and Puzzles,” *Journal of Labor Economics*, 20, 4 (2004), accessed on January 8, 2016, at <http://em.berkeley.edu/~card/papers/skill-tech-change.pdf>.
 29. Lydia DePillis, “Losing a Job Is Always Terrible, for Workers over 50 It’s Worse,” *Washington Post* (March 30, 2015), accessed on January 9, 2016, at www.washingtonpost.com/news/wonk/wp/2015/03/30/losing-a-job-is-always-terrible-for-workers-over-50-its-worse/.
 30. Sara J. Czaja and Joseph Sharit, *Aging and Work: Issues and Implications*

- (Baltimore: Johns Hopkins University Press, 2009), p. 259.
31. T. F. Rizzuto and S. Mohammad, *Workplace Technology and the Myth about Older Workers*, paper presented at the Annual Conference of the Society for Industrial and Organizational Psychology (2005), cited in Ron P. Githens, “Older Adults in E-Learning, Opportunities and Barriers,” http://rodgithens.com/papers/older_adults_elearning_2007.pdf (accessed August 26, 2010); Leora Friedberg, “The Impact of Technological Change on Older Workers: Evidence from Data on Computers,” Department of Economics, University of California, San Diego, 1999, www.escholarship.org/uc/item/1s97n77x#page-2 (accessed August 26, 2010).
 32. Colin Gordon, “The Computer Did It? Technology and Inequality,” *Dissent* (Spring 2014), accessed on January 12, 2016, at www.dissentmagazine.org/article/the-computer-did-it-technology-and-inequality.
 33. United States Department of Labor, Bureau of Labor Statistics, “Occupations with the Most Job Growth, 2014–2024” (December 8, 2015), accessed on May 13, 2016, at www.bls.gov/news.release/ecopro.t06.htm.
 34. For a discussion of intermodal transport and its implications for labor, see Edna Bonacich and Jack B. Wilson, *Getting the Goods: Ports, Labor, and the Logistics Revolution* (Ithaca, NY: Cornell University Press, 2008).
 35. Frank Levy and Richard J. Murnane, *The New Division of Labor: How Computers Are Creating the Next Job Market* (Princeton and Oxford: Princeton University Press, 2004), pp. 13–30.
 36. “Creative Compensation,” *The Economist* (January 23, 2016): 23–24.
 37. Thomis, *Town Labourer*, p. 147.

Chapter 11 Notes

1. Terry Reynolds, *Stronger than a Hundred Men* (Baltimore: Johns Hopkins University Press, 1983).
2. B. J. Lewis, J. M. Cimbala, and A. M. Wouden, “Major Historical Developments in the Design of Waterwheels and Francis Hydroturbines,” 27th IAHR Symposium on Hydraulic Machinery and Systems (2014), accessed on January 18, 2016, at <http://iopscience.iop.org/article/10.1088/1755-1315/22/1/012020/pdf>.
3. Melvin Kranzberg and Joseph Gies, *By the Sweat of Thy Brow: Work in the Western World* (New York: G. P. Putnam’s Sons, 1975), p. 112.
4. Daniel Nelson, *Managers and Workers: Origins of the New Factory System in the United States, 1880–1920* (Madison: University of Wisconsin Press, 1975), pp. 4–7.
5. Quoted in Stewart Holbrook, *The Story of American Railroads* (New York: Crown, 1947), p. 15.
6. Walter Licht, *Working for the Railroad: The Organization of Work in the Nineteenth Century* (Princeton, NJ: Princeton University Press, 1983), p. 88.
7. Daniel T. Rodgers, *The Work Ethic in Industrial America* (Chicago: University of Chicago Press, 1978), p. 67.
8. Frederick Engels, “On Authority,” in Karl Marx and Frederick Engels, *Selected Works* (Moscow: Foreign Languages Publishing House, 1962), p. 637.
9. Malcolm I. Thomis, *The Town Labourer* (New York: Barnes and Noble, 1974), pp. 108–9.
10. Witold Rybczynski, *Taming the Tiger: The Struggle to Control Technology* (New York: Viking/Penguin, 1985), pp. 46–47.
11. Charles F. Sabel, *Work and Politics: The Division of Labor in Industry* (Cambridge: Cambridge University Press, 1982), p. 41.
12. N. S. B. Gras, *Industrial Evolution*, quoted in Sidney Pollard, *The Genesis of Modern Management: A Study of the Industrial Revolution in Great Britain* (Harmondsworth, England: Penguin, 1968), pp. 22–23.
13. Harry Braverman, *Labor and Monopoly Capital: The Degradation of Work in the Twentieth Century* (New York: Monthly Review Press, 1974), p. 195.
14. J. Patrick Wright, *On a Clear Day You Can See General Motors* (New York: Avon Books, 1979), p. 94.
15. David A. Hounshell, *From the American System to Mass Production, 1800–1932: The Development of Manufacturing Technology in the United States* (Baltimore: Johns Hopkins University Press, 1984), pp. 217–61.
16. Henry Ford, in collaboration with Samuel Crowther, *My Life and Work* (Garden City, NY: Doubleday, Page & Company, 1922) pp. 81, 82–83.
17. Job enrichment in the automobile industry was pioneered in the 1970s by Volvo. See Charles H. Gibson, “Volvo Increases Productivity through Job Enrichment” *California Management*, 15, 4 (Summer 1973): 64–66, accessed on May 16,

- 2016, at <https://cmr.berkeley.edu/search/articleDetail.aspx?article=5035>.
18. See Charles Rumford Walker and Robert H. Guest, *The Man on the Assembly Line* (Cambridge, MA: Harvard University Press, 1953).
 19. Quoted in Braverman, *Labor and Monopoly Capital*, p. 118.
 20. *Ibid.*, p. 113.
 21. Frederick Winslow Taylor, *The Principles of Scientific Management* (New York: Norton, 1967 [originally published in 1911]), p. 36.
 22. Larry Hirschhorn, *Beyond Mechanization: Work and Technology in a Post-industrial Age* (Cambridge, MA: MIT Press, 1984), pp. 61–86.
 23. *Ibid.*, p. 157.
 24. “The Technology Payoff,” *Business Week* (July 14, 1993): 59.
 25. Sabel, *Work and Politics*, op. cit., p. 74.
 26. Robert B. Reich, *The Next American Frontier* (Harmondsworth, England: Penguin, 1984), p. 81.
 27. U.S. Bureau of Labor Statistics, “Office and Administrative Support Occupations Make Up Nearly 16 Percent of U.S. Employment May 2013” (April 9, 2014), accessed on January 18, 2016, at www.bls.gov/opub/ted/2014/ted_20140409.htm.
 28. Michael W. Miller, “Computers Keep an Eye on Workers and See If They Perform Well,” *Wall Street Journal* (June 3, 1985), p. 1.
 29. Ellen Alderman and Caroline Kennedy, *The Right to Privacy* (New York: Random House, 1995), p. 316.
 30. Jill Andresky Fraser, *White Collar Sweatshop: The Deterioration of Work and Its Rewards in Corporate America* (New York and London: W.W. Norton, 2001), pp. 87–90.
 31. Roslyn L. Feldberg and Evelyn Nakano Glenn, “Technology and Women’s Degradation: Effects of Office Automation on Women Clerical Workers,” in Joan Rothschild (Ed.), *Machina ex Dea: Feminist Perspectives on Technology* (New York: Pergamon Press, 1983), pp. 59–78.
 32. Barbara A. Gutek and Tora K. Bikson, “Differential Experiences of Men and Women in Computerized Offices,” *Sex Roles* 13 (1985): 3–4.
 33. Alina Tugend, “It’s Unclearly Defined, but Telecommuting Is Fast on the Rise,” *New York Times* (March 7, 2014), accessed on January 19, 2016, at www.nytimes.com/2014/03/08/your-money/when-working-in-your-pajamas-is-more-productive.html?_r=0.
 34. Jeffrey M. Jones, “In U.S., Telecommuting for Work Climbs to 37%,” *Gallup* (August 19, 2015), accessed on January 19, 2016, at www.gallup.com/poll/184649/telecommuting-work-climbs.aspx.
 35. Joel Mokyr, *The Gifts of Athena: Historical Origins of the Knowledge Economy* (Princeton, NJ: Princeton University Press, 2002), p. 160.
 36. The Editorial Board, “Defining ‘Employee’ in the Gig Economy,” *New York Times* (July 18, 2015), accessed on January 19, 2016, at www.nytimes.com/2015/07/19/opinion/sunday/defining-employee-in-the-gig-economy.html.
 37. Patrick Gillespie and Sara Ashley O’Brien, “The Gig Economy: More People

- Might Have Jobs than You Think,” *CNNMoney* (October 2, 2015), accessed on January 19, 2016, at <http://money.cnn.com/2015/10/02/news/economy/jobs-report-gig-on-demand-economy/>.
38. Josh Zumbun and Anna Louie Sussman, “Proof of ‘Gig’ Economy Revolution Is Hard to Find,” *Wall Street Journal* (July 26, 2015), accessed on January 19, 2016, at www.wsj.com/articles/proof-of-a-gig-economy-revolution-is-hard-to-find-1437932539. For the number of self-employed workers from 2006 to 2016, see U.S. Department of Labor, Bureau of Labor Statistics, “Labor Force Characteristics” (April 21, 2016), accessed on May 16, 2016, at www.bls.gov/cps/lfcharacteristics.htm.
 39. Frank Levy and Richard J. Murnane, *The New Division of Labor: How Computers Are Creating the Next Job Market* (Princeton and Oxford: Princeton University Press, 2004), pp. 47ff.
 40. The changing skill requirements of auto mechanics are explored in Kevin Borg, *Auto Mechanics: Technology and Expertise in Twentieth Century America* (Baltimore and London: Johns Hopkins University Press, 2007).
 41. U.S. Bureau of Labor Statistics, “Occupational Employment Projections to 2020,” *op. cit.*, p. 89.
 42. U.S. Bureau of Labor Statistics, “Occupations with the Greatest Job Growth,” accessed on March 26, 2012, at www.bls.gov/emp/ep_table_104.htm.
 43. *Ibid.*
 44. Arne Kalleberg, *The Mismatched Worker* (New York and London: W.W. Norton, 2007), p. 50.
 45. *Ibid.*, p. 107.
 46. Ruth Milkman and Cydney Pullman, “Technological Change in an Auto Assembly Plant: The Impact on Workers’ Tasks and Skills,” *Work and Occupations* 18, 2 (May 1991).
 47. William Form, Robert L. Kaufman, Toby L. Parcel, and Michael Wallace, “The Impact of Technology on Work Organization and Work Outcomes: A Conceptual Framework and Research Agenda,” in George Farkas and Paula England (Eds.), *Industries, Firms, and Jobs: Sociological and Economic Approaches* (New York: Plenum Press, 1988).
 48. Louis E. Davis and James C. Taylor, “Technology, Organization, and Job Structure,” in Robert Dubin (Ed.), *Handbook of Work, Organization, and Society* (Chicago: Rand-McNally, 1976), p. 412.

Chapter 12 Notes

1. Quoted in Maurice N. Richter, Jr., *Technology and Social Complexity* (Albany: State University of New York Press, 1982), pp. 16–17.
2. Jared Diamond, *Guns, Germs, and Steel: The Fate of Human Societies* (New York and London: W. W. Norton, 1997), pp. 215–38.
3. James Thorpe, *The Gutenberg Bible: Landmark in Learning* (San Marino, CA: Huntington Library, 1975), p. 3.
4. Xing Runchuan, “The Invention and Development of Printing and Its Dissemination Abroad,” in *Ancient China’s Technology and Science* (Beijing: Foreign Languages Press, 1983), pp. 383–91.
5. Albert Kapr, *Johann Gutenberg: The Man and His Invention*, translated by Douglas Martin (Aldershot, England: Scolar Press, 1996).
6. Frances and Joseph Gies, *Cathedral, Forge, and Waterwheel: Technology and Invention in the Middle Ages* (New York: HarperCollins, 1994).
7. Kapr, *Johan Gutenberg*, pp. 109–22.
8. D. S. L. Cardwell, *Turning Points in Western Technology: A Study of Technology, Science and History* (New York: Science History Publications, 1972), pp. 20–24.
9. Thorpe, *The Gutenberg Bible*, p. 4.
10. Ferdinand Braudel, *Capitalism and Material Life, 1400–1800* (New York: Harper & Row, 1975), p. 298.
11. Elizabeth Eisenstein, *The Printing Revolution in Early Modern Europe* (New York: Cambridge University Press, 1984), pp. 195–99.
12. Lewis Mumford, *Technics and Civilization* (New York: Harcourt, Brace and World, 1934), pp. 21–22.
13. Eisenstein, *The Printing Revolution*, p. 75.
14. *Ibid.*, pp. 43–44.
15. *Ibid.*, p. 239.
16. *Ibid.*, p. 147.
17. Richard Gawthorp and Gerald Strauss, “Protestantism and Literacy in Early Modern Germany,” *Past and Present* 104 (August 1984): 6.
18. Quoted in David Cressy, *Literacy and the Social Order: Reading and Writing in Tudor and Stuart England* (New York: Cambridge University Press, 1980), p. 3.
19. Eisenstein, *The Printing Revolution*, p. 170.
20. Cressy, *Literacy and the Social Order*, p. 16.
21. A. L. Stinchcombe, “Social Structure and the Invention of Organizational Forms,” in Tom Burns (Ed.), *Industrial Man* (Harmondsworth, England: Penguin, 1969), pp. 163–65.
22. Scott Cook, “Technology and Social Change: The Myth of Movable Type,” *The Weaver* 4, 1 (Fall 1985): 5.
23. Terry Forsyth, “A Brief History of the Korean Language,” Department of

- Linguistics, Brigham Young University (1999), accessed on January 21, 2016, at <http://linguistics.byu.edu/classes/ling450ch/reports/korean2.html>. See also “Superscript,” *The Economist*, October 10, 2015, p. 40.
24. Cressy, *Literacy and the Social Order*, p. 176.
 25. Barry Sanders, *A Is for Ox: The Collapse of Literacy and the Rise of Violence in an Electronic Age* (New York: Random House, 1995), pp. 29–32.
 26. See Herbert Marshall McLuhan, *The Gutenberg Galaxy: The Making of Typographic Man* (Toronto: University of Toronto Press, 1962), and *Understanding Media: The Extensions of Man* (New York: New American Library, 1964).
 27. McLuhan, *The Gutenberg Galaxy*, p. 111.
 28. Robert W. Desmond, *The Information Process: World News Reporting to the Twentieth Century* (Iowa City: University of Iowa Press, 1978), pp. 62–63.
 29. Edwin Emery and Michael Emery, *The Press and America: An Interpretive History of the Mass Media*, 7th ed. (Englewood Cliffs, NJ: Prentice-Hall, 1992), p. 115.
 30. Desmond, *The Information Process*, p. 295.
 31. Emery and Emery, *The Press and America*, p. 188.
 32. John F. Kasson, *Civilizing the Machine: Technology and Republican Values in America, 1776–1900* (New York: Penguin Books, 1977), pp. 203–04.
 33. Desmond, *The Information Process*, p. 298.
 34. John Tebbel, *The Compact History of the American Newspaper* (New York: Hawthorne Books, 1969), p. 121.
 35. Emery and Emery, *The Press and America*, p. 93.
 36. Desmond, *The Information Process*, p. 77.
 37. Emery and Emery, *The Press and America*, p. 85.
 38. Edwin Emery, *The Press and America*, 3rd ed. (Englewood Cliffs, NJ: Prentice-Hall, 1972), p. 285.
 39. Emery and Emery, *The Press and America*, p. 191.
 40. Desmond, *The Information Process*, p. 388.
 41. Edwin Emery, *The Press and America*, 3rd ed. (Englewood Cliffs, NJ: Prentice-Hall, 1972), p. 365.
 42. George H. Douglas, *The Golden Age of the Newspaper* (Westport, CT, and London: Greenwood, 1999), p. 111.
 43. Lee Rainie and Andrew Perrin, “Slightly Fewer Americans Are Reading Print Books, New Survey Finds,” Pew Research Center (October 19, 2015), accessed on January 21, 2016, at www.pewresearch.org/fact-tank/2015/10/19/slightly-fewer-americans-are-reading-print-books-new-survey-finds/.
 44. Michael Barthel, “Newspapers: Fact Sheet,” Pew Research Center (June 15, 2016), accessed on July 19, 2016, at www.journalism.org/2016/06/15/newspapers-fact-sheet/.
 45. Ibid.
 46. Tess Stynes, “Print Magazine Sales Decline in 1st Half of 2014,” *Wall Street Journal* (August 7, 2014), accessed on July 19, 2016, at www.wsj.com/articles/print-magazine-sales-decline-in-1st-half-of-2014-

1407423959.

47. Barthel, "Fact Sheet," op. cit.
48. Ibid.
49. Alex T. Williams, "Paying for Digital News: The Rapid Adoption and Current Landscape of Digital Subscriptions at U.S. Newspapers," American Press Institute (February 29, 2016), accessed on July 19, 2016, at www.americanpressinstitute.org/publications/reports/digital-subscriptions/.
50. Barthel, "Fact Sheet," op. cit.
51. Kristine Lu and Jesse Holcomb, "Digital News Audience: Fact Sheet," Pew Research Center (June 15, 2016), accessed on July 22, 2016, at www.journalism.org/2016/06/15/digital-news-audience-fact-sheet/.
52. Joseph Lichterman, "New Pew Data: More Americans Are Getting News on Facebook and Twitter," Nieman Foundation (July 14, 2014), accessed on July 22, 2016, at www.niemanlab.org/2015/07/new-pew-data-more-americans-are-getting-news-on-facebook-and-twitter/.
53. Jeffrey Gottfried, Michael Barthel, Elisa Shearer, and Amy Mitchell, "The 2016 Presidential Campaign—A News Event That's Hard to Miss," Pew Research Center: (February 4, 2016), accessed on August 4, 2016, at www.journalism.org/2016/02/04/the-2016-presidential-campaign-a-news-event-thats-hard-to-miss/.
54. American Press Institute, "How Americans Get Their News" (March 17, 2014), accessed on July 19, 2016, at www.americanpressinstitute.org/publications/reports/survey-research/how-americans-get-news/.
55. Gottfried, et al., "The 2016 Presidential Campaign".
56. Naomi Baron, "How E-Reading Threatens Learning in the Humanities," *The Chronicle of Higher Education* (July 14, 2014), accessed on July 19, 2016, at <http://chronicle.com/article/How-E-Reading-Threatens/147661/>.
57. Maria Konnikova, "Being a Better Online Reader," *The New Yorker* (July 16, 2014), accessed on July 19, 2016, at www.newyorker.com/science/maria-konnikova/being-a-better-online-reader.
58. Alan Jacobs, "How Problematic is E-Reading?" *The New Atlantis* (July 16, 2014), accessed on July 19, 2016, at <http://text-patterns.thenewatlantis.com/2014/07/how-problematic-is-e-reading.html>.
59. Benjamin Herold, "Digital Reading Poses Learning Challenges for Students," *Education Week* (May 6, 2014), accessed on July 22, 2016, at www.edweek.org/ew/articles/2014/05/07/30reading_ep.h33.html.
60. Ibid.
61. Konnikova, "Online Reader," op. cit.
62. Anne Niccoli, "Paper or Tablet? Reading Recall and Comprehension," *Educause Review* (September 28, 2015), accessed on July 22, 2016, at <http://er.educause.edu/articles/2015/9/paper-or-tablet-reading-recall-and-comprehension>.

Chapter 13 Notes

1. Tom Standage, *The Victorian Internet: The Remarkable Story of the Telegraph and the Nineteenth Century's On-Line Pioneers* (New York: Berkley Publishing Group, 1999).
2. For extensive coverage of the early history of radio, see Hugh G. J. Aitken, *Syntony and Spark: The Origins of Radio* (Princeton, NJ: Princeton University Press, 1985), and *The Continuous Wave: Technology and American Radio, 1900–1932* (Princeton, NJ: Princeton University Press, 1985).
3. Eric Barnouw, *Tube of Plenty: The Evolution of American Television* (New York: Oxford University Press, 1975), pp. 4–5.
4. Albert Abramson, *Zworykin, Pioneer of Television* (Urbana and Chicago: University of Illinois Press, 1995), pp. 87–113.
5. W. Rupert Maclaurin, *Invention and Innovation in the Radio Industry* (New York: Macmillan, 1949), pp. 225–40.
6. Tom Lewis, *Empire of the Air: The Men Who Made Radio* (New York: HarperCollins, 1991), pp. 268–69, 300–7.
7. Barnouw, *Tube of Plenty*, p. 100.
8. National Cable & Telecommunications Association, “Michael Powell,” accessed on January 25, 2016, at www.ncta.com/who-we-are/leadership/bio/169.
9. Preeti Vissa, “The Revolving Door Continues,” *Huffington Post* (July 17, 2011), accessed on January 25, 2016, at www.huffingtonpost.com/preeti-vissa/the-revolving-door-contin_b_862784.html.
10. Barry Cole and Mel Oettinger, *Reluctant Regulators: The FCC and the Broadcast Audience* (Reading, MA: Addison-Wesley, 1978).
11. Megan McArdle, “It’s Normal for Regulators to Get Captured,” *Bloomberg View* (October 1, 2014), accessed on January 25, 2016, at www.bloombergvie.com/articles/2014-09-30/it-s-normal-for-regulators-to-get-captured.
12. Ben Leubsdorf, “We’re Working More Hours—and Watching More TV,” *Wall Street Journal* (June 24, 2015), accessed on January 25, 2016, at www.wsj.com/articles/were-working-more-hoursand-watching-more-tv-1435187603.
13. “Time Spent Watching TV,” *AdAge Mediaworks* (April 18, 2011), accessed on March 29, 2012, at <http://adage.com/article/mediaworks/time-spent-watching-tv/227022/>.
14. Wayne Friedman, “Income, Education Levels Impact Television Viewing,” *MediaPost* (April 2, 2013), accessed on August 16, 2016, at www.mediapost.com/publications/article/197108/income-education-levels-impact-tv-viewing.html.
15. Mary Dooe, “Beyond the Data: TV Viewing and Income.” *Marketplace* (November 4, 2013), accessed on August 16, 2013, at www.marketplace.org/2013/11/04/wealth-poverty/income-upshot/behind-data-

- tv-viewing-and-income.
16. Eugene V. Beresin, "The Impact of Media Violence on Children and Adolescents: Opportunities for Clinical Interventions," *American Academy of Child and Adolescent Psychiatry* (2015), accessed on January 26, 2016, at www.aacap.org/aacap/Medical_Students_and_Residents/Mentorship_Matters/D
 17. Albert Bandura, Dorothea Ross, and Sheila A. Ross, "Transmission of Aggression through Imitation of Aggressive Models," *Journal of Abnormal and Social Psychology* 63, 3 (1961): 575–82.
 18. George A. Comstock and Erica Scharrer, *Television: What's On, Who Is Watching, and What It Means* (San Diego and London: Academic Press, 1999), p. 278.
 19. George Comstock and Erica Scharrer, *Media and the American Child* (Amsterdam: Elsevier, 2007), pp. 204–7.
 20. *Ibid.*, pp. 210–19.
 21. Wilbur Schramm, Jack Lyle, and Edwin B. Parker, *Television in the Lives of Our Children* (Stanford, CA: Stanford University Press, 1961), p. 1.
 22. "Youth Violence: A Report of the Surgeon General" (November and December 2001), accessed on April 2, 2012, at www.surgeongeneral.gov/library/youthviolence/default.html.
 23. George Comstock, *Television in America* (Beverly Hills, CA: Sage, 1980), p. 83.
 24. Comstock and Scharrer, *Media and the American Child*, pp. 239–41.
 25. American Psychological Association, "Violence in Mass Media," accessed on January 26, 2016, at www.apa.org/about/policy/media.aspx.
 26. Federal Communications Commission, "The V-Chip: Putting Restrictions on What Your Children Watch" (November 4, 2015), accessed on January 26, 2016, at www.fcc.gov/consumers/guides/v-chip-putting-restrictions-what-your-children-watch.
 27. Barnouw, *Tube of Plenty*, p. 314.
 28. Katerina Eva Matsa, "Network News Fact Sheet" (April 29, 2015), accessed on August 3, 2016, at www.journalism.org/2015/04/29/network-news-fact-sheet/, p. 38.
 29. Andrea Caumont, "12 Trends Shaping Digital News," Pew Research Center (October 16, 2013), accessed on August 4, 2016, at www.pewresearch.org/fact-tank/2013/10/16/12-trends-shaping-digital-news/#tw2.
 30. Pew Research Center for People and the Press, "Public Knowledge of Current Affairs Little Changed by News and Information Revolutions" (April 15, 2007), accessed on April 3, 2012, at www.people-press.org/2007/04/15/public-knowledge-of-current-affairs-little-changed-by-news-and-information-revolutions/.
 31. Comstock and Scharrer, *Television: What's On*, p. 123.
 32. Neil Postman, *Amusing Ourselves to Death: Public Discourse in the Age of Show Business* (New York: Viking/Penguin, 1985), p. 152.
 33. Melvin L. DeFleur and Everette E. Dennis, *Understanding Mass Communication*, 2nd ed. (Boston: Houghton Mifflin, 1985), p. 450.

34. Jacob Premuk, "Trump Spent About Half of What Clinton Did on His Way to the Presidency," CNBC (November 9, 2016), accessed on November 15, 2016, at www.cnn.com/2016/11/09/trump-spent-about-half-of-what-clinton-did-on-his-way-to-the-presidency.html.
35. Ezra Klein, "Your Slip Is Showing and Reshowing," *Los Angeles Times* (May 18, 2008), p. M5.
36. Postman, *Amusing Ourselves*, pp. 125–141; Jerry Mander, *Four Arguments for the Elimination of Television* (New York: Quill, 1978).
37. Patricia Marks Greenfield, *Mind and Media: The Effects of Television, Video Games, and Computers* (Cambridge, MA: Harvard University Press, 1984), pp. 17, 33.
38. Comstock and Scharrer, *Television: What's On*, pp. 231–32.
39. Greenfield, *Mind and Media*, pp. 88–89.
40. Johannes W. J. Beentjes and Tom H. A. Van der Voort, "Television's Impact on Children's Reading Skills: A Review of Research," *Reading Research Quarterly* 23, 4 (Fall 1988).
41. Shalini Ramachandran, "TV Viewing Slips as Streaming Booms, Nielsen Report Shows," *Wall Street Journal* (December 3, 2014), accessed on January 26, 2016, at www.wsj.com/articles/tv-viewing-slips-as-streaming-booms-nielsen-report-shows-1417604401.

Chapter 14 Notes

1. Janet Abbate, *Inventing the Internet* (Cambridge, MA: MIT Press, 1999).
2. Brian Winston, *Media Technology and Society: A History: From the Telegraph to the Internet* (London and New York: Routledge, 1998), p. 324.
3. Alex Roland, “Will Nuclear War Interrupt My Email?” Address at the annual meeting of the Society for the History of Technology, Henry Ford Museum, Dearborn, Michigan, October 14, 1999.
4. World Wide Web Foundation, “History of the Web,” accessed on August 31, 2016, at <http://webfoundation.org/about/vision/history-of-the-web/>.
5. Adrienne LaFrance, “How Many Websites Are There?” *The Atlantic* (September 30, 2015), accessed on August 10, 2016, at www.theatlantic.com/technology/archive/2015/09/how-many-websites-are-there/408151/.
6. United Nations, “Information and Communications Technology (ICT),” accessed on April 9, 2012, at <http://www.un.org/cyberschoolbus/briefing/technology/tech.pdf>.
7. Internet Live Stats, “Total Number of Websites,” accessed on January 28, 2016, at www.internetlivestats.com/total-number-of-websites/.
8. Malcolm Gladwell, “Clicks and Mortar,” *The New Yorker* (December 6, 1999): 106–15.
9. Seth Fiegerman, “Facebook is Unstoppable,” *CNN Money* (July 27, 2016), accessed on September 9, 2016 at <http://money.cnn.com/2016/07/27/technology/facebook-earnings-high-expectations/>
10. Statista, “Numbers of LinkedIn Members from 1st Quarter 2009 to 3rd Quarter 2015,” accessed on August 31, 2016, at www.statista.com/statistics/274050/quarterly-numbers-of-linkedin-members/.
11. Statista, “Number of Monthly Active Twitter Users Worldwide from 1st Quarter 2010 to 2nd Quarter 2016,” accessed on August 31, 2016, at www.statista.com/statistics/282087/number-of-monthly-active-twitter-users/.
12. Internet Live Stats, “Twitter Usage Statistics,” accessed on January 29, 2016, at www.internetlivestats.com/twitter-statistics/.
13. Aaron Smith, “6 New Facts about Facebook,” Pew Research Center (February 3, 2014), accessed on August 8, 2016, at www.pewresearch.org/fact-tank/2014/02/03/6-new-facts-about-facebook/.
14. James B. Stewart, “Facebook Has 50 Minutes of Your Time Each Day. It Wants More.” *New York Times* (May 5, 2016), accessed on August 8, 2016, at www.nytimes.com/2016/05/06/business/facebook-bends-the-rules-of-audience-engagement-to-its-advantage.html?_r=0.
15. U.S. Department of Education, Center for Education Statistics, “Student Reports of Bullying and Cyberbullying” (April 2015), accessed on August 10, 2016, at <http://nces.ed.gov/pubs2015/2015056.pdf>.

16. Randye Hoder, "Study Finds Most Teens Sext before They're 18," *Time* (July 3, 2014), accessed on August 8, 2016, at <http://time.com/2948467/chances-are-your-teen-is-sexting/>.
17. Sherry Turkle, "The Flight from Conversation," *New York Times* (April 21, 2012), p. 2, accessed on September 7, 2012, at www.nytimes.com/2012/04/22/opinion/sunday/the-flight-from-conversation.html?pagewanted=1&r=2.
18. Vincent Chua, Julia Madej, and Barry Wellman, "Personal Communities: The World According to Me," in Peter Carrington and John Scott (Eds.), *Handbook of Social Network Analysis* (Thousand Oaks, CA: Sage, 2011), p. 106.
19. *Ibid.*, p. 105.
20. Claude S. Fischer, *America Calling: A Social History of the Telephone to 1940* (Berkeley, CA: University of California Press, 1992).
21. Gartner, Inc., "Worldwide Smartphone Sales Grew 9.7 Percent in Fourth Quarter of 2015" (February 18, 2016), accessed on August 10, 2016, at www.gartner.com/newsroom/id/3215217.
22. Aaron Smith, "U.S. Smartphone Use in 2015," Pew Research Center (April 1, 2015), accessed on August 10, 2016, at www.pewinternet.org/2015/04/01/us-smartphone-use-in-2015/.
23. Statista, "Cumulative Number of Apps Downloaded from the Apple App Store from July 2008 to June 2015," accessed on January 29, 2016, at www.statista.com/statistics/263794/number-of-downloads-from-the-apple-app-store/.
24. Victor Luckerson, "This Is How Many Apps You're Really Using on Your Smartphone," *Fortune* (September 24, 2015), accessed on January 30, 2016, at <http://fortune.com/2015/09/24/apps-smartphone-facebook/>.
25. Antonio Regalado, "How Mobile Phones Jump-Start Developing Economies," *Technology Review* (November 22, 2010), accessed on June 29, 2012, at www.technologyreview.com/news/421769/how-mobile-phones-jump-start-developing-economies/.
26. Grace Dobush, "How Mobile Phones Are Changing the Developing World," Consumer Technology Association (July 27, 2015), accessed on January 29, 2016, at www.cta.tech/Blog/Articles/2015/July/How-Mobile-Phones-Are-Changing-the-Developing-World.aspx.
27. Bill Wasik, "Crowd Control," *Wired* (January 2012): 78.
28. Wael Ghonim, *Revolution 2.0: The Power of the People Is Greater than the People in Power* (New York and Boston: Houghton Mifflin Harcourt, 2012), pp. 292–93.
29. Evgeny Morozov, "The Digital Dictatorship," *Wall Street Journal* (February 20, 2010), accessed on September 6, 2012, at <http://online.wsj.com/article/SB100014240527487039830045750739111474045>
30. Malcolm Gladwell, "Small Change: Why the Revolution Will Not Be Tweeted," *The New Yorker* (October 4, 2010), accessed on April 11, 2012, at www.newyorker.com/reporting/2010/10/04/101004fa_fact_gladwell?currentPage=4.

31. "The Great Firewall: The Art of Concealment," *The Economist* (April 6, 2013), accessed on August 30, 2016, at www.economist.com/news/special-report/21574631-chinese-screening-online-material-abroad-becoming-ever-more-sophisticated.
32. Matthew Ingram, "Open vs. Closed: What Kind of Internet Do We Want?" GigaOM (March 23, 2012), accessed on June 29, 2012, at <http://gigaom.com/2012/03/23/open-vs-closed-what-kind-of-internet-do-we-want/>.
33. Quentin Hardy, "Court Decides All Bits Are Equal," *New York Times* (June 15, 2016), accessed on September 1, 2016, at <http://www.nytimes.com/2016/06/16/technology/court-decides-all-bits-are-equal.html?rref=collection%2Ftimestopic%2FNet%20Neutrality&action=click&contentCol>
34. Eduardo Porter, "Keeping the Internet Neutral," *New York Times* (May 8, 2012), accessed on August 18, 2012, at www.nytimes.com/2012/05/09/business/economy/net-neutrality-and-economic-equality-are-intertwined.html?_r=0.
35. Internet World Stats, "Internet Users in the World by Regions, November 2015," accessed on January 29, 2016, at www.internetworldstats.com/stats.htm.
36. Ibid.
37. Andrew Perrin and Maeve Duggan, "Americans' Internet Access, 2000–2015," Pew Research Center (June 26, 2015), accessed on January 29, 2016, at www.pewinternet.org/2015/06/26/americans-internet-access-2000-2015/.
38. Ibid.
39. Ibid.
40. Ibid.
41. Monica Anderson, "Racial and Ethnic Differences in How People Use Mobile Technology," Pew Research Center (April 30, 2015), accessed on January 29, 2016, at www.pewresearch.org/fact-tank/2015/04/30/racial-and-ethnic-differences-in-how-people-use-mobile-technology/.
42. Jamilah King, "How Big Telecom Used Smartphones to Create a New Digital Divide," *Colorlines* (December 6, 2011), accessed on September 7, 2012, at http://colorlines.com/archives/2011/12/the_new_digital_divide_two_separate_b
43. Dale North, "155 Million Americans Play Video Games, and 80% of Households Own a Gaming Device," *Venturebeat* (April 14, 2015), accessed on January 29, 2016, at <http://venturebeat.com/2015/04/14/155-million-americans-play-video-games-and-4-out-of-5-households-own-a-gaming-device/>.
44. Tom DiChristopher, "Digital Gaming Sales Hit Record \$61 Billion in 2015: Report," *CNBC* (January 26, 2016), accessed on January 29, 2016, at www.cnn.com/2016/01/26/digital-gaming-sales-hit-record-61-billion-in-2015-report.html.
45. Tim Cross, "All the World's a Game," *The Economist* (December 8, 2011), accessed on July 3, 2012, at www.economist.com/node/21541164.
46. Entertainment Software Association, "Essential Facts about the Computer and Video Game Industry" (April 2015), accessed on January 29, 2016, at

- www.theesa.com/wp-content/uploads/2015/04/ESA-Essential-Facts-2015.pdf, p. 3.
47. Ibid., p. 8
 48. Keith Stuart, "Modern Warfare 3 Smashes Records: \$775 Million in Five Days," *The Guardian* (November 18, 2011), accessed on April 20, 2011, at www.theguardian.com/technology/2011/nov/18/modern-warfare-2-records-775m.
 49. Melissa Telecki et al., "Sex Differences and Similarities in Video Game Experience: Implications for the Gaming Industry," *Current Psychology*, 30, 1 (December 2010): 22–33.
 50. C. Heeter et al., "Alien Games: Do Girls Prefer Games Designed by Girls?" *Games and Culture*, 4, 1 (2009): 74–100. Cited in *ibid.*
 51. American Psychological Association, "APA Review Confirms Link between Playing Violent Video Games and Aggression" (August 13, 2015), accessed on January 29, 2016, at www.apa.org/news/press/releases/2015/08/violent-video-games.aspx.
 52. George Comstock and Erica Scharrer, *Media and the American Child* (Amsterdam: Elsevier, 2007), pp. 234–38.
 53. Ibid., p. 236.
 54. *Science Daily*, "American Psychiatric Association Considers 'Video Game Addiction'" (June 25, 2007), accessed on June 29, 2012, at www.sciencedaily.com/releases/2007/06/070625133354.htm.
 55. J. P. Mangalindan, "Play to Win: The Game-Based Economy," *Fortune and CNN Money* (September 3, 2010), accessed on September 26, 2012, at <http://tech.fortune.cnn.com/2010/09/03/the-game-based-economy/>; Gamification Wiki, "Gamification" (June 11, 2012), accessed on September 26, 2012, at <http://gamification.org/wiki/Gamification>.
 56. "Videotaping without Guilt," *New York Times* (January 22, 1984), section 4:1.
 57. Sam Costello, "Court Orders Napster to Stay Shut" (March 25, 2002), accessed on April 23, 2012, at www.pcworld.com/article/91144/court_orders_napster_to_stay_shut.html.
 58. Apple Press Info, "Apple's App Store Downloads Top Ten Billion" (January 22, 2011), accessed on April 22, 2012, at www.apple.com/pr/library/2011/01/22Apples-App-Store-Downloads-Top-10-Billion.html.
 59. The American Assembly, "The Copy Culture Survey: Infringement and Enforcement in the US" (November 15, 2011), accessed on September 8, 2012, at <http://piracy.ssrc.org/the-copy-culture-survey-infringement-and-enforcement-in-the-us/>.
 60. Felix Oberholzer-Gee and Koleman Strumpf, "The Effect of File Sharing on Record Sales: An Empirical Analysis," accessed on August 14, 2008, at www.utdallas.edu/~liebowitz/intprop/OS%202006-12-12.pdf.
 61. Ben Sisario and Karl Russell, "In Shift to Streaming, Music Business Has Lost Billions," *New York Times* (March 24, 2016), accessed on September 1, 2016, at www.nytimes.com/2016/03/25/business/media/music-sales-remain-steady-

- but-lucrative-cd-sales-decline.html.
62. Daniel Solove, "The End of Privacy?" *Scientific American* 299, 3 (September 2008): 104.
 63. Robert Hof, "What Facebook's FTC Privacy Settlement Means to Marketers," *Forbes* (November 29, 2011), accessed on April 10, 2012, at www.forbes.com/sites/roberthof/2011/11/29/what-facebooks-ftc-privacy-settlement-means-to-marketers/.
 64. Evan Halper, "Privacy at Risk in Hunt for Data on Voters," *Los Angeles Times* (January 28, 2016), pp. A1, A9.
 65. Michael Cooney, "10 Common Mobile Security Problems to Attack," *PC World* (September 21, 2012), accessed on January 30, 2016, at www.pcworld.com/article/2010278/10-common-mobile-security-problems-to-attack.html.
 66. Katherine Albrecht, "RFID Tag—You're It." *Scientific American* 299, 3 (September 2008): 72–77.
 67. Simson L. Garfunkel, "Information of the World Unite!" *Scientific American* 299, 3 (September 2008): 82–87.
 68. Joan Biskupic, "Supreme Court Rules GPS Tracking Requires Warrant," *USA Today*, January 24, 2012, p. 2A.
 69. Connie Davis Powell, "'You Already Have Zero Privacy. Get Over It!' Would Warren and Brandeis Argue for Privacy for Social Networking?" *Pace Law Review*. 146 (2011) Accessed on September 9, 2016 at: <http://digitalcommons.pace.edu/plr/vol31/iss1/4>.
 70. The most influential book on this issue is Robert Putnam, *Bowling Alone: The Collapse and Revival of American Community* (New York: Simon and Schuster, 2000).
 71. Raymond Williams, *The Long Revolution* (New York: Penguin Books, 1965), pp. 26–27.

Chapter 15 Notes

1. Victor Davis Hanson, *The Western Way of War: Infantry Battle in Ancient Greece* (New York: Knopf, 1989).
2. Stephen Morillo, Jeremy Black, and Paul Lococo, *War in World History: Society, Technology, and War from Ancient Times to the Present* (New York: McGraw-Hill, 2009), p. 59.
3. James K. Finch, *Engineering and Western Civilization* (New York: McGraw-Hill, 1951), p. 22.
4. Doyne Dawson, *The Origins of Western Warfare: Militarism and Morality in the Ancient World* (Boulder, CO: Westview, 1996), p. 112.
5. William Reid, *The Lore of Arms: A Concise History of Weaponry* (New York: Facts on File, 1984), p. 15.
6. E. W. Marsden, *Greek and Roman Artillery: Historical Development* (Oxford: Clarendon Press, 1969), pp. 86–91.
7. Robert Laffont, *The Ancient Art of Warfare*, vol. 1 (Greenwich, CT: New York Graphic Society, 1968), pp. 121, 128–29.
8. Geoffrey Parker (Ed.), *The Cambridge Illustrated History of Warfare: The Triumph of the West* (Cambridge: Cambridge University Press, 1995), p. 84.
9. Charles William Chadwick Oman, *A History of the Art of War: The Middle Ages from the Fourth to the Fourteenth Century* (London: Methuen, 1898), pp. 73–115.
10. Hugh D. H. Soar, *The Crooked Stick: A History of the Longbow* (Yardley, PA: Westholme, 2004), pp. 1–17.
11. Archer Jones, *The Art of War in the Western World* (New York and Oxford: Oxford University Press, 1987), pp. 156–57.
12. Gervase Phillips, “Longbow and Hackbutt: Weapons Technology and Technology Transfer in Early Modern England,” *Technology and Culture* 40, 3 (July 1999): 579.
13. Richard A. Preston, Sydney F. Wise, and Herman O. Werner, *A History of Warfare and Its Interrelationships with Modern Society* (New York: Frederick A. Praeger, 1956), p. 85.
14. Vernard Foley, George Palmer, and Werner Soedel, “The Crossbow,” *Scientific American* 252, 1 (January 1985): 104–10.
15. Laffont, *The Ancient Art of Warfare*, p. 444.
16. Lynn White, Jr., *Medieval Technology and Social Change* (New York: Oxford University Press, 1966), p. 102.
17. Paul E. Chevedden, Les Eigenbrod, Vernard Foley, and Werner Soedel, “The Trebuchet,” *Scientific American* 273, 1 (July 1995).
18. Martin van Creveld, *Technology and War: From 2000 B.C. to the Present* (New York: The Free Press, 1989).
19. Alex Roland, “Secrecy, Technology, and War: Greek Fire and the Defense of Byzantium, 678–1204,” *Technology and Culture* 33, 4 (October 1992).

20. China Science and Technology Museum, *China's Ancient Technology* (Beijing: China Reconstructs Magazine, 1983), pp. 18–20.
21. William H. McNeill, *The Pursuit of Power: Technology, Armed Force, and Society since A.D. 1000* (Chicago: University of Chicago Press, 1982), p. 91.
22. For a listing of all of these procedures, see Kenneth Chase, *Firearms: A Global History to 1700* (Cambridge: Cambridge University Press, 2003), p. 25.
23. Michael Howard, *War in European History* (London: Oxford University Press, 1976), p. 33.
24. Quoted in Walter Buehr, *Firearms* (New York: Thomas Y. Crowell, 1967), pp. 134–135.
25. McNeill, *The Pursuit of Power*, p. 141.
26. van Creveld, *Technology and War*, p. 107.
27. H. W. Koch, *The Rise of Modern Warfare: From the Age of Mercenaries through Napoleon* (New York: Crescent, 1982), p. 18.
28. Richard Bean, “War and the Birth of the National-State,” *Journal of Economic History* 33, 1 (March 1973): 203–21.
29. Charles Tilly, “Reflections on the History of European State-Making,” in Charles Tilly (Ed.), *The Formation of National States in Western Europe* (Princeton, NJ: Princeton University Press, 1975), p. 42.
30. Quoted in Bernard Brodie and Fawn Brodie, *From Crossbow to H-Bomb* (Bloomington: Indiana University Press, 1973), p. 61.
31. Howard, *War in European History*, p. 123.
32. Carlo M. Cipolla, *European Culture and Overseas Expansion* (Harmondsworth, England: Penguin, 1970), pp. 70–72.
33. Elting E. Morison, *From Know-How to Nowhere: The Development of American Technology* (New York: New American Library, 1977), pp. 139–52.
34. Geoffrey Parker, *The Military Revolution: Military Innovation and the Rise of the West, 1500–1800* (Cambridge: Cambridge University Press, 1988), p. 154.
35. See Daniel R. Headrick, *The Tools of Empire: Technology and European Imperialism in the Nineteenth Century* (New York: Oxford University Press, 1981), pp. 117–19.
36. Morillo, Black, and Lococo, *War in World History*, pp. 468–69.
37. John Ellis, *The Social History of the Machine Gun* (Baltimore: Johns Hopkins University Press, 1975), pp. 111–47.
38. James L. Stokesbury, *A Short History of Air Power* (New York: Morrow, 1986), p. 78.
39. Brodie and Brodie, *From Crossbow to H-Bomb*, p. 224.
40. Theodore Ropp, *War in the Modern World* (New York: Collier Books, 1962), p. 379.
41. “The Atomic Bombings of Hiroshima and Nagasaki,” *AtomicArchive.com*, accessed on February 1, 2016, at http://www.atomicarchive.com/Docs/MED/med_chp10.shtml.
42. Noble Frankland, *Bomber Offensive: The Devastation of Europe* (New York: Ballantine, 1970), p. 149.
43. Stephen L. McFarland, *America's Pursuit of Precision Bombing, 1910–1945*

- (Washington and London: Smithsonian Institution Press, 1995), p. 203.
44. Ian Hogg, *The Weapons That Changed the World* (New York: Arbor House, 1986), p. 144.
 45. Walter Millis, *Arms and Men: A Study in American Military History* (New York: New American Library, 1956), p. 277.
 46. B. H. Liddell Hart, *The Revolution in Warfare* (London: Faber and Faber, 1946), p. 25.
 47. Randall Forsberg, "A Bilateral Nuclear-Weapon Freeze," *Scientific American* 247, 5 (November 1982): 61.
 48. Quoted in Michael S. Sherry, *The Rise of American Air Power: The Creation of Armageddon* (New Haven, CT: Yale University Press, 1987), pp. 209–10.

Chapter 16 Notes

1. Martin W. Bowman, *The USAAF Handbook 1939–1945* (Gloustershire, England: Sutton, 1997) p. 232.
2. Luftwaffe Resource Center, “Fi-103/V-1 ‘Buzz Bomb,’” accessed on May 1, 2012, at <http://www.warbirdsresourcegroup.org/LRG/v1.html>.
3. Sharon Weinberger, “Cruise Missiles: The Million Dollar Weapon,” *The Huffington Post* (May 25, 2011), accessed on May 1, 2012, at http://www.huffingtonpost.com/2011/03/25/cruise-missiles-missile_n_840365.html.
4. “Ruhrstahl X-1” *Wehrmacht History 1939 to 1945*, accessed on May 2, 2012, at <http://www.wehrmacht-history.com/luftwaffe/missiles/ruhrstahl-x-1-anti-ship-missile.htm>.
5. Fred Kaplan, “Smart Bombs, Dumb Targets,” *Slate* (December 16, 2003), accessed on May 3, 2012, at http://www.slate.com/articles/news_and_politics/war_stories/2003/12/smart_bom
6. Robert A. Gurriero, “Space-Based Reconnaissance,” accessed on May 2, 2012, at <http://www.armyspace.army.mil/spacejournal/Article.asp?AID=13>.
7. James Risen, “A Military and Intelligence Clash over Spy Satellites,” *New York Times* (April 19, 2012), accessed on May 2, 2012, at <http://www.nytimes.com/2012/04/20/us/politics/spy-satellite-clash-for-military-and-intelligence-officials.html?pagewanted=all>.
8. P. S. Singer, *Wired for War: The Robotics Revolution and Conflict in the Twenty-First Century* (New York: Penguin Press, 2009), pp. 117–18.
9. *Ibid.*, pp. 54–55.
10. Robert M. Gates, “Remarks by Secretary Gates at the United States Air Force Academy,” U.S. Department of Defense, *News Transcript*, accessed on May 4, 2012, at <http://www.defense.gov/transcripts/transcript.aspx?transcriptid=4779>.
11. Brian Bennett and David S. Cloud, “Obama’s Counter-Terror Advisor Defends Drone Strikes,” *Los Angeles Times* (April 30, 2012), accessed on May 4, 2012, at <http://articles.latimes.com/2012/apr/30/world/la-fg-brennan-drones-20120501>.
12. Scott Shane, “Drone Strikes Reveal Uncomfortable Truth: U.S. Is Often Unsure about Who Will Die,” *New York Times* (April 23, 2015), accessed on February 1, 2016, at http://www.nytimes.com/2015/04/24/world/asia/drone-strikes-reveal-uncomfortable-truth-us-is-often-unsure-about-who-will-die.html?_r=0.
13. *Ibid.*
14. W. J. Hennigan, “Push to Elevate Drone Pilots,” *Los Angeles Times* (November 9, 2015), pp. A1, A13.
15. United States Department of Defense, “The Budget for Fiscal Year 2015,” accessed on June 20, 2016, at <https://www.whitehouse.gov/sites/default/files/omb/budget/fy2015/assets/defense>
16. Sarah Tully, “U.S. Defense Spending vs. Global Defense Spending,” *The Center*

- for Arms Control and Non-proliferation* (May 14, 2015), accessed on February 2, 2016, at <http://armscontrolcenter.org/u-s-defense-spending-vs-global-defense-spending/>.
17. "Defense Spending in a Time of Austerity," *The Economist* (August 26, 2010), accessed on May 4, 2012, at <http://www.economist.com/node/16886851>.
 18. Military Analysis Network, "Joint Direct Munitions (JDM)" (May 2, 2012), accessed on May 2, 2012, at <http://www.fas.org/man/dod-101/sys/smart/jdam.htm>.
 19. "How Much Does an M1A2 Abrams Battle Tank Cost?" *Quora* (July 5, 2011), accessed on May 6, 2012, at <http://www.quora.com/How-much-does-an-M1A2-Abrams-battle-tank-cost>.
 20. Robert Farley, "US Navy Orders 10 Virginia-Class Submarines at a Record Cost of \$17.6 Billion," *The Diplomat* (May 3, 2014), accessed on February 2, 2016, at <http://thediplomat.com/2014/05/us-navy-orders-10-virginia-class-submarines-at-a-record-cost-of-17-6-billion/>.
 21. James P. Harrison, "History's Heaviest Bombing," in Jayne S. Werner and Luu Doan Huynh (Eds.), *The Vietnam War: Vietnamese and American Perspectives* (Armonk, NY: M. E. Sharpe, 1993), p. 133.
 22. *Iraq Coalition Casualty Count*, "Coalition Military Fatalities by Year," accessed on June 20, 2016, at <http://icasualties.org/IRAQ/index.aspx>.
 23. Singer, *Wired for War*, pp. 218–19.
 24. Gilmore Commission First Annual Report, "Reasons and Rationales behind Potential CBRN Terrorism," in Yonah Alexander and Milton Hoenig (Eds.), *Super Terrorism: Biological, Chemical, and Nuclear* (Ardsey, NY: Transnational Publishers, 2001), p. 16.
 25. Daniel R. Headrick, *Power over Peoples: Technology, Environments, and Western Imperialism, 1450 to the Present* (Princeton and Oxford: Princeton University Press, 2010), pp. 322–27.
 26. Christine M. Gosden, "The 1988 Chemical Weapons Attack on Halabja, Iraq," in Alexander and Hoenig, *Super Terrorism*, p. 8.
 27. Jessica Stern, *The Ultimate Terrorists* (Cambridge, MA and London: Harvard University Press), p. 24.
 28. Joseph F. Pilat, "The Bioterrorism Threat: Technological and Political Considerations," in Alexander and Hoenig, *Super Terrorism*, p. 64.
 29. Robert W. Taylor, Tory J. Caeti, D. Kall Loper, Eric J. Fritsch, and John Liederbach, *Digital Crime and Digital Terrorism* (Upper Saddle River, NJ: Pearson Prentice-Hall, 2006), pp. 23–28.
 30. Misha Glenny, "A Weapon We Can't Control," *New York Times* (June 24, 2012), accessed on July 13, 2012, at http://www.nytimes.com/2012/06/25/opinion/stuxnet-will-come-back-to-haunt-us.html?_r=1&ref=stuxnet.
 31. Julie Hirschfeld Davis, "Hacking of Government Computers Exposed 21.5 Million People," *New York Times* (July 9, 2015), accessed on February 2, 2016, at http://www.nytimes.com/2015/07/10/us/office-of-personnel-management-hackers-got-data-of-millions.html?_r=0.

32. Manuel Castells, *The Rise of the Network Society* (Malden, MA: Blackwell, 2000).
33. For the derivation of these terms, see Faisal Irshaid, "Isis, Isil, IS or Daesh? One Group, Many Names," *BBC News* (December 2, 2015), accessed on June 20, 2016, at <http://www.bbc.com/news/world-middle-east-27994277>.
34. Brendan I. Koerner, "#Jihad," *Wired*, 24, 4 (April 2016): 78.
35. B. H. Liddell Hart, *The Revolution in Warfare* (London: Faber and Faber, 1946), p. 30.
36. Singer, *Wired for War*, p. 347.
37. *Ibid.*, pp. 382–87.
38. *Ibid.*, p. 312.
39. *Ibid.*, p. 364.
40. Quoted in *ibid.*, p. 296.

Chapter 17 Notes

1. See, for example, Richard P. Hallion, *Storm over Iraq: Air Power and the Gulf War* (Washington and London: Smithsonian Institution Press, 1992), pp. 59–61.
2. The narrative is based on Thomas Esper, “The Replacement of the Longbow by Firearms in the English Army,” *Technology and Culture* 6, 3 (Summer 1965): 382–93.
3. *Ibid.*, pp. 392–93. See also Hugh D. H. Soar, *The Crooked Stick: A History of the Longbow* (Yardley, PA: Westholme, 2004), pp. 82, 99.
4. Philippe Contamine, *War in the Middle Ages* (Oxford: Basil Blackwell, 1984), p. 217.
5. Bert S. Hall, *Weapons and Warfare in Renaissance Europe: Gunpowder, Technology, and Taxes* (Baltimore and London: Johns Hopkins University Press, 1997), p. 148.
6. Geoffrey Parker (Ed.), *The Cambridge Illustrated History of Warfare: The Triumph of the West* (Cambridge: Cambridge University Press, 1995), p. 178.
7. William H. McNeill, *The Pursuit of Power: Technology, Armed Force, and Society since A.D. 1000* (Chicago: University of Chicago Press, 1982), p. 83.
8. Peter Browning, *The Changing Nature of Warfare: The Development of Land Warfare from 1792 to 1945* (Cambridge: Cambridge University Press, 2002), p. 100.
9. David A. Armstrong, *Bullets and Bureaucrats: The Machine Gun and the United States Army, 1861–1916* (Westport, CT: Greenwood Press, 1982), p. 173.
10. Armin Hall, *Tanks: An Illustrated History of Fighting Vehicles* (New York: Crescent Books, 1971), p. 28.
11. David E. Johnson, *Fast Tanks and Heavy Bombers: Innovation in the U.S. Army, 1917–1945* (Ithaca and London: Cornell University Press, 1998), p. 98.
12. *Ibid.*, pp. 136–37.
13. Witold Rybczynski, *Taming the Tiger: The Struggle to Control Technology* (New York: Viking/Penguin, 1985), p. 171.
14. Richard A. Preston, Sydney F. Wise, and Herman O. Werner, *A History of Warfare and Its Interrelationships with Western Society* (New York: Frederick A. Praeger, 1970), p. 281.
15. Quoted in Hall, *Tanks*, p. 79.
16. Preston, Wise, and Werner, *A History of Warfare*.
17. Walter Millis, *Arms and Men: A Study of American Military History* (New York: New American Library, 1956), p. 16.
18. B. H. Liddell Hart, *The Revolution in Warfare* (London: Faber and Faber, 1946), pp. 40–45.
19. Millis, *Arms and Men*, p. 48.
20. Michael Howard, *War in European History* (London: Oxford University Press, 1976), p. 99.

21. Ken Alder, *Engineering the Revolution: Arms and Enlightenment in France, 1763–1815* (Princeton, NJ: Princeton University Press, 1997), pp. 173, 333.
22. Preston, Wise, and Werner, *A History of Warfare*, p. 320.
23. Seymour Melman, “Swords into Plowshares: Converting from Military to Civilian Production,” *Technology Review* 89, 1 (January 1986): 64.
24. Stockholm International Peace Research Institute, *SIPRI Yearbook, 1984* (Stockholm: SIPRI, 1984), p. 170.
25. Mark Hourihan, “A Primer on Recent Trends in R&D Budgets,” *The American Association for the Advancement of Science* (15 January 2015), accessed on February 3, 2016, at <http://www.aaas.org/sites/default/files/R%26D%20Budget%20Overview.pdf>.
26. Robert S. Woodbury, “The ‘American System’ of Manufacturing,” in Edwin T. Layton, Jr. (Ed.), *Technology and Social Change in America* (New York: Harper & Row, 1973), pp. 47–63.
27. Maurice Pearton, *Diplomacy, War, and Technology since 1830* (Lawrence: University Press of Kansas, 1984), pp. 64–76.
28. Howard, *War in European History*, p. 116.
29. Bernard Brodie and Fawn Brodie, *From Crossbow to H-Bomb* (Bloomington: Indiana University Press, 1973), p. 10.
30. *Ibid.*
31. William Reid, *The Lore of Arms: A Concise History of Weaponry* (New York: Facts on File, 1984), p. 88.
32. Quoted in Daniel R. Headrick, *The Tools of Empire: Technology and European Imperialism in the Nineteenth Century* (New York: Oxford University Press, 1981), p. 86.
33. James E. Dougherty, *How to Think about Arms Control and Disarmament* (New York: Crane, Russak, 1973), pp. 43–44.
34. Marek Pruszeicz, “How Deadly Was the Poison Gas of WW1?” *BBC World Service* (January 30, 2016), accessed on February 4, 2016, at <http://www.bbc.com/news/magazine-31042472>.
35. Quoted in Frederic J. Brown, *Chemical Warfare: A Study in Restraints* (Princeton, NJ: Princeton University Press, 1968), p. 41.
36. *Ibid.*, p. 40.
37. Noel Perrin, *Giving Up the Gun: Japan’s Reversion to the Sword, 1543–1879* (Boston: David R. Godine, 1979), p. 19.
38. The narrative is based on *ibid.*, pp. 33–45.
39. John H. Barton, *The Politics of Peace: An Evaluation of Arms Control* (Stanford, CA: Stanford University Press, 1981), p. 105.
40. Harvard Nuclear Study Group, *Living with Nuclear Weapons* (Cambridge, MA: Harvard University Press, 1983), p. 34.
41. John Steinbruner, “Launch under Attack,” *Scientific American* 251, 1 (January 1984): 38.
42. Dietrich Schroeer, *Science, Technology, and the Nuclear Arms Race* (New York: John Wiley & Sons, 1984), pp. 158–59.
43. Steinbruner, “Launch under Attack.”

44. Herbert Scoville, Jr., "The SALT Negotiations," *Scientific American* 237, 2 (August 1977): 24.
45. Harvard Nuclear Study Group, *Living with Nuclear Weapons*, p. 153.
46. United Nations Office for Disarmament Affairs, "Treaty on the Non-Proliferation of Nuclear Weapons (NPT)," accessed on September 1, 2012, at <http://www.un.org/disarmament/WMD/Nuclear/NPT.shtml>.

Chapter 18 Notes

1. Ron Westrum, *Technologies and Society: The Shaping of People and Things* (Belmont, CA: Wadsworth, 1991), p. 57.
2. Alex Inkeles, *One World Emerging? Convergence and Divergence in Industrial Societies* (Boulder, CO: Westview Press, 1998).
3. David Halberstam, *The Coldest Winter: America and the Korean War* (New York: Hyperion, 2007), p. 223.
4. Darryl E. Brock and Chunjuan Nancy Wei (Eds.), *Mr. Science and Chairman Mao's Cultural Revolution: Science and Technology in Modern China* (Lanham, MD: Lexington Books, 2013).
5. Michael J. Mazaar, *Unmodern Men in the Modern World: Radical Islam, Terrorism, and the War on Modernity* (New York: Cambridge University Press, 2007), p. 132.
6. William Form and Kyu Han Bae, "Convergence Theory and the Korean Connection," *Social Forces* 66, 3 (March 1988).
7. Frederick Fliegel et al., "Technology and Cultural Convergence: A Limited Empirical Test," *Journal of Cross-Cultural Psychology* 10, 1 (March 1979): 3–21.
8. Robert M. Marsh, "A New Test of Convergence Theory," *Comparative Sociology* 6 (2007), pp. 251–94.
9. David S. Landes, *The Unbound Prometheus: Technological Change and Industrial Development in Western Europe from 1750 to the Present* (Cambridge: Cambridge University Press, 1972), p. 545.
10. Robert S. Merrill, "The Role of Technology in Cultural Evolution," *Social Biology* 19, 3 (Spring 1972): 246.
11. Mark Ware and Michael Mabe, "The STM Report: An Overview of Scientific and Scholarly Publishing," International Association of Scientific, Technical and Medical Publishers (2015), accessed on June 21, 2016, at www.stm-ssoc.org/2015_02_20_STM_Report_2015.pdf.
12. Duncan MacRae, Jr., "Science and the Formation of Policy in a Democracy," in Thomas J. Kuehn and Alan L. Porter (Eds.), *Science, Technology, and National Policy* (Ithaca, NY: Cornell University Press, 1981), p. 497.
13. Jeremy Hsu, "There Are More Boys than Girls in China and India: Preference for Sons Could Spell Trouble for China and India," *Scientific American* (August 2008).
14. Binyamin Appelbaum, "As U.S. Agencies Put More Value on a Life, Businesses Fret," *New York Times* (February 16, 2011), accessed on May 16, 2012, at http://www.nytimes.com/2011/02/17/business/economy/17regulation.html?_r=2&pagewanted=1&adxnnl=1&adxnnlx=1337187742-UDghkEx8sVNI25Jz13kqNA.
15. H. H. Gerth and C. Wright Mills (Eds.), *From Max Weber: Essays in Sociology* (New York: Oxford University Press, 1958), p. 233.

16. David Collingridge, *The Social Control of Technology* (New York: St. Martin's Press, 1980), pp. 135–38.
17. Nico Stehr and Reiner Grundmann. *Experts: The Knowledge and Power of Expertise* (New York and London: Routledge, 2011), pp. 45–46.
18. David Willman, "NIH to Curb Scientists' Deals with Drug Firms," *Los Angeles Times* (June 23, 2004): A1.
19. David L. Parnas, "Why I Quit Star Wars," *Common Cause* 12, 3 (May–June 1986): 32, 34.
20. Debra Javeline, Jessica I. Hellman, Rodrigo Castro Cornejo, and Gregory Shufeldt, "Expert Opinion on Climate Change and Threats to Biodiversity," *BioScience* 63, 8 (2013), accessed on February 16, 2016, at <https://bioscience.oxfordjournals.org/content/63/8/666>.
21. NASA, "Scientific Consensus: Earth's Climate Is Warming" (February 11, 2016), accessed on February 15, 2016, at <http://climate.nasa.gov/scientific-consensus/>.
22. Gayathri Vaidyanathan, "Big Gap Between What Scientists Say and Americans Think about Climate Change," *Scientific American* (January 30, 2015), accessed on February 15, 2016, at <http://www.scientificamerican.com/article/big-gap-between-what-scientists-say-and-americans-think-about-climate-change/>.
23. David M. Herszenhorn, "Votes in Congress Move to Undercut Climate Pledge," *New York Times* (December 1, 2015), accessed on February 16, 2016, at <http://www.nytimes.com/2015/12/02/us/politics/as-obama-pushes-climate-deal-republicans-move-to-block-emissions-rules.html>.
24. Mark R. Berg, "The Politics of Technology Assessment," in Kuehn and Porter, *Science, Technology, and National Policy*, p. 494.
25. Max Lerner (Ed.), *The Portable Veblen* (New York: Viking, 1948), p. 440.
26. *Ibid.*, p. 442.
27. *Ibid.*, p. 463.
28. See William E. Akin, *Technocracy and the American Dream: The Technocrat Movement, 1900–1941* (Berkeley: University of California Press, 1977).
29. Daniel Bell, *The End of Ideology* (Glencoe, IL: Free Press, 1967), p. 43.
30. John Kenneth Galbraith, *The New Industrial State*, 2nd ed. (Boston: Houghton Mifflin, 1971), pp. 59–71.
31. Richard Parker, *John Kenneth Galbraith: His Life, His Politics, His Economics* (New York: Farrar, Straus, and Giroux, 2005), pp. 439–50.
32. Rudi Volti, *An Introduction to the Sociology of Work and Occupations* (Thousand Oaks, CA: Sage, 2012), pp. 153–72.
33. Robert Zussman, *Mechanics of the Middle Class: Work and Politics among American Engineers* (Berkeley: University of California Press, 1985), p. 58.
34. *Ibid.*, pp. 122–23.
35. Craig Musselman, "The 80% Myth in the Engineering Profession, Part II: National Society of Professional Engineers" (March 1, 2011), accessed on February 13, 2016, at <http://www.nspe.org/resources/blogs/pe-licensing-blog/80-myth-engineering-profession-part-ii>.

36. Zussman, *Mechanics of the Middle Class*, p. 151.
37. Samuel C. Florman, "Up and Down the Dual Ladder," *Technology Review* 88, 6 (August–September 1985): 12.
38. Edwin T. Layton, Jr., *The Revolt of the Engineers: Social Responsibility and the American Engineering Profession* (Cleveland: Case Western Reserve University Press, 1971), p. 8.
39. Deena Weinstein, "Bureaucratic Opposition: Whistle-Blowing and Other Tactics," in Ron Westrum and Khalil Samaha (Eds.), *Complex Organizations: Growth, Struggle, and Change* (Englewood Cliffs, NJ: Prentice-Hall, 1984), p. 255.
40. Frank Vandiver, "Why Should My Conscience Bother Me?" in Robert Heilbroner et al., *In the Name of Profit* (New York: Doubleday, 1972), pp. 3–31.
41. Diane Vaughan, *The Challenger Launch Decision: Risky Technology, Culture, and Deviance at NASA* (Chicago and London: University of Chicago Press, 1996).
42. Douglas Martin, "Roger Boisjoly, 73, Dies; Warned of Shuttle Danger," *New York Times* (February 3, 2012), accessed on February 14, 2016, at http://www.nytimes.com/2012/02/04/us/roger-boisjoly-73-dies-warned-of-shuttle-danger.html?_r=0.
43. Layton, *The Revolt of the Engineers*, passim.
44. Ralph Nader, Peter J. Petkas, and Kate Blackwell, *Whistle Blowing: The Report on the Conference on Professional Responsibility* (New York: Grossman, 1972), p. 52.

Chapter 19 Notes

1. Robert Blauner, *Alienation and Freedom* (Chicago: University of Chicago Press, 1964).
2. Joan Woodward, *Industrial Organization: Theory and Practice* (London: Oxford University Press, 1965).
3. Recent assessments of Woodward's work along with some personal reminiscences appear in Nelson Phillips, Dorothy S. Griffiths, and Graham Sewell (Eds.), *Technology and Organization: Essays in Honour of Joan Woodward, Research in the Sociology of Organizations*, vol. 24 (Bingley, UK: Emerald Group Publishing, 2010).
4. Markus Perkman and Andre Spicer, "What Are Business Models? Developing a Theory of Performative Representations" in *ibid*, pp. 265–75.
5. Adapted from Charles Perrow, "A Framework for the Comparative Analysis of Organizations," *American Sociological Review*, 32 (1967): 194–208.
6. W. Richard Scott, *Organizations: Rational, Natural, and Open Systems*, (Upper Saddle River, NJ: Prentice-Hall, 1981), p. 37.
7. Stephen P. Robbins, *Organization Theory: Structure, Design, and Applications*, 3rd ed. (Englewood Cliffs, NJ: Prentice Hall, 1998), p. 239.
8. Stephen P. Robbins and Timothy A. Judge, *Organizational Behavior*, 13th ed. (Upper Saddle River, NJ: Pearson Prentice Hall, 2009), pp. 536–37.
9. Richard Daft, *Organization Theory and Design*, 10th ed. (Mason, OH: South-Western Cengage Learning, 2010), p. 398.
10. Karlene Roberts and Martha Grabowski, "Organizations, Technology, and Structuring," in Stewart R. Clegg, Cynthia Hardy, and Walter R. Nord, *Handbook of Organization Studies* (London and Thousand Oaks, CA: Sage, 1996), p. 415.
11. The original "Skunk Works" was a small, semiautonomous part of the Lockheed Aircraft Corporation that developed, among other things, the U-2 spy plane and the record-setting SR-71 bomber. See the memoirs of its first director, Clarence "Kelly" Johnson, *Kelly: More than My Share of It All* (Washington, DC: Smithsonian Institution Press, 1985).
12. Charles Perrow, *Complex Organizations: A Critical Essay*, 2nd ed. (Glenview, IL: Scott, Foresman, 1979), pp. 13–16.
13. Mark Granovetter and Patrick McGuire, "The Making of an Industry: Electricity in the United States," in Michel Callon (Ed.), *The Laws of the Markets* (Oxford: Blackwell, 1998), pp. 147–73.
14. David F. Noble, *Forces of Production: A Social History of Industrial Automation* (New York: Oxford University Press, 1986).
15. David F. Noble, "Social Choice in Machine Design: The Case of Automatically Controlled Machine Tools," in Andrew Zimbalist (Ed.), *Case Studies in the Labor Process* (New York: Monthly Review Press, 1979), p. 34.
16. United States Bureau of Labor Statistics, *Occupational Outlook Handbook*,

- “Machinists and Tool and Die Makers” (December 17, 2015), accessed on February 22, 2016, at <http://www.bls.gov/ooh/production/machinists-and-tool-and-die-makers.htm>.
17. Shoshana Zuboff, *In the Age of the Smart Machine: The Future of Work and Power* (New York: Basic Books, 1988), p. 268.
 18. *Ibid.*, p. 250.
 19. *Ibid.*, p. 252.
 20. *Ibid.*, p. 264.
 21. John Kenneth Galbraith, *American Capitalism: The Concept of Countervailing Power* (Boston: Houghton Mifflin, 1952), p. 86.
 22. For a review of research on the relationship between organizational size and technological innovation, as well as an empirical study of this relationship in one industry, see Gregory N. Stock, Noel P. Greis, and William A. Fischer, “Firm Size and Dynamic Technological Innovation,” *Technovation* 22, 9 (September 2002).
 23. National Science Foundation, “Industrial Research and Development Information System, Historical Data 1953–2007,” Table 50, accessed on March 7, 2016, at http://www.nsf.gov/statistics/iris/search_hist.cfm?indx=7.
 24. Clayton M. Christensen, *The Innovator’s Dilemma: When New Technologies Cause Great Firms to Fail* (Boston, MA: Harvard Business School Press, 1997).
 25. JoAnne Yates, *Control through Communication: The Rise of System in American Management* (Baltimore and London: Johns Hopkins University Press, 1989).
 26. Janet Fulk and Gerardine DeSanctis, “Articulation of Communication Technology and Organizational Form,” in Jay M. Shafritz and J. Steven Ott (Eds.), *Classics of Organization Theory*, 5th ed. (Belmont, CA: Wadsworth, 2001), pp. 500–01.
 27. Erik Brynjoliffson and Lorin Hitt, “Beyond Computation: Information Technology, Organizational Transformation and Business,” *The Journal of Economic Perspectives* 14, 4 (Autumn 2000): 35.
 28. Darin Barney, *Prometheus Wired: The Hope for Democracy in the Age of Network Technology* (Chicago: University of Chicago Press, 2000), pp. 155–63.
 29. Claude S. Fischer, *America Calling: A Social History of the Telephone to 1940* (Berkeley, CA: University of California Press, 1992).
 30. Frank Levy and Richard J. Murnane, *Windows on the Workplace: Technology, Jobs, and the Organization of Office Work*, 2nd ed. (Princeton, NJ: Princeton University Press, 2004), pp. 83–92.
 31. James M. Utterback, “The Process of Technological Innovation within the Firm,” *Academy of Management Journal* 14, 1 (March 1971); Donald A. Schon, *Technology and Change: The New Heraclitus* (New York: Dell, 1967), pp. 161ff.
 32. Robert E. Cole, “Quality Control Practices in the Auto Industry: United States and Japan Compared,” in Robert E. Cole (Ed.), *The Japanese Automobile Industry: Model and Challenge for the Future* (Ann Arbor: University of

- Michigan, Center for Japanese Studies, 1981), p. 92.
33. Christopher Freeman, *The Economics of Industrial Innovation*, 2nd ed. (Cambridge, MA: MIT Press, 1982), p. 176.
 34. T. R. Reid, *The Chip: How Two Americans Invented the Microchip and Launched a Revolution* (New York: Random House, 2001), p. 250.
 35. This account is based on Elting E. Morison, *Men, Machines, and Modern Times* (Cambridge, MA: MIT Press, 1966), pp. 17–44.
 36. Walter Isaacson, *Steve Jobs* (New York: Simon and Schuster, 2011).

Chapter 20 Notes

1. University of California Office of Technology Transfer, “The Bayh-Dole Act: A Guide to the Law and Implementing Regulations” (April 24, 2009), accessed on June 11, 2012, at <http://www.ucop.edu/ott/faculty/bayh.html>.
2. Richard Pérez-Peñanov, “Patenting Their Discoveries Does Not Pay Off for Most Universities, a Study Says,” *New York Times* (November 21, 2013), accessed on February 25, 2016, at http://www.nytimes.com/2013/11/21/education/patenting-their-discoveries-does-not-pay-off-for-most-universities-a-study-says.html?_r=1.
3. Daniel Gross, “A Flighty Wind: Thanks to Government Gridlock, the Wind Energy Industry Is Grinding to a Halt,” *Slate* (March 5, 2015), accessed on February 25, 2016, at http://www.slate.com/articles/business/the_juice/2015/03/wind_industry_growth_about_to_slow_to_a_trickle_thanks_to_government.html
4. Mary Kate Zago, “ “Second Class Children: The Intestate Inheritance Rights Denied to Posthumously Conceived Children and How Legislative Reform and Estate Planning Techniques Can Create Equality,” *Law School Student Scholarship*. Paper 609 (2014), accessed on February 11, 2016, at http://scholarship.shu.edu/student_scholarship/609.
5. National Science Federation, “Science and Technology in Times of Transition: The 1940s and 1990s,” Table 1-3, accessed on June 11, 2012, at <http://www.nsf.gov/statistics/seind00/c1/tt01-03.htm>.
6. Matt Hourihan, “A Primer on Recent Trends in Federal R&D Budgets,” American Association for the Advancement of Science (January 15, 2015), accessed on February 23, 2016, at <http://www.aaas.org/news/primer-recent-trends-federal-rd-budgets>.
7. National Aeronautic and Space Administration, “The Apollo Program,” accessed on June 13, 2012, at <http://spaceflight.nasa.gov/history/apollo/index.html>.
8. Brad Plumer, “NASA Wants to Keep the International Space Station Going until 2024. Is That a Good Idea?” *Washington Post* (January 9, 2014), accessed on January 23, 2016, at <https://www.washingtonpost.com/news/wonk/wp/2014/01/09/nasa-plans-to-keep-the-international-space-station-going-until-2024-is-that-a-good-idea/>.
9. Mary Acland-Hood, “Statistics on Military Research and Development Expenditure,” in Stockholm International Peace Research Institute, *World Armaments and Disarmament* (London: Taylor and Francis, 1984), pp. 169–70.
10. Hourihan, “A Primer on Recent Trends,” op. cit.
11. James Bamford, “Black Box,” *Wired* 20, 4 (April 2012).
12. Fred Sisine, “Renewable Energy R&D Funding: A Comparison with Funding for Nuclear Energy, Fossil Energy, and Energy Efficiency R&D,” Congressional Research Service (March 7, 2012), accessed on June 12, 2012, at

- <http://www.fas.org/sgp/crs/misc/RS22858.pdf>. The remaining 15.1 percent went for electric systems R&D.
13. Daniel Okimoto, *Between MITI and the Market: Japanese Industrial Policy for High Technology* (Stanford, CA: Stanford University Press, 1989), pp. 55–111. For a much less laudatory analysis of MITI’s role in fostering technological and economic advance, see Richard Katz, *Japan, the System That Soured: The Rise and Fall of the Japanese Economic Miracle* (Armonk, NY and London: M. E. Sharpe, 1998).
 14. Richard C. Levin, “The Semiconductor Industry,” and Barbara Goody Katz and Almarin Phillips, “The Computer Industry,” both in Richard R. Nelson (Ed.), *Government and Technical Progress* (New York: Pergamon Press, 1982).
 15. David C. Mowery and Nathan Rosenberg, “The Commercial Aircraft Industry,” in *ibid.*
 16. SSTi, “The Changing Nature of U.S. Basic Research: Trends in Funding Sources” (May 28, 2015), accessed on February 24, 2016, at <http://ssti.org/blog/changing-nature-us-basic-research-trends-funding-sources>.
 17. Bruce L. R. Smith, *The Advisers: Scientists in the Policy Process* (Washington, DC: Brookings Institution Press, 1992), pp. 155–88.
 18. Office of Science and Technology Policy, “About OSTP,” accessed on February 24, 2016, at <https://www.whitehouse.gov/administration/eop/ostp/about>.
 19. Richard Barke, *Science, Technology, and Public Policy* (Washington, DC: CQ Press, 1986), p. 43.
 20. W. Henry Lambright, *Governing Science and Technology* (New York: Oxford University Press, 1976), p. 24.
 21. Laura van Dam and Robert Howard, “How John Gibbons Runs through Political Minefields: Life at the OTA,” *Technology Review* 91, 7 (October 1988): 50.
 22. John G. Burke, “Bursting Boilers and Federal Power,” *Technology and Culture* 7, 1 (Winter 1966): 1–23.
 23. Allan Mazur, *The Dynamics of Technical Controversy* (Washington, DC: Communications Press, 1981), p. 97.
 24. *Ibid.*, p. 90.
 25. *Ibid.*, p. 111.
 26. Lambright, *Governing Science and Technology*, p. 202.
 27. James W. Kuhn, *Scientific and Managerial Manpower in the Nuclear Industry* (New York: Columbia University Press, 1966), p. 115.
 28. John F. Hogerton, “The Arrival of Nuclear Power,” *Scientific American* 218, 2 (February 1968): 21–31.
 29. David Collingridge, *The Social Control of Technology* (New York: St. Martin’s Press, 1980), p. 138.
 30. Quoted in Robert Bell, *Impure Science: Fraud, Compromise and Political Influence in Scientific Research* (New York: John Wiley and Sons, 1992), p. 80.
 31. Richard E. Sclove, *Democracy and Technology* (New York and London: Guildford Press, 1995), pp. 119–38.
 32. This prediction was made in 1954 by Lewis L. Strauss, the Chairman of the Atomic Energy Commission. It is usually assumed that he was speaking of

electricity generated by nuclear fission power, but in reality he was speaking about the future in general while perhaps thinking about the potential of fusion energy. See Thomas Wellock, “ ‘Too Cheap to Meter’: A History of the Phrase,” U.S. Nuclear Regulatory Commission (June 3, 2016), accessed on June 7, 2016, at <https://public-blog.nrc-gateway.gov/2016/06/03/too-cheap-to-meter-a-history-of-the-phrase/>.

33. Herb Brody, “Great Expectations: Why Technology Predictions Go Awry,” *Technology Review* (July 1991).
34. Thomas Jefferson, letter to William C. Jarvis (1820), accessed on June 12, 2012, at <http://tcfir.org/opinion/Thomas%20Jefferson%20on%20Educating%20the%20P>

INDEX

- ABC (television), 265
- AbioCor artificial heart, 136 (*ill.*)
- Abrams battle tank, 64
- Accelerated depreciation of capital equipment, 403
- Acta diurna*, 241
- Active suspension systems, 8
- Adaptation, 87–88
- Ad-hocracies, 386
- Adoption, 87–88
- Advertising
 - Facebook, 278
 - newspaper, 246
 - political, 267–268
- Aerial bombardment, 312–313, 343–345, 344 (*ill.*), 352
- Aerial torpedo, 319
- Aerodynamics, 119
 - research in, 71, 84
- Affordable Care Act, 128
- Afghanistan
 - drone strikes on, 324, 325
 - IEDs in, 327
 - women in, 368 (*ill.*)
- Africa, deforestation in, 109
- African Americans
 - internet usage by, 284
 - smartphone use by, 284

Agriculture

- bioengineering and, 150–153
- conservation tillage in, 150–151
- development of, 171
- displacement of, by industry, 196
- economics of production in, 153
- farming techniques and patterns of work in, 172–174, 173 (*ill.*)
- foraging in, 171, 180
- irresponsible practices in, 110
- irrigated, 173
- monoculture in, 153
- overproduction in, 153
- per-acre crop yields in, 90
- production and jobs in, 188, 189
- sedentary, 172, 173–174
- settled, 173, 174
- slash-and-burn, 172–173, 173 (*ill.*), 174, 180
- soil erosion in, 110

Aiken, Howard, 51

Airbnb, 224

Air Force F-22 fighter, 57, 325

Airline industry, employment in, 192–193

Airplanes, 343–345, 344 (*ill.*)

- Boeing 707, 86

- in China, 86

- Concorde, 7, 94

- development of, 6

- Lockheed C5A transport, 377

- military, 57, 325, 343, 344–345, 344 (*ill.*)

Air pollution, 111, 402

Aitken, Hugh, 93

Alderman, Ellen, 221

Alexander the Great, 301

Alphabet, phonetic, 239

al-Qaeda, 328, 332

- attacks on, 321, 324

Alternative technologies, 90

Aluminum industry, recycling in, 118
Amateur radio operators, 255
Amazon, 288
 Prime, 270
America Online, 283
American Academy for the Advancement of Science, 372, 376
American Civil War, 180, 311
 Gettysburg in, 307
 weapons in, 307, 307 (*ill.*)
American Institute of Industrial Engineers, 377
American Medical Association, opposition to patenting of genes, 149
American penny paper, 243
American Revolutionary War, 346
American Society of Composers, Authors, and Publishers (ASCAP), 256
American Telephone and Telegraph, 259
Amiens, 181–182
Amish, 364
Amniocentesis, 141
Analytical engine, 45, 46 (*ill.*)
Ancient world, military technology in the, 299–301
Anthrax, 329
Antibiotics, 57, 128
Apache helicopter, 64
Apollo program, 404
Apple Computer, 283, 288, 398
 Apple II, 391 (*ill.*)
 iPad, 279
 iPhone, 280, 288
 iTunes, 288
 Newton personal digital assistant and, 93
 start-up of, 390
Applied science, 61
Apprenticeships, 177–178
Appropriate technology, 89–92
Arab Spring of 2011, 281–283
Archery, versus gunnery, 339–340
Archimedes, 168

Aristotle, 180

Arms control, 334, 355
 successful example of, 351–353

Arms race, 314

Armstrong, Edwin, 261

Armstrong-Siddeley aircraft engine factory, 349 (*ill.*)

Armstrong-Vickers (Britain), 347

ARPANET, 275–276
 computer networking through, 276

Artificial hearts, 134–136, 135 (*ill.*), 147

Artificial insemination, 141

Artillery, 306, 308

Asphyxiating gas, 351

Aspirin, 7, 133

Assembly line, 216, 220

Association for Molecular Pathology et al. v. Myriad Genetics, Inc., et al.,
 150

Association of Edison Illuminating Companies (AEIC), 387

Asymmetrical warfare, 326–330

Atari home computers, 285

Athos, Anthony, 44

Atomic bomb, dropping of first, 312

Atomic Energy Commission, 113, 411

Attention deficit hyperactive disorder (ADHD), 32

Augustine, Norman, 325

Aum Shinrikyo (Aum Supreme Truth), 329, 329 (*ill.*)

Australopithecines, 167

Automated manufacturing systems, 193, 199

Automatic typesetting, development of, 242

Automobile(s), 8
 effective use of, 402
 experimental, 120 (*ill.*)
 fuel consumption, 118–119
 granting of patent for, 97, 98 (*ill.*)
 hybrids, 119
 improved technology in, 118
 internal combustion engine for, 42, 119

- Model T, 57, 190
 - as negative externality, 402
 - self-drive, 47
 - as technological fix, 30–31
- Automobile industry, 382
 - assembly line in, 194 (*ill.*)
 - employment in, 192
 - skilled toolmakers in, 215–216
 - transfer of technology in, 395
- Autonomy, professionalism and, 374
- Auto Union grand prix racing cars, 11
- Auxiliary consequences, technological changes and, 402

- B-17 Flying Fortress, 344–345
- Babbage, Charles, analytical engine developed by, 45, 46 (*ill.*)
- Babies, making and sustaining, 140–142
- Bacon, Francis, 369
- Bakelite, 84
- Baker, Meredith Attwell, 261
- Ballistic missile defense, 338
- Balloon angioplasty, 133
- Ballpoint pen, 66
- Bangladesh, flooding in, 108
- Barbarians, 301
- Barcode readers, 277
- Battleships, 350
 - technological change and naval culture in the era of, 309–310
- Bauer, Andreas, 242
- Bayh-Dole Act (1980), 402
- Beethoven, Ludwig van, 9
- Belated demand, 51–52
- Bell, Alexander Graham, 51
- Bell, Daniel, 373
- Bemba (of Zimbabwe), 172
- Berlin, aerial bombardment of, 312–313
- Berners-Lee, Tim, 276
- Bernoulli principle, 68

Bessemer, Henry, 43
Bessemer process, 43
Beta-blockers, 133
Beta testing, 47
Bible, 234, 238
Bigelow, Jacob, 4
Bijker, Wiebe E., 41
bin Laden, Osama, 332
Bioengineering on the farm, 150–153
Biological research, 70
Biological weapons, 329–330, 329 (*ill.*)
Biomass, 116
Bismarck, Otto von, 325
Blake, Peter, 26
Blauner, Robert, 381–382, 384
Blister agents, 328
Blogs, 282, 291
Blood agents, 328
Blood thinners, 133
Boeing
 B-17 Flying Fortress, 344–345
 B-29 Superfortress, 344 (*ill.*)
 707 airliner, 86
Bombs and bombing
 car, 328
 “dirty,” 328
 dropping of first atomic, 312
 in Oklahoma City, 331
 roadside, 328
 “smart,” 321, 322, 325
 strategic, 312–315, 344
Borders bookstore, closure of, 23 (*ill.*)
The Boston News-Letter, 241
Boyer, Herbert, 402
Braun, Ferdinand, 258
Brazil, computer factory in, 85 (*ill.*)
BRCA1, 149

BRCA2, 149
Brin, Sergey, 84
British Broadcasting Corporation (BBC), 258
British Marconi Company, 259
Bronowski, Jacob, 4
Brown Bess flintlock musket, 309
Brunel, Marc, 210
Bryjolfsson, Erik, 199
Bureaucracies, 396
Burke, Edmund, 15
Bury, abbey library of, 234
Bush, George W., 158
 administration of, 370, 371, 409
BuzzFeed, 246

Cable TV, 261, 291
Caliente, Nevada, servicing of steam locomotives in, 24–25, 25 (*ill.*)
California Labor Commission, opposition to Uber, 23–24, 24 (*ill.*)
Caloric theory, 67–68
Calvinist doctrine, 181
Cambridge University, library of, 234
Cameras
 Polaroid, 42–43
 television, 84
Cancer, 143
Cannons, 306, 337
 ship-mounted, 310
Canterbury, abbey library of, 234
Capital, 21
Capital equipment, accelerated depreciation of, 403
Capital investment, 403
Capitalism
 history of, 121
 rise of, 53
Car bombs, 328
Carbon-based fuels, 372
Carbon dioxide (CO₂)

- capture of, 109
- emissions of, 106–108, 118
- environmental consequences of, emissions of, 123
- production of, 118
- release of, 109

Carbon paper, 392

Carlson, Chester, 51

Carnegie, Andrew, 43

Caste system in India, 175, 176 (*ill.*)

Castles, 304–305, 306

Catalytic converter, 47

Catapults, 301

Cathode ray tube, 45

Catholic Church

- Second Lateran Council and, 350
- use of printing by, 238

CBS (television), 261, 265

Celera Genomics, 148–149

Cellophane, 97

Centralized state, war and, 308–309

Centrally planned economies

- obstacles to innovation in, 53–54
- performance of, 121

CERN (European Organization for Nuclear Research), 276

Cesium-137, 328

Chain drive transmission, 82

Chain mail, replacement of, by plate armor, 303–304

Challenger space shuttle, loss of the, 3, 376, 377 (*ill.*)

Charlemagne, 239

Chemical weapons, 328–329, 329 (*ill.*), 352–353

Chengdu, 234

Cherokee Indians, written language for, 233

Chiang Kai-shek, 83

Chief technology officer, 407

Children, viewing of television by, 262–264, 268–269

China

- agriculture in, 172–173

- airplanes in, 86
- Communism in, 83
- cultural elements in, 367 (*ill.*)
- economy of, 53–54
- foreign inventions and, 82, 83
- gender ratio in, 370
- Great Firewall of, 366
- Great Proletarian Cultural Revolution in, 366
- gunpowder in, 305–306, 368–369
- infusion of Western ideas, 82–83
- labor force in, 85
- manufacturing in, 117
- Mao Zedong and, 83, 366
- Opium War (1839–1842) in, 311
- printing in, 234, 235
- resource consumption in, 89
- smog in, 106 (*ill.*)
- as suspect in cyberterrorism, 331
- Tang Dynasty in, 305
- technology in, 81–82
- Wade-Giles system of Romanization and, 82
- wariness of foreign importation and, 366

Chinese Academy of Science, 372

Chivalry, culture of, 302

Chlorine, 329, 352

Choking and incapacitating agents, 328–329

Cigarette smoking, health effects of, 136

Clark, Barney, 135

Clickbait, 278

Climate change, 110, 150, 372

- causes of, 106–108
- effect of deforestation on, 109

Clinton, Hillary, 267

Clinton administration, 407

Clocks, 181–183, 182 (*ill.*)

Cloning, 155–157, 156 (*ill.*)

Closed systems, 32

Clothing factories, layout in, 217 (*ill.*)
Clubs, 299
CNC machine tools, 389–390
Coal, 111–112
Cobalt-60, 328
Cohen, Stanley, 402
The Colbert Report, 266
Cold War, 325, 333, 348, 355
 waning of, 404
“Collective bargaining by riot,” 27
Columbia space shuttle, loss of, 3
Comcast, 261
Commerce, U.S. Department of, 259, 284
Commodity, conversion of time into, 183
Communication, 231–232
 digital, 282
 electronic, 275, 276, 279, 394, 417
 face-to-face, 394
 mobile, 231, 279–281
 satellites in global, 57
Communications Act (1934), 260
Communications equipment industry, money spent on R&D, 391
Communism, 83
The Communist Manifesto (Marx and Engels), 53
Compact fluorescent lamps (CFLs), 118
Compass, 81
Computability, 92
Complementary technologies, development of, 47
Complexity, 92
Complex societies, 398
Compression ratios, 46
Computer(s), 284
 digital, 16, 17
 history of, 45
 technical development of, 17
Computer-aided design (CAD), 193, 195
Computer-aided manufacturing (CAM), 193, 195

Computer-based centralization, 389
Computer-based expert systems, 196
Computerized tomography, 128
Computerized typesetting, 382
Computer numerical control (CNC) machines, 389
Computer Science Network (CSNET), 276
Computer worms, 330, 331
Concorde airliner, 7, 94, 371
Conservation, distinguishing from curtailment, 117, 123
Conservation tillage, 150–151
Conspiracy theories, 18
Constant, Edward, 48
Constantinople, 306
Constitution, U.S., encouragement of technological advance in, 401
Contingency theory, 383
Continuous-process technologies, 383 (*ill.*)
Convergence theory, 365–366, 368–369
Copyright, 288
 infringement of, 288
Corned gunpowder, 306
Corona spy satellite program, 323
Corporate average fuel economy (CAFE) standards, 119
Cotton picker, mechanical, 189
Coupling process, technological development as, 48
Coventry ribbon-weaving industry, 214
Craft workshops, 178
Crecy, Battle of (1346), 303
Creech Air Force Base, 324 (*ill.*)
Crick, Francis, 148
Crispr-Cas9, 161
Cromwell, Oliver, 309
Crossbow, 303, 305, 350
Cross-pollination, 151
Cruise missiles, 319–321, 320 (*ill.*), 325, 357
Crusades, 304
Cultural change, 365
Cultural convergence, 365–369

Cultural lag
 hidden value judgment and, 364
 technological advances and, 363–365

Curtailement, distinguishing conservation from, 117, 123

Cyanogen chloride, 328

Cyberbullying, 275, 278

Cyberterrorism, 330–332

Cystic fibrosis, 142, 162

Daedalus project, 7

Daesh, 331

Daguerre, 49

The Daily Show, 266

Damascus steel, 62–63

Darwin, Charles, 159

Data
 need for accurate, 236–237
 personal, 275

daVinci, Leonardo, 350

DDT, 49

Death, determination of, 142–143

Deep reading, 247

Defense, U.S. Department of, 17, 29, 63, 408
 Advanced Research Projects Agency (DARPA), 275, 326
 research budget of, 348

Defensive medicine, 137

de Forest, Lee, 255

Deforestation, 105
 effect on climate change, 109

Delorean, John, 215

Demand
 belated, 51–52
 effective, 49
 level of, 190

Democracy, 19
 direct, 415
 representative, 415

spread of, 347

Democratic control of technology, 413–416, 415 (*ill.*)

Dengue fever, 329

Depletion, 103, 104, 105

Depreciation, accelerated, of capital equipment, 403

Dervishes, 311

Design process, involvement of suppliers in, 395

De-skilling of workers, 219

Determinism, technological, 16–18

Deterrence, 355–357

Detribalization of society, 241

Diagnostic and Statistical Manual of Mental Disorders, 287

Diagnostic technologies, 103, 137–139, 138 (*ill.*)

Dictating machines, 392, 393 (*ill.*)

Diesel locomotives, 24–25, 112

Differential effects of technological change, 21–22

Differential gear, 82

Diffusion, 87

Digital age, piracy in the, 290–291

Digital communication, 282

Digital computers, 16, 17

“Digital detox,” 28

Digital divide, 284–285

Digital media, 283

Digital reading, 247–248

Digital searches, 290

Digital video recorders (DVRs), 270

Diode, 255

Direct democracy, 415

“Dirty bombs,” 328

Discovery Project, 323

Disenchantment, 15

Distrust, 18–19

Diuretics, 133

Division of labor, 167–168

 industrial technology and, 215–217

DNA (deoxyribonucleic acid), 147, 148

- testing, 154–155
- Dolly (cloned sheep), 155, 156 (*ill.*)
- Downloading
 - illegal, 288, 289
 - legal, 289
- Downsizing, 123
- Down syndrome, 141, 160
- Drake, Sir Francis, 309
- Drones, 290, 323–325, 323 (*ill.*), 332–333, 350
- Dry farming, 173
- Dumdum bullets, 351
- Dunlop, John, 49
- DuPont, 97

- Earth, climate of, 107, 108
- Earthquake detection devices, 82
- eBay, 84
- Ebola, 329
- Eckert, J. Presper, 390
- E-commerce, 277
- Economic analysis, conventional, 21
- Economic globalization, 201–202
 - consequences of, 202 (*ill.*)
- Economic growth
 - source of, 21
 - technological advances as source of, 21
- Economic relationships, urbanization, specialization and, 174–177, 176 (*ill.*)
- Economies
 - centrally planned, 53–54, 121
 - market-based, 39, 52–53, 121, 175, 183–184
 - plantation, 179
- Economies of scale, 21
- Economy, technology and, 11–12
- Edible vaccines, 150
- Edison, Thomas, 6, 42, 48, 51, 72, 84 (*ill.*)
 - inventions of, 73

Edison effect, 72 (*ill.*)

Education

- federal aid to, 402
- importance of credentials, 199

Edward I, 303

Effective demand, 49

Egypt, social media and political change in, 281–283

Eisenhower administration, 407

Eisenstein, Elizabeth, 237

Electricity, 113

- sources of, 116, 387

Electrocardiographs, 137

Electromagnetic radiation, 93

Electromagnetic waves, 52

Electronic communication, 417

Electronic cottage, 223

Electronic media, 253–271

- advances in, 415
- delivering of news with, 265–267, 266 (*ill.*)
- invention of radio, 253–255, 254 (*ill.*)

Electronic media (*Continued*)

- involvement of federal government with, 259–261
- in modern society, 291–292
- origins of commercial radio, 255–257, 256 (*ill.*), 257 (*ill.*)
- rise of television, 257–259
- television and politics and, 265–268
- television and thought and, 268–270
- television-viewing public and, 261–262
- violence on television and, 262–265, 364

Electronic trading, 197 (*ill.*)

Electron microscopes, 67

Elements of Technology (Bigelow), 4

Email, 275, 276, 279, 394

Emery, Edwin, 244

Emery, Michael, 244

Empirical studies of organizations and technology used, 381–386

Employment. *See also* Jobs

- gig economy and, 224–225
- indirect effects of new technologies on, 192–193
- smart technologies and, 225–227
- telework and, 222–224, 223 (*ill.*)

End-of-life issues, 142–143

End-stage renal disease, 130, 133

Energy

- alternative sources of, 403
- geothermal, 116
- global consumption of, 105
- hydro, 116
- nuclear, 113–115
- renewable, 115–117, 122
- solar, 115–116, 122
- wind, 115–116, 116 (*ill.*), 122

Energy, U.S. Department of, 29

- Nuclear Regulatory Commission, 407

Energy crises (1973–1974 and 1979), 110

Energy Information Agency, 105

Energy intensity, 117

Engels, Friedrich, 53, 212

Engineering, 65

Engineers in control of technology, 373–378, 375 (*ill.*)

Engineers, locomotive, 187–188

Engines, internal combustion, 46–47

England. *See also* Great Britain

- archery in, 339
- use of longbow in, 303
- under Victoria, 309
- in World War II, 320

Engines, internal combustion, 46–47

Engraving, 235

ENIAC, 51 (*ill.*), 390

Entrepreneurs, organizations and, 396–398

Environmental cleanup and protection, 190

Environmental damage

- in job creation, 191 (*ill.*)

- technological innovations as source of, 104
- Environmental health, 103
- Environmental pollution, 89
- Environmental Protection Agency, 109, 370
- Epidemic diseases, 111
- Epigenetics, 162
- Equal Opportunity Commission, 154
- Ethanol (ethyl alcohol), 117
- Eugenics, 159
 - negative, 159
 - positive, 159
 - support for, 160 (*ill.*)
 - in the twenty-first century, 160–161
- European Middle Ages, 62
- European Organization for Nuclear Research (CERN), 276
- Evelyn, John, 111
- Externalities
 - negative, 121, 402, 406
 - positive, 406
- Experts and expertise, 369–373

- Facebook, 246, 277–278, 281, 282 (*ill.*), 283, 290, 292
 - advertising on, 278
- Face-to-face communications, 394
- Factors of production, 21
- Factory system, development of, 210–211, 214–215
- Fair use, 288
- Famine, 110
- Farnsworth, Philo, 258
- Federal Aviation Administration (AAA), 411
- Federal Communications Commission (FCC), 259, 260–261, 283, 411
- Federal government. *See also* Government
 - aid to education, 402
 - electronic media and, 259–261
 - involvement in research and development, 404–405
 - as source of financial support for research and development, 28–29
- Federal Radio Commission, 259–260

Federal Trade Commission (FTC), 290
Feedback, 11–12, 17
Feeding tubes, 142
Ferguson, Eugene, 67
Fessenden, Ronald, 255
Fetal heart monitors, 137
Feudalism, 302
 military technology and, 301–302
 new weapons and the decline of, 302–305
Fever, 7
File sharing, 287, 288, 289
Filing systems, 392
Fine tuning, 87
Firearms, 308, 338, 339–340, 353–355
Fire Fly drone, 323
Fishing reels, 82
Fitzgerald, Ernest, 376–377, 412
Flash mob, 281
Fleming, John Ambrose, 73, 73 (*ill.*), 255
Flintlocks, 347
Florman, Samuel C., 374–375
Flour mills, 183
Flyball governor, 11, 12 (*ill.*)
FM frequencies, 260–261
Food and Drug Administration, 371
Foraging, 180
Ford, Henry, 8, 30, 97, 190, 216
Ford, Henry, II, 94
Ford Motor Company, 57
Forecasting, 417
Foreign technologies
 effective use of, 86
 importation of, 83–84
Formal rules, importance of, 381
Fossil fuels, 109
 alternatives to, 113–117
 reliance on, 110

use of, 106
Fracking, 109, 409
France
 archery in, 339
 invasion of Russia by, 346
Frankenfoods, 161
Franklin, Benjamin, 55
Franklin Institute, 409
Frederick the Great of Prussia, 340
Freeman, Christopher, 48
Free rider problem, 406
French Revolution (1789–1799), 15, 346
Freon refrigerants, 94
Freund, Julian, 15
Friendster, 277
Fukushima nuclear plant, failure of, 3, 114, 114 (*ill.*)
Fuller, J. F. C., 342–343
Fulminates, 347
Future, challenges of the, 417
FX-1400 “Fritz,” 321

Galbraith, John Kenneth, 373–374, 390
Galileo, 183
Galton, Francis, 159
Galvanometers, 67, 73
Gamification, 287
Gas mileage, improved, 118–119
Gates, Robert, 324
Gatling guns, 340
Gaul, 178–179
Gender
 technology and, 15–16, 19
 video games and, 285–287
 work and, 364
General Electric, 55, 97, 256, 259
Genes, discovering and patenting, 149–150
Genetically modified organisms (GMOs), 103, 150, 152 (*ill.*)

- opposition to, 151, 153
- Genetic Information Nondiscrimination Act (2008), 154
- Genetic modifications, 150–151
- Genetic technologies, 147–162
 - advances in, 103–104
 - cloning and, 155–157, 156 (*ill.*)
 - discovering and patenting genes, 149–150
 - DNA and, 147, 148
 - eugenics and, 158–161
 - genetic mapping and screening, 153–155
 - perils of intervention, 158–161
 - stem cells and, 157–158
- Geoengineering, 108 (*ill.*)
- George III, King of England, 82
- Geothermal, 116
- Germany
 - aerial bombardment of, in World War II, 312–313
 - disarmament of, 342
 - naval strategy of, in World Wars, 311, 312
 - Nazi, 10 (*ill.*), 11, 14
- Gettysburg, battle of, 307
- Giffard, Henri, 68
- Gig economy, 224–225
- Gig mill, 27
- Gladwell, Malcolm, 283
- Global communication, satellites for, 57
- Global consumption of energy, 105
- Globalization, 365–369
 - technology, cultural convergence and, 365–369
- Global Positioning Systems (GPS), 57, 321–322
- Global Village, 279
- Global warming, 107–108, 109, 118
- Goddard, Robert, 55, 56 (*ill.*), 57
- Go/no-go decisions, 92
- Google, 84, 283
 - Google Glass, 93
- Gorbachev, Mikhail, 54

Government. *See also* Federal government
actions of, in the shaping of technology, 401–404
consequences of policies, 121–122
granting of patent rights by, 401
institutions in, for the guidance of technology, 407–408
opposition to ride-sharing services, 23–24, 24 (*ill.*)
policies of, in shaping technological change, 409–412
promotion of technological advance and, 57–58

GPS devices, 290

GPS navigation, 279

Great Britain
gas attacks and, 352
industry and employment in, 189
National Health Service in, 133
national radio in, 256–257

Great person approach to the history of technology, 48

Greece
slavery in, 179–180
technology and, 61–62

Greek fire, 305

Greek phalanx, 299–300, 300 (*ill.*), 303

Greenhouse effect, 107, 108 (*ill.*)

Greenhouse gases, 107, 109
buildup of, 108

Groundwater, withdrawal of, 111

Groupthink, 371

Guild organization, technological change and, 177–179, 178 (*ill.*), 211

Gulf of Mexico oil spill, 3

Gulf War (1991–1992), 321–322

Gunnery versus archery, 339–340

Gunpowder, 81–82, 87, 368–369
“corned,” 306
first weapons using, 305–306
revolutionary changes caused by use of, 309

Guns, 353–355
Gatling, 340
handheld, 306

- machine, 312 (*ill.*), 337, 340–341
 - Maxim, 340
 - in Japan, 353–355
- Gustavus Adolphus, 306, 309
- Gutenberg, Johann, 235, 237, 245
 - “Gutenberg Galaxy,” 241
- Gyroscope, 319

- Haig, Douglas, 342
- Halberds, 303
- Halfway technologies, 103, 143, 144, 147
- Hall, A. Rupert, 309
- Hall, Bert, 339
- Handheld guns, 306
- Handlooms, 27, 188
- Handwriting, 6
- Hangul, 239–240
- Hart, B. H. Liddell, 314
- Health
 - environmental, 103
 - human, 103
- Health care, rising costs of, 103, 104, 128–129, 137, 190
- Hearst, William Randolph, 244, 245
- Heart bypass surgery, 133
- Heart disease, 133–137
- Heart transplantation, 134–135
- Helicopters
 - Apache, 64
- Hellfire missiles, 324
- Hertz, Heinrich, 93, 254
- Hewlett-Packard, start-up of, 390
- Hidden value judgment, cultural lag and, 364
- Hierarchical structure of organizations, 376
- High-tech surveillance, 322–323
- Hipporoller, 90 (*ill.*)
- Hiroshima, 312, 313 (*ill.*)
- Hitler, personality of, 14

Hobbes, Thomas, 169
Hoe, Richard, 242
Hoe rotary printing press, 243 (*ill.*)
Homo, genus, 167
Hoplite, 299
Horse collars, 82
Horses, use in battle, 301–302
House of Representatives, U.S.
 Armed Services Subcommittee, 408
Hubble Space Telescope, 67, 70
Huffington Post, 246
Hughes, Thomas P., 42
Human genome, mapping of, 148–149
Human Genome Project, 148
Human health, 103
Humanity, organizing, 5–8, 5 (*ill.*)
Human life, value of, 371–372
Hunter, Louis, 43
Hurricane Katrina, 3
Hussein, Saddam, 322, 327, 328
Huygens, Christian, 183
Hydraulic fracturing, 109
Hydrogen cyanide, 328
Hydropower, 116
Hypertext transfer protocol (<http>), 276

IBM, 51
Illegal downloading, 288, 289
Imaging satellites, 325
Imported technologies, 86
Improvised explosive devices (IEDs), 327–328, 327 (*ill.*)
Incandescent bulbs, replacement of, 118
Income
 technology and inequality in, 198–199, 200
 technology and the distribution of, 198–201
Incremental transformations, 39
India

- caste system in, 175, 176 (*ill.*)
- gender ratio in, 370
- nuclear proliferation and, 358
- resource consumption in, 89
- Industrial computers, 193
- Industrialization, 165
- Industrial production, 209–211
- Industrial Revolution, 74, 107, 117, 188, 204, 209, 210, 214
 - causes of, 1
- Industrial technology
 - division of labor and, 215–217
 - in the service of war, 347–357
- Industrial work, technological developments and, 219–220
- Industry, displacement of agriculture by, 196
- Infantry, arming of, 306–308
- Information attacks, 330
- Infrared goggles, 326–327
- Infrastructure attacks, 330–331
- Innocent II, Pope, 350
- Innovation
 - invention versus, 391
 - obstacles to, in centrally planned economies, 53–54
- Insull, Samuel, 387
- Integrated circuits, 22
- Intellectual property, 275, 287–290
- Intercontinental ballistic missiles, 350, 356
- Interindustry transfers of technology, 48
- Intermediate technologies, 90
- Intermodal transportation, 201
- Internal combustion engines, 42, 46, 47, 49, 112, 119
- Internal resistance to technological innovation, 95
- Internal Revenue Service, 36
 - computerization in, 222
- International Space Station, 77, 404, 405 (*ill.*)
- internet, 231, 245, 275–293
 - access to, 283
 - and the recruitment of terrorists, 332

- as a source of news, 265–266
- birth and growth of, 275–277
- rise of, 415 (*ill.*)
- success of, 291

internet service providers (ISP), 283

Interorganizational relations, technological development and, 395–396

Interurban electric railroad lines, 30

Invention versus innovation, 391

In-vitro fertilization, 140, 141, 142, 157, 158, 403

Iran

- Iraq War (1980–1988), 328
- nuclear program in, 331
- overthrow of the Shah, 366

Iraq

- cruise missile target of, 321–322
- IEDs in, 327
- occupation of Kuwait, 321

Iridium-192, 328

Iron triangle, 412

Irrigated agriculture, 173

ISIS (Islamic State), 321, 331

Islands of automation, 193

Jacquard loom, 214

Japan

- baseball in, 369
- emergence of industrial enterprises, 83
- gun control in, 353–355
- Meiji Restoration in, 83
- Ministry of Economy, Trade, and Industry in, 405
- Ministry of International Trade and Industry (MITI) in, 405
- steel industry in, 88–89

Jarvik-7 artificial heart, 135

Javelin antitank missile, 64

Jefferson, Thomas, 417

Jennett, Bryan, 129

Jerusalem, siege of, 301

Jevons, W. Stanley, 112
Jitneys, 22
Job enrichment, 216
Jobs. *See also* Employment
 rebounding from losses, 202–204
 technology in creating, 191–192
Jobs, Steve, 8 (*ill.*), 391 (*ill.*), 398
John Bull, 87 (*ill.*)

Kaczynski, Theodore, 28
Kang Youwei, 82
Karman, Theodore von, 84
KDKA, 256
Kennedy, Caroline, 221
Kenya, bombing of embassy in, 321
Kepler, Johannes, 67
Kettering, Charles, 46, 319
Kettering Bug, 319
Keystroke monitoring, 221
Khan Academy, 198
Kidney dialysis, 128, 130–133, 130 (*ill.*), 132 (*ill.*), 142
Kilby, Jack, 396
Kinetic theory of heat, 68
Knights, 302
 mounted, 303, 337
Knives, stone, 299
Knowledge
 commercial value of, 371
 growth of, 370–371
 printing and the expansion of, 236–237
 technology and, 1
 transmission of, 95
Koenig, Friedrich, 242
Kolff, Willem, 130–131, 130 (*ill.*)
Korea
 labor force in, 85
 printing in, 239–240

Kranzberg, Melvin, 76
Krupp (Germany), 347
Kuhn, Thomas, 63
!Kung San (Bushmen), 169–170, 170 (*ill.*), 172, 183, 413
Kuwait, Iraq’s occupation of, 321

Labor, 21
 machine-paced, 211–213
Labor, U.S. Department of, 259
Labor unions, 223
 opposition to telework, 223
Lab tests, increase in, 137
Laennec, Rene, 138 (*ill.*)
Land, Edwin, 42–43
Land clearance, excessive, 111
Landes, David, 368
Large batch production, 382
Large Hadron Collider, 70
Laser
 invention of, 68
 uses of, 69 (*ill.*)
Latin America
 deforestation in, 109
 Treaty of Tlatelolco and, 357–358
Latinos
 internet usage by, 284
 smartphone use by, 284
“Law of the hammer,” 7
Leapfrogging, 86
Lee, Richard, 169
Le Goff, Jacques, 180
Leisure in technologically primitive societies, 169–171, 170 (*ill.*)
Lenin, Vladimir, 35
Leukemia, 157
Leverage, principle of, 168
Levy, Frank, 225
Lewis, C. S., 18

Licenses, 95
Life, ending of, 142–143
Life-extending technologies, 32
Lightbulbs, 6, 73
Light-emitting diodes (LEDs), 118
Lindberg, Charles, 315
LinkedIn, 277
Linotype machine, 242
Literacy
 growth of, 82
 printing and, 238–240
 Protestantism and, 238
Lockheed C5A transport plane, 377
Lodge, Oliver, 93, 254
Longbow, 303, 305, 337, 338
Lovelace, Ada, 45
Luddites, 26–27
Ludlum, Ned, 26
Lump of labor fallacy, 189
Luther, Martin, 238
Lyft, 22

Machine-based technology, 215
Machine guns, 311–312, 337, 340–341
 in World War I, 312 (*ill.*)
Machine-paced labor, 211–213
Machines, technology and, 193–195, 194 (*ill.*)
Machine-scored exams, 196
Madrid, cyberterrorism in, 331–332
Magnetic storage devices, 45
Maine (battleship), 244
Malpractice suits, 137
Management hierarchy, 384
Manifest destiny, 244
Manned space exploration, 7
Mao Zedong, 83, 366
Maps, distribution of, 236

Marconi, Guglielmo, 73, 93, 254, 254 (*ill.*)
Marie Antoinette, 15
Market economy, 175
 development of, 183–184
 in driving technological innovation, 39, 52–53
 imperfections of, 121
 as stimulus for technological innovations, 39
Market timing, 51–52
Marsh, Robert, 366
Marx, Karl, 53, 212
Masculine approach, 15–16
Maser, 69
Massachusetts Institute of Technology
 Servomechanism Laboratory at, 387
Massive open online courses (MOOCs), 196
Mass production, 348, 382
Matchlock, 306
Mathematics, 75
Mathias, Peter, 74
Mauchly, John, 390
Maudslay, Henry, 210
Maxim guns, 340
Maxwell, James Clerk, 52, 93, 254
McAfee, Andrew, 199
McCormick reapers, 210
 manufacturing plant for, 25
McLuhan, Marshall, 240–241, 247, 268–269, 279
Mechanical cotton picker, 189
Media
 digital, 283
 electronic (*See Electronic media*)
 person-to-person, 292
 social (*See Social media*)
Medicaid, 128, 132
Medical expenditures, 128–129
Medical ethics, 140–143
Medical research, 7

Medical technology, 127–144
 achievements in, 190
 advances in, 127
 antibiotics in, 57
 choices and tradeoffs in, 129–139
 costs of, 57
 deeming as inappropriate, 129
 development of, 32, 103–104
 diagnostic, 137–139, 138 (*ill.*)
 effectiveness of, 370
 ending of life, 142–143
 genetic advances and, 103–104
 as halfway technologies, 103, 143, 144
 heart disease and, 133–137, 136 (*ill.*)
 improvements in, 349
 kidney dialysis and, 130–133, 130 (*ill.*), 132 (*ill.*)
 knowledge base of, 127
 making and sustaining babies, 140–142
 medical ethics and, 140–143
 patient care and, 128
 penicillin in, 44–45
 in poor countries, 369
 regional differences in, 128
 supply and demand for, 143
Medicare, 128–129, 132, 137
Medieval warfare, 302
Meiji Restoration, 83
Melville, Herman, 14
Mendel, Gregor, 147–148
Mercedes racing car, 11
Mercenary soldiers, 340, 346
Mergenthaler, Ottmar, 242
Metadata, 290
Metalworking industries, 47
Metaphor, technology as a, 11–12
Methane (CH₄), 107
Methanol (methyl alcohol), 117

Microsoft, Zune media player and, 93
Microwave spectroscopy, advances in, 68–69
Midgley, Thomas, 46
Midvale Steel Co., 34 (*ill.*)
Military action and reaction, 337–338
Military campaigns, cost of, 308
Military intelligence, breakdowns in, 322
Military research and development, government expenditures on, 404
Military technology
 in the ancient world, 299–301
 in a changing world, 332–334
 controlling, 350–357
 feudal order and, 301–302
 social structure and the development of, 338–345, 341 (*ill.*), 343 (*ill.*),
 344 (*ill.*)
Millis, Walter, 314
Ministry of International Trade and Industry (MITI), 405–406
Minow, Newton, 260
MIRVs (multiple independently targeted reentry vehicles), 356
Mitchell, General Billy, 343, 345
Mnemonic devices, 234
Mobile communications, 279–281
 devices in, 231
Mobile phones, 275, 280 (*ill.*)
Moby Dick (Melville), 14
Monasteries, Medieval, 181
Monitoring of workers, 220–222
Monoculture, 153
Monopoly power, 97
Moore, David S., 161
Moral superiority, 14
Morgan, Thomas Hunt, 148
Morse Code, 253
Morton-Thiokol, 376
Mounted knights, 302
Movable type, 245
 invention of, 236

MP3 format, 288
Mubarak, Hosni, 281–283
Multinational corporations, 201
Mumford, Lewis, 5, 6
Murnane, Richard, 225
Murrah, Alfred P., Federal Building (Oklahoma City),
 destruction of, 331
Mustard gas, 328, 352
Mutually assured destruction (MAD), 355–356
Myriad Genetics, 149–150
Myspace, 277
M1A2 Abrams battle tank, 326

Nader, Ralph, 372
Napoleon
 defeat of, 27
 invasion of Russia, 346
Napster, 288
Narrowcasting, 283, 292
National Academy of Sciences, 372
National Aeronautics and Space Administration (NASA), 29, 404, 407, 408
National Association of Patients on Hemodialysis and Transplantation, 132
National Broadcasting Corporation (NBC), 258
National Cable & Telecommunications Association, 261
National Electric Light Association (NELA), 387
National Health Service (Great Britain), 133
National Institutes of Health, 371, 404
Nationalism, spread of, 347
National Reconnaissance Office, 322, 323
National Science and Technology Council, 407
National Science Foundation (NSF), 276, 407
National Security Agency, 404
National Union of Iron Molders, 25
Natural gas, 112, 113
Natural philosophers, 63
Nature versus nurture debate, 157, 162
Naval culture
 technological changes and, 309–310
Nazi Germany, 14, 342–343
 technological progress of, 10 (*ill.*), 11
NBC (television), 260, 261, 265
NBC Universal, 261
Negative eugenics, 159
Negative externalities, 121, 402, 406
Nellis Air Force Base, 325
Nelson, Admiral, 310
Neolithic Agriculture Revolution, 171
Neo-Luddism, 27–28

Nerve agents, 328
Net neutrality, 283
Netflix, 270
“Netizens,” 276
Network effect, social media and, 277–279
The New Industrial State (Galbraith), 373–374
New information technologies, organizations and, 392–395
New Life Movement in China, 83
New Orleans, breach of levees in, 3
News
 digitizing of, 245–247
 electronic media in delivering, 265–266, 266 (*ill.*)
Newspapers, 241–245
 advertising in, 246
 circulation wars and the shaping of public opinion, 243–245
 declining influence of, 247
 digital editions of, 246
 employment by, 245–246
 fall in circulation, 245
Newton, Isaac, 74
Newtonian physics, 16–17
New York Journal, 244
New York Stock Exchange, 197 (*ill.*)
New York Sun, 243
New York World, 244
Niepce, 49
Nitrous oxide (N₂O), 107
Nixon, Richard, 132, 407
Nobel Prize, 69–70
Noble, David, 387
Noncombatants in war, 302
Noneconomic sources of technological advance, 54–58, 56 (*ill.*)
Nonindustrial societies, work in, 167–184
Nonrational thought, technological advances and, 75
North Korea, nuclear proliferation and, 358
Not Invented Here syndrome, 94–95
Novels, 240

NPR (National Public Radio), 265–266
Nuclear energy, 113–115
 need for “closed cycle” process, 115
Nuclear fusion, 117
Nuclear Nonproliferation Treaty, 357–358
Nuclear wastes
 as long-term problem, 114
 storage of, 115
Nuclear weapons, 328, 355
 control of, 355–357
 proliferation and, 357–358
 testing of, 357
Numerically controlled machine tools, 387–389, 388 (*ill.*)

Obama, Barrack, 158
 administration of, 370–371, 407
 “Obamacare,” 128
Objectivity, rationality and, 15
Observability, 92
Occupational specialization, 174
Office of Science and Technology Policy (OSTP), 407
Office of Technology Assessment (OTA), 408
Office workers, 220, 221 (*ill.*)
Ogburn, William F., 363
Oil industry, American, 112
Oil shortages, 110
Omdurman, Battle of (1898), 311
Omidyar, Pierre, 84
Onagers, 301
On-screen reading, 248
OPEC oil embargo, 121
Open-heart surgery, 133–137
Opium War (1839–1842), 311
Optics, laws of, 254
Optimism, case of, 189–190
Organ failure, 142
Organizational changes, complementarity of technological changes and,

308

Organizational structure

defined, 381

technology as cause of, 381–386

technology as consequence of, 386–390

Organizations, 5

empirical studies of, 381–386

entrepreneurs and, 396–398

new information technologies and, 392–395

technological diffusion and, 92–93

technological innovation and size of, 390–392

Original equipment manufacturers (OEMs), 395

O-rings, 376

Oscillating waves, 255

Oscillation valve, 73

Oscillator, 254

Output-to-energy ratio, 117

Outward flow of technology, 96

Overgrazing, 111

Overproduction, 153

Packets, 275

Paddle wheel boats, 82

Pakistan

drone strikes on, 324, 325

farm technology in, 90

nuclear proliferation and, 358

Pandora, 289

Paper, 81–82

invention of, 236

Parenthood, 403

Parity, military, 356

Partial convergence, 369

Pascale, Richard, 44

Patents

diffusion of technology and, 96–98

electronic media and, 259

- gene, 149–150
- granting of, 401
- involvement of universities, 402
- “submarine,” 97
- Patent stacking, 149
- Patient care, fragmented approach to, 128
- Peak oil thesis, 109
- Peer-reviewed journals, 370
- Pendulum, 183
- Penicillin, 44–45
- Pentagon, September 11 attack on, 328
- Percussion caps, 347, 351
- Perrow, Charles, 384, 387
- Persistent vegetative state, 142
- Personal data, 275
- Personnel Management, Office of, 331
- Person-to-person media, 292
- Petroleum, 112
- Petroleum “reserves,” 109–110
- Phalanx, 299–300, 300 (*ill.*)
- Philip of Macedon, 301
- Philip VI, king of France, 181–182
- Phonetic alphabet, 239
- Photocopying, 51
- Photographic portrait studios, 50, 50 (*ill.*)
- Photographs, 49
- Pikes, 303, 305, 337
- Piracy, 86, 288
 - in the digital age, 290–291
- Pirsig, Robert, 74
- P.L. 96-517, 402
- Plagiarism
 - technological, 86
- Plague, 329
- Plantation economies, 179
- Plate armor, replacement of chain mail by, 303–304
- Platt Brothers & Co., 83

Plutonium, 328
Pneumatic tire, 49, 392
Poison gas, 328, 331, 352–353, 353 (*ill.*)
Polaroid camera, 42–43
Political advertising, 267–268
Political polarization, 415 (*ill.*)
Politics, television and, 265–268
Pollution, 103, 104, 105, 109, 110
 air, 111, 402
 environmental, 89
Polymerase chain reaction machines, 148
Pont du Gard, 62 (*ill.*)
Pony Express, 22
Porcelain, 82
Pork barrel benefits, 411
Positive eugenics, 159
Positive externalities, 406
Positive feedback loop, 308
Post, Robert, 7
Postindustrial economy and society, 165
Poultry processing, 213 (*ill.*)
Powell, Michael K., 261
Power looms, 183, 188, 214
Predator drones, 324
Preimplantation genetic diagnosis, 141
Premature babies, medical technology and, 141–142
Presidential Science Advisory Committee (PSAC), 407
Price inelasticity, 190
Printed works, invention and diffusion of, 231
Printing, 82, 233–248, 382
 digital reading and, 247–248
 digitizing of news and, 245–247
 expansion of knowledge and, 236–237
 literacy, social change and, 238–240
 of newspapers, 241–245
Protestant Reformation and, 283
psychological effects of, 240–241

- revolution in, 234–236, 235 (*ill.*)
- rise of Protestantism and, 237–238
- Printing press, steam-powered, 242
- Print shop, 235–236, 235 (*ill.*)
- Privacy
 - in the digital age, 290–291
- Probabilities, 17
- Problem solving, rational method of, 14
- Productivity growth, 187
- Professionalism, autonomy and, 374
- Progress, 1
 - ironies of, 174
 - technological advances and, 8–9, 8 (*ill.*), 10 (*ill.*), 11
- Project Hindsight, 63, 64
- Project Hindsight Revisited, 64
- Proliferation, perils of, 357–358
- Protect Intellectual Property Act (PIPA), 289 (*ill.*)
- Protestantism, 181
 - literacy and, 239
 - printing and the rise of, 237–238
- Protestant Reformation, 82, 237–238, 240
 - printing and, 283
 - Psychological effects of printing, 240–241
 - Public opinion, newspapers in shaping, 243–245
 - Pulitzer, Joseph, 244, 245
 - Pulley blocks, 210
 - Punch*, 257
 - Putting out system, 214
 - Pyramids, building of, 5 (*ill.*)

- Quality of working life, 165

- Radio, 231
 - delivering of news on, 265–266, 266 (*ill.*)
 - Federal government and, 259–261
 - history of, 51–52, 93
 - invention of, 253–255, 254 (*ill.*)

- origins of commercial, 255–257, 256 (*ill.*), 257 (*ill.*)
- success of, 291
- Radioactive wastes, 110
- Radio Corporation of America (RCA), 258, 259, 260–261
- Radio Frequency Identification (RFID), 290
- Railroad(s), 242
 - employment of, 187–188
 - improvements in, 43–44
 - John Bull, 87 (*ill.*)
 - as mature industry, 43
 - and time, 211–212
 - servicing of steam locomotives and, 24–25, 25 (*ill.*)
- Railroad industry, advances in, 43–44, 211–212, 212 (*ill.*)
- Rationality
 - limits of, 13–16
 - technology and, 13–16
- Rational thought processes, 74
- Reaction, action and, 337–338
- Reading
 - deep, 247
 - digital, 247–248
 - on-screen, 248
- Reagan, Ronald, Strategic Defense Initiative of, 408
- Reaper UAVs, 324
- Reciprocating steam engines, 112
- Reconnaissance satellites, 322, 333
- Record-playback method, 388
- Recycling, 118
- Refractory furnaces, 183
- Refrigerators, 118
- Regional differences in medical technology, 128
- Reich, Robert, 220
- Reiser, Stanley Joel, 139
- Relative advantage, 92
- Remote-control warfare, 325
- Renewable energy, 115–117, 122
- Representative democracy, 415

Research

aerodynamic, 71, 84

biological, 70

scientific, 63–64, 71

Research and development (R&D)

costs of, 57

defense-related, 348

development in, 44–45

energy-related, 122

federal government as source of financial support for, 28–29, 404–405

international distribution of expenditures, 91–92

Resource depletion, 89, 110, 118

Respirators, 142

Reverse engineering, 86

Rhapsody, 288

Ride-sharing services, 22–23

government opposition to, 23–24, 24 (*ill.*)

Risk and uncertainty, 94

Roadside bombs, 328

Robots, 193–194, 194 (*ill.*), 195

Rogue state, 329

Romans

combat by, 300

technology of, 62, 62 (*ill.*)

Rome

barbarian invasions of, 301

slavery in, 179–180

Roosevelt, Theodore, 397

Rosing, Boris, 258

Rotary press, 242, 243 (*ill.*)

Royal Chemical Society, 372

Rule of St. Benedict, 181

Russia

Napoleon's invasion of, 346

Russian Revolution, 342

Ruttan, Vernon, 86

Sahlins, Marshall, 170
St. Benedict, Rule of, 181
Saint-Etienne armory, 347
Salmonella, 329
Sarin gas, 328, 329, 329 (*ill.*)
Satellites
 communication, 57
 imaging, 325
 reconnaissance, 322, 333
 spy, 323
 uses for, 57
 for weather prediction, 57
Scaling up, 44
Schiavo, Terri, 142
Schmookler, Jacob, 49
Schramm, Wilbur, 264
Science
 commonalities of technology and, 74–76
 differences between technology and, 64–67
 historical separation of technology and, 61–63
 legitimizing through technology, 70–71
 need for accurate data in, 236–237
 paying for, 404–405
 translation of, into technology, 72–73
Scientific discovery as source of technological advance, 39, 67–70
Scientific inquiry, 65, 74
Scientific knowledge
 expansion of, 63
 technological knowledge and, 66–67
Scientific management, 33, 34 (*ill.*), 35–36, 217–219
 fallacy of, 36
 technocratic spirit of, 35
Scientific research, 63–64, 71
Scientific theories, 75
Search and seizure, unreasonable, 154
Search engines, 290
Seattle Artificial Kidney Center Admissions and Policy Committee, 131,

135–136
Second Lateran Council, 350
Sedentary agriculture, 172, 173–174
Segmental arch bridge, 82
Selden, George B., 97
 patent for automobile invented by, 97, 98 (*ill.*)
Selective access, 283
Selective breeding, 150
Semiconductor industry, 204
Senate, U.S.
 Agriculture Committee, 408
 Committee on the Environment and Public Works, 372
Sensationalist newspapers, 244
September 11, 328, 332
Service core, mass production of, 26
Service occupations, 195–196
Servomechanism Laboratory
 at Massachusetts Institute of Technology, 387
Settled agriculture, 173, 174
Sexting, 278
Shakespeare, William, 9
Sherman Tank, 343 (*ill.*)
Shipbuilding, improvements in, 53
Ship-mounted cannon, 310
Ships
 watertight bulkheads for, 82
“Shock and awe,” 327
Siege warfare, 301, 302–303
Sims, William S., 397
Sjoberg, Gideon, 180–181
Skills, worker, 212–213, 226–227
Skimming, 247
Skunk works, 386
Slash-and-burn agriculture, 172–173, 173 (*ill.*), 174, 180
Slater, Samuel, 83, 95, 96
Slavery, inhibition of technological development and, 179–180
Smallpox, 329

- Smart bombs, 321–322, 325
- Smartphones, 279, 280–281, 284
 - growth in ownership of, 284
 - ubiquity of, 22–23
- Smart technologies, 225–227
- Smith, Adam, 12, 175
- Smog, 107, 111
 - in China, 106 (*ill.*)
- Smokeless powders, 347
- SM-2MR surface-to-air missiles, 322
- Social changes
 - printing and, 238–240
 - technological changes and, 36
- Social construction of a science approach, 65
- Social construction of technology approach, 16
- Social constructivism, 17–18, 41–42
 - benefits of, 42
 - strength of, 42
- Social media, 232, 275, 290
 - limitations of, 283
 - network effect and, 277–279
 - news access and, 246–247
 - social movements and, 281–283
- Social movements, social media and, 281–283
- Social networking, 275, 291
- Social problems
 - technocratic approach to, 33
 - television violence as, 264
 - use of technology in solving, 31–32
- Social process in technological change, 39, 41–44
- Social progress, gulf between technological progress and, 29
- Social Security
 - upgrade of computers in, 408
- Social structure
 - development of military technologies and, 338–345, 341 (*ill.*), 343 (*ill.*), 344 (*ill.*)
- Sociopolitical problems

- distinction between technical problems and, 35–36
- Soil erosion, 110
- Solar energy, 115–116, 122
- Soldiers, mercenary, 340, 346
- Solid-state electronics, 45
- Somalia, drone strikes on, 324
- Somme, Battle of, 311, 312 (*ill.*)
- Sony, Betamax and, 93
- Soviet Union, 334
 - arms control agreements with United States, 334
 - arms race between United States and, 314
 - army of, 342
 - dissolution of, 333
 - economy of, 53–54
 - explosion of first nuclear bomb, 96
 - launch of *Sputnik*, 409
 - satellite surveillance of, 323
- Space exploration
 - Apollo program in, 404
 - Challenger* space shuttle explosion and, 3, 376, 377 (*ill.*)
 - Columbia* space shuttle in, 3
 - International Space Station in, 77, 404, 405 (*ill.*)
 - launch of *Sputnik* in, 409
 - manned, 7
- Spanish–American War, 244–245, 397
- Spanish Armada, 309
- Specialization, 167–168
 - urbanization, economic relationships and, 174–177, 176 (*ill.*)
- Species extinction, 110
- Speer, Albert, 14
- Sphygmomanometer, 139
- Spina bifida*, 141
- Spindletop, 112
- Spinning jennies, 183, 188
- Spinning wheel, 82
- Spotify, 289
- Springfield rifled musket, 307, 307 (*ill.*)

Sputnik, launch of, 409
Standardized forms, 392
Star Wars antiballistic weapon program, 371–372
Statins, 133
Steamboats, 43
Steam engines, 49, 210, 211, 309–310
 flyball governor for, 11, 12 (*ill.*)
 reciprocating, 112
Steam injector, 67, 68
Steam power, 214
Steamboats, 43
Steamships, 242
Steel, Damascus, 62–63
Steel industry
 Bessemer process in, 43
 employment in, 188
 in Japan, 88–89
 production in, 188
Steinmetz, Charles, 84, 84 (*ill.*)
Stem-cell research, 409
Stem cells, 157–158
Sterilization, 159
Stethoscopes, 137, 138 (*ill.*)
Stinger anti-aircraft missile, 64
Stirrup, 301–302
Stone Age technology, 168
Stone knives, 299
Stone tools, 168
Stop Online Piracy Act (SOPA), 289 (*ill.*)
Strategic Arms Limitation Treaty (SALT I), 356–357
Strategic bombing, 344
Strategic Defense Initiative (SDI), 338, 371–372, 408
Strategic Triad, 356
Streamlining, 71
Stuxnet, 331
Submarines, 311–312
 patent for, 97

Suburban growth, 30
Subversive force, technology as a, 22–26, 23 (*ill.*), 24 (*ill.*), 25 (*ill.*)
Supercomputers, 404
Superconducting materials, 66, 66 (*ill.*)
Superconducting supercollider, 77
Superfund sites, 109
Supersonic transport (SST) plane, 409
Suppliers, involvement in the design process, 395
Supply and demand, 48–50
 for medical technologies, 143
Supreme Court, U.S.
 on digital searches, 290
 on inheritance for posthumously conceived children, 403–404
Surrogate mothers, 140–141
Sustainability, 92, 123
SynCardia artificial heart, 135
Synthetic materials, 61
System, 5–6

Tablets, 248 (*ill.*), 284
Tabun, 328
Taiwan, labor force in, 85
Talbot, Fox, 49
Taliban, 324
Tanks as weapons, 64, 326, 337, 341, 342, 343 (*ill.*)
Tanzania, bombing of embassy in, 321
Tartaglia, Niccolò, 350
Taxation, war and, 346
Tax codes, 36
Taxi drivers, opposition to Uber, 23–24, 24 (*ill.*)
Taylor, Frederick W., 33, 35
Tay-Sachs disease, 142, 160
TCP (Transmission Control Program), 276
Technocracy, 373
 appeal of, 33, 34 (*ill.*), 35
 delusion in, 35–36
Technological advances, 1, 6

- consequences of, 105
- cultural lag and, 363–365
- image of progress and, 8–9, 8 (*ill.*), 10 (*ill.*), 11
- kinds of, 52
- noneconomic sources of, 54–58, 56 (*ill.*)
- nonrational thought and, 75
- process of, 9, 9 (*ill.*)
- role of government in promotion of, 57–58
- scientific discoveries as source of, 39
- as source of economic growth, 21
- unemployment and, 204
- war and, 297

Technological borrowing, 86

Technological change, 1, 3, 6–7, 361

- as a social process, 39, 41–44
- auxiliary consequences and, 402
- complementarity of organizational changes and, 308
- differential effects of, 21–22
- government policies in shaping, 409–412
- guild organization and, 177–179, 178 (*ill.*)
- importance of complementary, 46
- naval culture and, 309–310
- optimism and, 189–190
- process of, 39
- social changes and, 36
- as uncertain process, 412
- white-collar work and, 220–222

Technological closure, achievement of, 42

Technological determinism, 16–18, 361

Technological development

- industrial work and, 219–220
- Interorganizational relations and, 395–396
- slavery and inhibition of, 179–180

Technological diffusion, organizations and, 92–93

Technological dynamism, 398

Technological enthusiasm, 7

Technological fixes, 29–31, 103, 120, 292

- limitations of, 153
- of the past, 111–113
- problems with, 31–33
- Technological innovation, 397
 - as coupling process, 48
 - internal resistance to, 95
 - market economics in driving, 39, 52–53
 - organization size and, 390–392
 - as source of environmental damage, 104
- Technological knowledge, scientific knowledge and, 66–67
- Technologically primitive societies, work and leisure in, 169–171, 170
(*ill.*)
- Technological plagiarism, 86
- Technological progress, 11, 21
 - gulf between social progress and, 29
- Technological society, living in a, 18–19
- Technological sophistication, cost of, 325–326
- Technological threat, historical perspective of, 187–189
- Technology
 - alternative, 90
 - appropriate, 89–92
 - blaming, 213–215
 - as cause of organizational structure, 381–386
 - commonalities of science and, 74–76
 - complementary, 47
 - as consequence of organizational structure, 386–390
 - continuous-process, 383 (*ill.*)
 - in creating jobs, 191–192
 - defined, 1, 4–8
 - democratic control of, 413–416, 415 (*ill.*)
 - diagnostic, 137–139, 138 (*ill.*)
- Technology (*Continued*)
 - differences between science and, 64–67
 - diffusion of, 81–85
 - dual nature of, 7–8
 - economy and, 11–12
 - efforts in restricting the diffusion of, 95–96

electronic information, 392–393
engineers in control of, 373–378, 375 (*ill.*)
in facilitating scientific discovery, 67–70
foreign, 83–84, 86
gender and, 15–16, 19
genetic (*See* Genetic technologies)
globalization, cultural convergence and, 365–369
government actions in the shaping of, 401–404
government institutions for the guidance of, 407–408
growth of, 29
halfway, 103, 143, 144, 147
historical separation of science and, 61–63
history of, 7
as human creation, 361
imported, 86
inability to understand, 3
income inequality and, 198–199
indirect effects of new, on employment, 192–193
industrial, 215–217, 347–357
interindustry transfers of, 48
intermediate, 90
in job creation, 191–192
knowledge and, 1
legitimizing science through, 70–71
life-extending, 32
linguistic roots of, 4
Luddites and, 26–27
machine-based, 215
machines and, 193–195, 194 (*ill.*)
malleability of, 41
medical (*See* Medical technology)
as a metaphor, 11–12
military (*See* Military technology)
myths of, 21
nature of, 3
neo-Luddism and, 27–28
new information, 392–395

- organizing humanity and, 5–8, 5 (*ill.*)
- outward flow of, 96
- patents and the diffusion of, 96–98
- paying for, 404–405
- as problem or solution, 110–111
- rationality and, 13–16
- shaping of, 369–373
- smart, 225–227
- in solving social problems, 31–32
- spinoffs in, 70
- as a subversive force, 22–26, 23 (*ill.*), 24 (*ill.*), 25 (*ill.*)
- support of, 3
- terminator, 153
- terrorism and, 328–330
- tools and techniques in, 4
- transfer, 47–48
- translation of science into, 72–73

Technology in Retrospect and Critical Events in Science (TRACES) (study), 64

Technology transfer, 85 (*ill.*)

- clearing bottlenecks through, 47–48

Technoscience, 75

Technostructure, 374

Teenagers, viewing of television by, 262, 263

Telegraphs, 22, 231, 242–243, 253, 392

- limitations of, 253

Telephone industry, employment in, 187, 188, 188 (*ill.*)

Telephones, 51, 392

Television, 231, 253, 369

- cable, 261, 291
- delivering of news on, 265–266, 266 (*ill.*)
- Federal government and, 259–261
- politics and, 265–268
- rise of, 257–259
- success of, 291
- thought and, 268–270
- time spent viewing, 262

- viewing of, by teenagers, 262, 263
- viewing public of, 261–262
- violence on, 262–265, 364
- Television camera, 84
- Telework, 222–224, 223 (*ill.*)
- Terminator technology, 153
- Terrorism, 328–330
 - cyber, 330–332
- Tesla (automobile), 47
- Tests, overuse of, 138
- Tetraethyl lead, 47
- Texas, flooding in, 410 (*ill.*)
- Textile industry, 95
- Thermodynamics, first law of, 68
- Third World, 366
- Thirty Years' War (1618–1648), 306
- Thomas, Lewis, 127
- Thoreau, Henry David, 211
- Thought, television and, 268–270
- Three Mile Island nuclear power plant, accident at, 261
- Throwing sticks, 168
- Tilly, Charles, 308
- Timber, depletion of, 111
- Timbuktu, 175–176
- Time
 - clocks and, 181–183, 182 (*ill.*)
 - conversion of, into a commodity, 183
 - measurement of, and changed working patterns, 180–181
- Time-and-motion studies, 35
- Times* of London, 242
- Tire, pneumatic, 49
- Tlatelolco, Treaty of, 357
- TNT, 314
- Tools
 - stone, 168
 - in technology, 4
 - working with the earliest, 167–168

Topsoil loss, 110
Townes, Charles, 69
Toxic sites, restoring, 109
Toyota automatic loom, 83
Trained incapacity, 177
Trait transmission, 148
Transistors, 22, 191
Transportation, advances in, 417
 Intermodal, 201
Trebuchets, 304–305, 304 (*ill.*), 305
Trench warfare, 341, 341 (*ill.*)
Trialability, 92
Trident II missiles, 351 (*ill.*)
Triode, 255
Trojan horses, 330
Trolleys, 31, 31 (*ill.*)
Truman, Harry, 266
Trump, Donald, 267
Tularemia, 329
Tunnel vision, 50
Turbojet engines, 48
Turkle, Sherry, 279
Twain, Mark, 242
Tweets, 291
Twitter, 246, 277, 281
Typewriters, 392, 393 (*ill.*)

Uber, 22, 23, 224
UFOs (unidentified flying objects), 18
UHF, 261
Unmanned Aerial Vehicles, 323–325
Unabomber, 28
Uncertainty and Risk, 94
Underconsumption, 190
Underdeveloped countries, appropriate technologies in, 90–91, 90 (*ill.*)
Unemployed workers over 50, 199–200
Unemployment, technological advances and, 204

Unit and small-batch production, 382
United Nations, Intergovernmental Panel on Climate Change, 107
U.S. Army Air Corps, 343, 344
U.S. Marines, 319
U.S. Navy, 397
U.S. Postal Service, 277
U.S. Strategic Bombing Survey, 313–314
United States
 arms control agreements with Soviet Union, 334
 arms race between Soviet Union and, 314
 resource consumption in, 89
Universities, involvement with patents, 402
Unmanned aerial vehicles (UAVs), 290, 323–325, 323 (*ill.*)
Uranium-225, 328
Urbanization, specialization, economic relationships and, 174–177, 176
 (*ill.*)
USS *Vincennes*, 322
Utilitarian transportation, 8

Vaccines, 143
 edible, 150
Vacuum tubes, 22, 73 (*ill.*)
 invention of, 72–73
Value of a human life, 370–371
Variable valve timing, 8
V-chip, 265
Veblen, Thorstein, 373
Venetian glass, 95
Vermeer, Johannes, 9
Victoria, Queen of England, 309
Videocassette recorders (VCRs), 270, 288
Video games, 285–287
 realism in, 286
 violent, 285–287
Videos, 282
Vietnam War, 321, 323, 326
 protests against, 414

Violence

on television, 262–265, 364

in video games, 285–287

Viruses, self-replicating, 330

Volitional evolution, 161, 162

Voltage indicator, 73

VX, 328

V-1 rockets, 319–320

V-2 rockets, 10 (*ill.*), 11, 320

Wade-Giles system of Romanization, 82

Walled gardens, 283, 284

Wang Zhen, 234

War. *See also* specific wars

asymmetrical, 326–330

centralized state and, 308–309

cost of campaigns in, 308

expanding the scale and scope of, 345–347

industrial technology in the service of, 347–357

mass-based, 347

medieval, 302

mercenary soldiers in, 340, 346

rational mindset behind, 314

remote-control, 325

siege, 301, 302–303

technological advances and, 297

technology in altering rules of, 314

trench, 341, 341 (*ill.*)

Waste, 109

Washington Conference on the Limitation of Armaments, 352

Water power, 209

Watertight bulkheads for ships, 82

Water turbines, 210

Waterwheels, 209–210, 211

Watson, James, 148

Watson, Thomas J., 51

Watt, James, 210

The Wealth of Nations (Adam Smith), 175

Weapons. *See also* War

- action and reaction and, 337–338
- aerial bombardment as, 312–313, 343–345, 344 (*ill.*)
- in the American Civil War, 307, 307 (*ill.*), 311
- archery versus gunnery as, 339–340
- arming of infantry with, 306–308
- armor and, 303
- armored cars as, 341–342
- arms race and, 314
- artillery as, 306, 308
- asymmetrical warfare and, 326–330
- atomic bombs as, 312, 313 (*ill.*)
- battleships in, 309–310, 350
- biological, 329–330, 329 (*ill.*)
- Brown Bess flintlock musket as, 309
- cannons as, 306, 310, 337
- catapults as, 301
- chemical, 328–329, 329 (*ill.*), 352–353
- clubs as, 299
- crossbows as, 303, 305, 350
- cruise missiles as, 308, 319–321, 320 (*ill.*)
- Crusades and, 304
- cyberterrorism and cyberattacks and, 330–332
- decline of feudalism and, 302–305
- deterrence and, 355–537
- drones as, 323–325, 323 (*ill.*), 350
- emergence of new, 337–358
- feudal order and, 301–302
- firearms as, 338, 339–340, 353–355
- flintlocks as, 347
- fulminates as, 347
- Gatling gun as, 340
- Greek fire as, 305
- of the Greeks, 299–300, 300 (*ill.*), 301, 303
- gunpowder as, 81–82, 87, 305–308, 309, 368–369
- guns as, 353–355

handheld, 306
machine, 311–312, 340–341
halberds as, 303
high-tech surveillance and, 322–323
historical attempts to limit, 350–357
hoplite, 299
horses and, 299, 301–302
improvised explosive devices as, 327–328, 327 (*ill.*)
intercontinental ballistic missiles as, 350, 356
longbows as, 303, 305, 337, 338
making of the modern world and, 310–315
matchlocks as, 306–307
military technology and, 299–301, 332–334
MIRVs as, 356
missiles as, 322
mounted knights in, 337
new, and the decline of feudalism, 302–305
nuclear, 328, 355
onagers as, 301
percussion caps as, 347, 351
perils of proliferation, 357–358
phalanx as, 299–300, 300 (*ill.*)
pikes as, 303, 305, 337
precision-guided, 337, 350
of the Romans, 300, 301
shock and awe and, 327
siege warfare and, 301, 302–303
smart bombs as, 321–322
smokeless powders as, 347
Springfield rifle-muskets at, 307, 307 (*ill.*)
stone knives as, 299
submarines as, 311–312
tanks as, 64, 326, 337, 341, 342, 343 (*ill.*)
technological change and, 309–310
technological sophistication and, 325–326
terrorism and, 328–330, 329 (*ill.*)
trebuchets as, 304–305, 304 (*ill.*)

in World War I, 311, 312, 312 (*ill.*)
in World War II, 312–313, 313 (*ill.*), 315, 319, 321, 331
Weather, capriciousness of, 13, 14 (*ill.*)
Weather prediction, satellites for, 57
Webb, James, 70
Weber, Max, 15, 371
Web pages, 275, 282
Web searches, 386
Websites, 291
Westernization, 366
Westinghouse Electric, 255–256
Whac-a-Mole, 333
Whistle-blowing, 375, 412
White-collar work, technological changes and, 220–222
Whitney, Eli, 348
Whitney, Willis, 55
Whittle, Frank, 390
Wiener, Norbert, 11
Wikipedia, 289 (*ill.*)
Wilson, Edward O., 161, 162
Wind energy, 115–116, 116 (*ill.*), 122
Winner, Langdon, 70–71
Wireless Telegraphy Company, 73
Women as gamers, 285
Woodblock printing, 234–235, 235 (*ill.*)
Woodward, Joan, 382–383, 384, 385
Work
 development of agriculture and, 171
 with the earliest tools, 167–168
 separation of workplace and, 394 (*ill.*)
 in technologically primitive societies, 169–171, 170 (*ill.*)
 time and changed patterns of, 180–181
Worker autonomy, 212, 382
Worker specialization, 381
Workers, older, 200
Workplace technologies, 394
World Trade Center, September 11 attack on, 328

World War I

- airplanes in, 343
- chemical weapons in, 328–329
- commercial radio and, 255
- consequences of military technologies, 352
- machine guns in, 312 (*ill.*), 337, 340–341
- tanks in, 342
- U-boats in, 311–312

World War II

- aerial bombardment in, 312–313, 326
- aerial combat in, 319
- airplanes in, 343–345, 344 (*ill.*)
- bombing sorties in, 315
- commercial television and, 260
- costs of weapons in, 325
- dropping of first atomic bomb in, 312
- European Theater of Operation in, 319
- Pacific Theater of Operation in, 319
- poison gas in, 331
- scientists and engineers in, 348
- tanks in, 341, 343 (*ill.*)

World Wide Web (WWW), 84, 276

Wozniak, Steve, 391 (*ill.*)

Wright brothers, 42

Writing, invention of, 231

Written language, development of, 233–234

Xenophon, 175

Xerox machines, 51

X-ray machines, 137

“Yankee ingenuity,” 84

Yellow fever, 329

Yellow journalism, 244

Yemen, drone strikes on, 324

YouTube videos, 269, 275

Yucca Mountain nuclear waste facility, 115

Yugoslavia, breakup of, 320
Y-10 airliner, 86

Zeppelins, 312
Zipper, 94
Zworykin, Vladimir, 258

Society and Technological Change is the definitive introduction to the study of society and technology. With an engaging and insightful presentation, Rudi Volti examines both how technology has influenced our lives and how it is shaped by the societies that create it.

New to the Eighth Edition:

- New coverage of work and the economy with a new example on **the success and effect of Uber and ride-sharing** and new sections on **The Gig Economy: Technology and Income Inequality**, and **Technology, Employment, and a Changing Workforce**.
- New coverage and updated coverage of communication technologies with new sections on **Digitizing the News**, **Reading Digitally: Social Media and the Network Effect**, and **Internet Access: Net Neutrality and Walled Gardens**.
- New and updated coverage of technology and warfare with new material on **the technological development of cruise missiles**, updated coverage on the use of **drone strikes**, and a new discussion of **cyberattacks**.
- New and updated coverage of technology and the environment with new coverage of **fracking**, **renewable energy sources**, and **climate change**.
- New and updated coverage of medical and biological technologies with new coverage of **gene patenting**, updated data on **health care costs**, and new coverage of **angioplasty and heart disease**.

Cover Photo: Maximilien Brice, CERN/Science Source



worth
publishers

Macmillan Learning

macmillanlearning.com