

Dynamic Effects of Information Disclosure on Investment Efficiency

SUNIL DUTTA* AND ALEXANDER NEZLOBIN*

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ABSTRACT

This paper studies how information disclosure affects investment efficiency and investor welfare in a dynamic setting in which a firm makes sequential investments to adjust its capital stock over time. We show that the effects of accounting disclosures on investment efficiency and investor welfare crucially depend on whether such disclosures convey information about the firm's future capital stock (i.e., balance sheet) or about its future operating cash flows (i.e., earnings). Specifically, investment efficiency and investor welfare unambiguously increase in the precision of disclosures that convey information about the future capital stock, since such disclosures mitigate the current owners' incentives to underinvest. In contrast, when accounting reports provide information about future cash flows, the firm can have incentives to either under- or overinvest depending on the precision of accounting reports and the expected growth in demand. For such disclosures, investment efficiency and investor welfare are maximized by an intermediate level of precision. The two types of accounting disclosures act as substitutes in that the precision of capital stock disclosures that maximizes investment efficiency (and investor welfare) decreases as cash flow disclosures become more informative and vice versa.

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*Haas School of Business, University of California, Berkeley.

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1. Introduction

A growing body of accounting literature investigates the equilibrium relationship between firms' disclosure environments and their production and investment decisions.¹ A central finding in this literature is that when investors cannot directly observe a firm's internal investment decisions, the efficiency of these decisions will be affected by the applicable disclosure requirements. Much of the work in this literature has focused on the real effects of information disclosure in static settings in which investments are made at a single point in time. We extend this real effects literature by examining a dynamic model of an infinitely lived firm that makes periodic investments to adjust its capital stock. The dynamic framework allows us to distinguish between accounting disclosures about capital stock (i.e., balance sheet) and disclosures about forthcoming earnings (i.e., performance reports). We investigate how these two types of accounting disclosures affect the efficiency of the firm's investment decisions and investor welfare.

Our model adopts the standard neoclassical framework in which the firm dynamically adjusts its capital stock by buying and selling capital goods in a competitive market in response to changing economic conditions. The firm faces two types of uncertainty about its future economic environment: stochastic demand in its output market and stochastic economic depreciation of its capital goods. The capital stock is fixed in the short run because the firm's investment decisions affect its productive capacity with a lag. As a consequence, the firm has to plan its capital stock based on imperfect information about future demand and future capacity of its existing assets.

We extend the standard neoclassical model by introducing a competitive market in which the firm's stock is traded among overlapping generations of risk-neutral investors. The overlapping generations framework is a convenient way to model the notion that the investors' rewards to ownership in the firm depend not only on the receipt of periodic dividends, but also on the time path of stock prices. The firm makes its internal investment decisions in the best interests of its current shareholders. Consistent with much of the real effects literature, we assume that investors do not have perfect information about the firm's investment choices. Instead, the stock market prices the firm based on the public financial reports that the firm releases prior to each trading date.² We distinguish between two different forms of accounting disclosures related to the two sources of uncertainty in our

¹ See Kanodia [2006] and Kanodia and Sapra [2016] for comprehensive surveys of this literature.

² Consistent with much of the real effects literature, we assume that mandatory financial reports are the only source of information to the market. This rules out nonaccounting sources of information such as voluntary disclosures. This is reasonable, however, since non-accounting sources of information are unlikely to be a perfect substitute for accounting reports. See Kanodia and Sapra [2016] for a further justification of this assumption in the real effects literature.

model: reports about the next period's capital stock and reports about one-period-ahead operating cash flows. While financial reports on capital stock inform investors about the firm's productive capacity in the next period, disclosures about operating cash flows reveal information about future demand in the firm's output market.

In the benchmark case of observable investments, we replicate a well-known result from the neoclassical investment theory. Specifically, we show that the firm's optimal investment policy sets the expected marginal product of capital in the next period equal to the Jorgenson [1963] *user cost of capital*, defined as the sum of the risk free interest rate and the expected economic depreciation rate of its capital stock.³ We show that the price of the firm's equity at each date can be decomposed into the discounted expected values of the following three components: (i) next period's operating cash flow, (ii) future replacement cost of assets in place, and (iii) over-the-horizon economic profits. The *future replacement cost of assets* is defined as the expected resale value of the firm's current capital stock at the end of the following period; *economic profits* are the difference between operating cash flows and a user cost of capital charge for the capital employed in a given period; and *over-the-horizon economic profits* are the economic profits to be earned starting two periods from now and thereafter.⁴

When investments are unobservable and accounting reports provide information about the firm's capital stock, we find that the firm underinvests in equilibrium. We characterize the *adjusted* user cost of capital that determines the firm's equilibrium investment policy and show that it monotonically decreases in the precision of accounting reports.⁵ When accounting disclosures are completely uninformative, the adjusted user cost of capital is infinite and the firm does not invest at all. On the other hand, if the accounting reports precisely reveal the future capital stock levels, investments approach first-best. We show that the current shareholders of the firm prefer an accounting regime in which the firm is committed to full disclosure in all future periods.

³This concept of the "user cost of capital" is different from the financial notion of cost of capital defined as the risk-free rate plus risk premium. We also note that characterization of the optimal investment policy in terms of the user cost of capital crucially hinges on the assumption of risk-neutrality. For other papers that rely on the user cost of capital concept, see Arrow [1964], Lucas and Prescott [1971], Abel and Eberly [1996], Fisher [2006], and Abel and Eberly [2011].

⁴The sum of the first two components in this decomposition is equal to the sum of the current replacement cost of the firm's assets and the discounted economic profits to be earned in the next period. Our decomposition of the equity value is therefore consistent with the standard result in the literature that the firm's equity value is equal to the replacement cost of its assets plus the present value of future economic profits (see, for instance, Lindenberg and Ross [1981] and Abel and Eberly [2011]).

⁵Our results thus contribute to the literature that extends the concept of the user cost of capital beyond the standard neoclassical framework. See, for instance, Rogerson [2008] for an expression for the user cost of capital in a setting with vintage capital, and Abel and Eberly [1996] for a generalization of this concept to a scenario with costly reversibility of investments.

The intuition behind this underinvestment result is the same as the one highlighted by Kanodia and Mukherji [1996] in their static setting. Specifically, since the stock market does not directly observe the firm's investments, it prices the firm based on its *conjecture* about the firm's investment choice and the firm's financial report of future capital stock. In our dynamic setting, disclosures about one-period-ahead capital stock are informative about the firm's one-period-ahead cash flow and the future replacement cost of assets in place, but not about over-the-horizon economic profits, since the market rationally anticipates that the firm will offset the impact of any favorable or unfavorable shock to its capacity by adjusting its investment in the next period. When accounting reports are imprecise, the market's conditional expectations of the first two components of the firm's equity value are partly based on the reported value of the capital stock and partly on its pre-report expectation of the capital stock, which, in turn, is based on its conjecture about the firm's investment choice. Therefore, the conditional expectations of the next period's operating cash flow and the future replacement cost of assets are less sensitive to the firm's *actual* investment choice than they would be in the first-best case. This generates unequivocally weaker investment incentives for the firm. The market rationally assigns more weight to more precise reports in pricing the firm, and hence the equilibrium investment choices become more efficient, and the current shareholders become better off, as accounting reports become more informative about future capital stock.

In contrast, we find that when accounting reports convey information about the forthcoming operating cash flows, equilibrium outcomes can entail either under- or overinvestment depending on the parameter values. Specifically, we find that firms with high expected growth in demand overinvest relative to the first-best levels, whereas firms facing low demand growth rates underinvest. Moreover, the critical value of the expected growth rate in demand at which equilibrium investment levels are first-best efficient is monotonically decreasing in the precision of accounting reports. Consequently, shareholders generally prefer an intermediate level of precision for disclosures about forthcoming operating cash flows. This optimal precision level is declining in the expected demand growth rate; that is, shareholders of high-growth firms prefer less informative reporting regimes.

To understand how overinvestment can happen in equilibrium when accounting reports provide information about future operating cash flows, notice that a report about demand in the next period is also useful in updating expectations about demand in all future periods because demand shocks have a persistent component. The value of the firm's over-the-horizon economic profits depends on demand for its output in future periods. Hence, the market uses the accounting reports to update its expectations about the firm's over-the-horizon economic profits. Though the firm's current investment choice has no effect on the expected value of its over-the-horizon economic profits in the first-best setting, the firm's

current shareholders attempt to inflate the buying investors' expectations of over-the-horizon economic profits by investing more today and generating a higher report about the next period's operating cash flow.⁶ While the current shareholders do not benefit from such overinvestment in equilibrium because the buying investors price the firm perfectly anticipating the firm's investment choice, they are trapped into this inefficient "signal-jamming" equilibrium (e.g., Stein [1989]). These overinvestment incentives are stronger for firms with higher growth rates in demand and firms with higher quality disclosures because the present value of over-the-horizon economic profits is more sensitive to the information contained in accounting reports for such firms.

When the firm simultaneously discloses both types of information, we find that such disclosures act as substitutes. That is, the precision of capital stock disclosures that maximizes investment efficiency and shareholders' welfare decreases in the informativeness of disclosures about one-period-ahead cash flows and vice versa. In particular, as long as accounting reports provide *any* information about the next period's operating cash flow, shareholders prefer less than full disclosure of the capital stock information. Conversely, if the disclosures about the firm's capital stock are imperfect, shareholders will prefer a disclosure regime that mandates informative reports about future cash flows. These results highlight that shareholders might prefer less than full disclosure *even* if it were costless for them to produce and disseminate information.

We thus show that a higher degree of financial reporting transparency does not necessarily result in higher social welfare. Similar to this result, Kanodia, Singh, and Spero [2005] demonstrate that imprecise accounting disclosures can be value enhancing. In their model, however, the firm's current shareholders have private information about the profitability of its investment and this information cannot be credibly communicated to the market. The market seeks to infer the firm's private information about the project profitability from its observation of the firm's accounting report about its investment choice. This results in a noisy signaling equilibrium with overinvestment, and the equilibrium overinvestment incentives decline as the accounting report becomes a less precise measure of the firm's investment choice. In contrast, our analysis shows that overinvestment incentives can arise (and hence imprecise accounting disclosures can be efficient) in dynamic settings *even* in the absence of any private information. While overinvestment is a consequence of private information and the associated signaling equilibrium in Kanodia, Singh, and Spero [2005], it arises from a "signal jamming" equilibrium effect in our model. Specifically, the firm overinvests with an attempt to favorably influence the market's inferences about future demand.

⁶A higher investment today leads to a higher expected capital stock in the next period, which leads to a higher expected operating cash flow next period and therefore a higher value of the accounting report.

Our analysis generates several empirical and policy implications regarding the effects of accounting disclosures on investment efficiency and investor welfare. With regard to investor' welfare, we find that shareholders prefer (i) the most precise disclosures about the next period's capital stock in the absence of disclosures about future operating cash flows, and (ii) an intermediate level of disclosure about forthcoming operating cash flows when there are no disclosures about the next period's capital stock. We characterize how the disclosure preferences of a firm's shareholders vary with the expected growth in the firm's product market. Specifically, we show that shareholders of high (low) growth firms prefer less (more) informative disclosure regimes.

Our theory also provides guidance for the empirical studies that seek to examine the link between disclosure quality and investment efficiency (see, e.g., Biddle and Hilary [2006], Biddle, Hilary, and Verdi [2009], Bushman and Smith [2001], and Goodman et al. [2014]). Much of the prior empirical research in this area does not distinguish between the balance sheet information and earnings reports. However, our analysis highlights that the link between disclosure quality and investment efficiency crucially depends on this distinction. Specifically, we find that the investment efficiency unambiguously improves in the precision of disclosures when such disclosures convey information about future capital stock (i.e., balance sheet). In contrast, investment efficiency is maximized at an intermediate level of precision for disclosures about future cash flows (i.e., earnings). Our theory also predicts that a firm's investments monotonically increase in the precision of its accounting disclosures *regardless* of whether such disclosures convey information about future balance sheets or earnings. In the presence of earnings-related disclosures, our analysis shows that either under- or overinvestment can arise in equilibrium. We characterize conditions under which each of these two types of investment inefficiency is more likely to emerge in equilibrium. Specifically, we show that firms with high expected growth in demand overinvest, whereas firms whose output markets are expected to grow at slow rates underinvest relative to the efficient investment levels.

Certain aspects of our modeling framework (i.e., dynamic setting with sequential capital investments, uncertain demand, and periodic information disclosure) are related to Kanodia [1980]. In a dynamic general equilibrium setting with long-lived risk averse investors, Kanodia [1980] characterizes how equity market valuations and firms' real investment/production decisions are simultaneously affected by the amount of information in the equity market. In this paper, we examine a more specialized partial equilibrium model with overlapping generations of risk-neutral investors.⁷ This

⁷The two papers also differ in terms of some other specific assumptions about investments and demand. While Kanodia [1980] considers a setting with irreversible investments and transient demand shocks, we investigate a model with reversible investments and permanent demand shocks.

framework allows us to make specific predictions about the effects of different types of accounting disclosures on firms' investment decisions and investor welfare.

The rest of the paper is organized as follows. Section 2 describes the model. Section 3 characterizes the equilibrium effects of financial disclosures on the firm's investment decisions and investor welfare when accounting disclosures convey information about the firm's future capital stock. Section 4 characterizes these equilibrium relationships when accounting reports provide information about the firm's future cash flows. This section also considers the case when the firm can simultaneously release both types of accounting information. Section 5 concludes the paper.

2. Model Setup

We consider a firm that uses a single type of capital good in producing its output. In each period, the firm can either buy or sell any number of units of the capital good in a competitive market at an expected unit price of one dollar. Let I_t be the number of units of capital stock purchased in period t . The cost of this investment is stochastic and given by $I_t \varepsilon_t$, where ε_t is a random variable. We assume that $\{\varepsilon_t\}$ are independently distributed random variables with a mean of one. In the limit case when all ε_t are non-stochastic and equal to one, we will refer to the firm's investment as *observable*, since the physical amount of investment can be exactly inferred from the investment cash out flow in this case.

Let K_t denote the firm's capital stock in period t , which evolves according to the following equation:

$$K_{t+1} = [(1 - \delta)K_t + I_t]\Delta_{t+1}. \tag{1}$$

Here, δ is the *expected* rate of economic depreciation and Δ_{t+1} is the random component of economic depreciation in period $t + 1$ with $E[\Delta_{t+1}] = 1$ for each t . Equation (1) reflects that investments come online with a lag of one period; that is, period t investment, I_t , becomes productive in period $t + 1$. We will use k_{t+1} to denote the unconditional *expected* value of capital stock in period $t + 1$; that is,

$$k_{t+1} \equiv E[K_{t+1}] = (1 - \delta)K_t + I_t.$$

The depreciation shocks $\{\Delta_{t+1}\}$ are assumed to be independently and lognormally distributed. Specifically, we assume that $\ln \Delta_{t+1}$ is normally distributed with mean $-\frac{\sigma_\delta^2}{2}$ and variance σ_δ^2 for all t . This assumption implies that $E[\Delta_{t+1}] = 1$ and $Var(\Delta_{t+1}) = \exp(\sigma_\delta^2) - 1$.⁸ Parameter σ_δ^2 measures

⁸ If $\sigma_\delta^2 = 0$, the capital evolution process in equation (1) reduces to the familiar deterministic model, $K_{t+1} = (1 - \delta)K_t + I_t$, used in the economics and finance literatures. Our results can be extended to a setting where the mean and variance of $\ln \Delta_{t+1}$ are not related to each other.

the degree of uncertainty about the firm’s one-period ahead capacity. It will be convenient to let $\overline{\Delta}^n$ denote the n th moment of Δ_{t+1} ; that is,

$$\overline{\Delta}^n \equiv E(\Delta_{t+1}^n) = \exp \left[\frac{(n^2 - n)\sigma_\delta^2}{2} \right].$$

For a given level of capital stock K_t , the firm’s net operating cash flow in period t is given by

$$CF_t = X_t K_t^\alpha, \tag{2}$$

where $0 < \alpha < 1$ is the elasticity of operating cash flow to capital and X_t is a stochastic parameter that represents the strength of demand for the firm’s output in period t . We note that X_t can also be interpreted more broadly as a parameter representing all those factors that affect the productivity of the firm’s assets (e.g., technology shocks, learning by doing, etc.). Importantly, for our analysis, the demand parameter X_t reflects factors that are beyond the firm’s control. The specification in (2) can be obtained from a more primitive set of assumptions about the firm’s production technology and output demand function.⁹

We assume that the demand parameter, X_t , evolves according to the following stochastic process:

$$X_{t+1} = G_{t+1} X_t, \tag{3}$$

where G_{t+1} is a stochastic shock to period $t + 1$ demand. The random variables $\{G_{t+1}\}$ are independently distributed such that $\ln G_{t+1}$ is normal with mean \bar{g} and variance σ_g^2 . Again, the following notation will be convenient:

$$\bar{G} \equiv E(G_{t+1}) = \exp \left(\bar{g} + \frac{\sigma_g^2}{2} \right)$$

and

$$\overline{G}^n \equiv E(G_{t+1}^n) = \exp \left(n\bar{g} + \frac{n^2 \sigma_g^2}{2} \right).$$

In this notation, $\bar{G} - 1$ is the expected growth rate of demand for the firm’s output. To ensure that the firm’s equity price is finite, we assume that $\bar{G}^{\frac{1}{1-\alpha}} < 1 + r$.

⁹ For example, suppose the output is determined by the standard Cobb–Douglas function, $q_t = K_t^\theta$ with $\theta > 0$. If the firm faces demand of constant elasticity $p_t(q_t) = X_t \cdot q_t^{-\frac{1}{\eta}}$ with $p_t(q_t)$ denoting the output price as a function of quantity q_t and $\eta > 1$ is the price elasticity of demand, the operating cash flow in period t is given by $CF_t = p_t(q_t) \cdot q_t = X_t K_t^{\theta(-\frac{1}{\eta}+1)}$. The assumption that $0 < \alpha \equiv \theta(-\frac{1}{\eta} + 1) < 1$ ensures that the firm’s value is always finite. The specification in (2) can also be obtained in a scenario where the firm uses a second production factor (e.g., labor) that can be purchased in the spot market on an as needed basis.

The firm's stock is actively traded among investors in a competitive market. While the firm is an indefinitely lived entity, investors have finite planning horizons. Such finitely lived investors' payoffs from ownership in the firm depend not only on the receipt of periodic dividends, but also on the time path of stock prices. To capture this notion, we consider an overlapping generations model in which generation t investors, who own the firm during period t , sell it to the next generation at date t . At first glance, the assumption that the shareholders fully cash out of the firm after just one period may appear extreme. However, we stress that this overlapping generations framework, which is frequently used in the economics and finance literatures, is just a convenient modeling device to capture the notion that shareholders care about stock price movements. The qualitative nature of our results would continue to hold if shareholders were to hold the firm for longer periods of time as long as their holding periods do not extend over the entire life of the firm.¹⁰

The investors of each generation are risk-neutral and discount future cash flows at rate $r > 0$. Let $\gamma \equiv \frac{1}{1+r}$ denote the corresponding discount factor.¹¹ Consistent with much of the accounting literature on real effects (e.g., Kanodia and Sapra [2016]), we assume that the firm is run by a benevolent manager who makes investment decisions in the best interest of its current owners. All parameters of the model (such as δ , σ_δ^2 , α , \bar{g} , σ_g^2) are common knowledge.

We now turn to describing the sequence of events in each period and the information available to the stock market at each trading date. At the beginning of period t , the firm's operating cash flow is realized, and both X_t and K_t are observed by all of the market participants. Next the firm chooses its period t investment level, I_t , so as to maximize the expected payoffs of its current shareholders. At the time when the firm makes its investment decision, it has imperfect information about future demand and the effective capacity of its assets. Specifically, while X_t and K_t are known, G_{t+1} and Δ_{t+1} are yet to be realized. After the investment is made, the net cash flow, $X_t K_t^\alpha - I_t \varepsilon_t$, is disbursed to (or, if negative, supplied by) generation t investors. Subsequently, the firm publicly releases an accounting report, R_t , that provides information about either future capital stock K_{t+1} , or operating cash flows CF_{t+1} , or both. We discuss the specifics of the information contained in R_t in sections 3 and 4. Lastly, at date t , the firm is sold to generation $t + 1$ investors at price P_t . This timeline is summarized in figure 1.

¹⁰ Kanodia and Sapra [2016] discuss more extensively why investors' payoffs in modern capital markets are determined by the time path of security prices, rather than by some notion of liquidating dividends.

¹¹ Our results can be generalized to a setting where each generation discounts cash flows with a stochastic discount factor, possibly correlated with G_t and Δ_t in each period. For models in which the pricing kernel is assumed to follow a geometric Brownian motion correlated with other processes governing the firm's cash flows, see, for example, Berk, Green, and Naik [2004] and Li [2011].

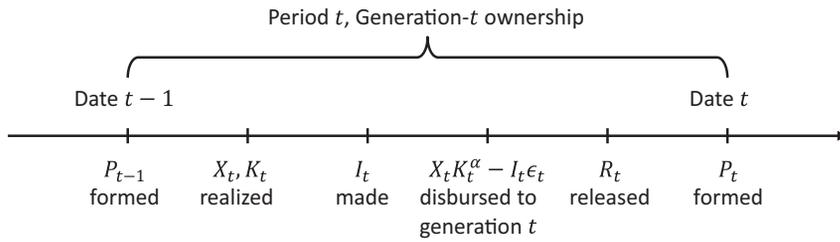


FIG. 1.—Sequence of events in period t .

The firm’s market price at date t will depend on the realization of the accounting report R_t , but the firm’s investment decision is made before R_t is realized. Accordingly, it will be convenient to use two expectation operators. Let $E_t[\cdot]$ denote the expectation conditional on all information available by date t (including R_t), and let $E_{t-}[\cdot]$ denote the conditional expectation operator based on all information available just prior to the release of R_t .

The firm’s investment choices are not directly observed by the stock market. We recall that the investment cash outflow, $I_t \epsilon_t$, provides only a noisy measure of the firm’s investment choice, I_t . At date $t + 1$, however, the investors have access to all the information that the investment choice was based upon, that is, X_t and K_t . Thus, the buying generation of shareholders prices the firm based on its conjecture about the investment amount, $\hat{I}_t(X_t, K_t)$. To simplify notation, we will often drop the arguments of $\hat{I}_t(\cdot)$, and simply write it as \hat{I}_t . In equilibrium, the buying generation’s conjecture is self-fulfilling; that is, the optimal investment from the perspective of generation t is indeed equal to the subsequent generation’s conjecture, $\hat{I}_t(X_t, K_t)$.

Formally, let $P_t(\hat{I}_t, R_t)$ denote the firm’s market price at date t as a function of the conjectured investment level \hat{I}_t and accounting signal R_t . The optimal investment choice of generation t shareholders is then given by

$$I_t^* \equiv \operatorname{argmax}_{I_t} E_{t-} \left[P_t(\hat{I}_t, R_t) - \epsilon_t I_t \right] = \operatorname{argmax}_{I_t} \left\{ E_{t-} \left[P_t(\hat{I}_t, R_t) \right] - I_t \right\}. \tag{4}$$

An equilibrium is characterized by a pricing function $P_t(\hat{I}_t, R_t)$ and a conjecture function $\hat{I}_t(X_t, K_t)$ such that (i) the stock market’s conjecture is self-fulfilling; that is, I_t^* from (4) satisfies

$$I_t^* = \hat{I}_t(X_t, K_t),$$

and (ii) the stock price process satisfies the following no-arbitrage condition:

$$P_t(\hat{I}_t, R_t) = \gamma \left\{ E_t \left[CF_{t+1} + P_{t+1}(I_{t+1}^*, R_{t+1}) - I_{t+1}^* \epsilon_{t+1} \right] \right\} \tag{5}$$

for all t . That is, it is indeed optimal for each generation of shareholders to implement the conjectured investment level and the price that generation

$t + 1$ pays for the firm at date t is equal to the present value of future cash flows received by that generation in the form of dividends and the resale price of the firm's stock.

3. Accounting Reports About Capital Stock

In our model, there are two sources of uncertainty regarding the firm's future economic environment: stochastic economic depreciation of its assets, Δ_{t+1} , and shocks to demand for its output, G_{t+1} . Conceivably, accounting disclosures can provide information useful in partially resolving both kinds of uncertainty. For example, the firm may learn, close to the end of period t , that some of its assets are impaired and will thus have lower than expected capacity in period $t + 1$. If this information is reflected in the balance sheet value of assets at date t , it will serve as a signal about the value of Δ_{t+1} .

In this section, we examine this scenario in which the firm's accounting report in each period provides a noisy estimate of its capital stock in the forthcoming period:

$$R_t = S_{t+1}K_{t+1},$$

where $\{S_{t+1}\}$ are independently and lognormally distributed noise terms. In particular, we assume that $\ln S_{t+1}$ is normally distributed with mean 0 and variance σ_s^2 . Since $E[\varepsilon_t I_t] = I_t$, the accounting report R_t is equal to the expected cost that the firm would have to incur at date t to replicate the capacity of its existing assets. Therefore, R_t can be interpreted as a noisy measure of the assets' replacement cost at date t . Under this information structure, σ_s^2 measures the noisiness of R_t as a signal of K_{t+1} . The accounting report R_t reveals K_{t+1} perfectly when $\sigma_s^2 = 0$ and provides no useful information when $\sigma_s^2 \rightarrow \infty$. We assume that G_i , Δ_j , and S_k are mutually independent for all i, j, k .

Before characterizing the equilibrium price and investment policy, it is useful to consider a benchmark scenario in which the firm is continuously owned by the same set of infinitely lived shareholders. In such a setting without any turnover of ownership, the intermediate accounting reports R_t would play no role in determining the firm's investment choices. With risk-neutral shareholders, the firm will simply choose its periodic investment to maximize the discounted sum of expected future cash flows. It is well known from the neoclassical investment theory literature (e.g., Jorgensen [1963]) that this maximization problem is equivalent to the firm myopically maximizing its expected *economic profit* π_{t+1} in each period, where the economic profit in a period is equal to the operating cash flow less the user cost of capital employed in that period. More precisely, the economic profit is defined as follows:

$$\pi_{t+1} \equiv CF_{t+1} - cK_{t+1}, \tag{6}$$

where

$$c = r + \delta \quad (7)$$

is the *user cost of capital*.

The per-unit user cost of capital, c , reflects the (hypothetical) capacity rental rate at which the firm would be indifferent between buying capital goods and renting them on an as needed basis. To see the intuition for expression (7), suppose that the firm buys one unit of capital good in period t , uses it for one period, and then sells it in the capital goods market at the end of period $t + 1$. Since the acquisition cost of one unit of capital purchased in period t is $1 + r$ (in period $t + 1$ dollars) and the expected revenue from the sale of this capital adjusted for its physical depreciation is $1 - \delta$, the net expected cost of these two transactions is $r + \delta$. Consequently, the firm is indifferent between purchasing capital and renting it at a price of c per one unit of capacity per one period of time.

The first-best investment amounts, I_t^o , are therefore given by

$$I_t^o = \operatorname{argmax}_{I_t} E_{t-}[\pi_{t+1}]. \quad (8)$$

The above optimization problem can be first solved with respect to k_{t+1}^o , where

$$k_t^o \equiv (1 - \delta)K_t + I_t^o$$

denotes the *target* level of capacity in the next period under the first-best investment policy. Substituting $E_{t-}[\pi_{t+1}] = \overline{GX}_t \overline{\Delta}^\alpha k_{t+1}^\alpha - ck_{t+1}$, the first-order condition yields the following expression for the first-best target capacity level:

$$k_{t+1}^o = c^{-\frac{1}{1-\alpha}} [\alpha \overline{GX}_t \overline{\Delta}^\alpha]^{\frac{1}{1-\alpha}}. \quad (9)$$

Note that the first-best capital stocks are decreasing in the user cost of capital, c , and are proportional to $X_t^{\frac{1}{1-\alpha}}$. For future reference, it will be useful to derive an expression for the expected value of economic profits under the first-best investment policy, $E_{t-}[\pi_{t+1}^o]$. Substituting (9) into the objective function in (8) yields

$$E_{t-}[\pi_{t+1}^o] = a(\alpha) \cdot c^{-\frac{\alpha}{1-\alpha}} [\overline{GX}_t \overline{\Delta}^\alpha]^{\frac{1}{1-\alpha}}, \quad (10)$$

where $a(\alpha) \equiv (1 - \alpha)\alpha^{\frac{\alpha}{1-\alpha}}$. We note that the expected value of optimized economic profits is decreasing in the user cost of capital c and proportional to $X_t^{\frac{1}{1-\alpha}}$.

It is worth stressing that the above characterization of the optimal investment policy in terms of the user cost of capital crucially hinges on the assumption of risk-neutrality. From the consumption-based asset pricing literature (see, e.g., Mehra [2012]), it is well known that the capitalization of future cash flows into present values depends on the investors' marginal rates of substitution between present and future consumption. With risk-neutral agents, this marginal rate of substitution is constant and simply

equal to the discount rate γ . This allows for the user cost of capital representation of the optimal investment policy.

Before describing our main results, it is useful to consider an additional benchmark setting in which the firm is owned by overlapping generations of investors, but the stock market directly observes the firm’s investment choices. Proposition 1 below shows that the firm will again invest the first-best amount I_t^o in each period. It is well known (see, for example, Thomadakis [1976], Lindenberg and Ross [1981], Salinger [1984], and Abel and Eberly [2011]) that the market price of the firm at each date can be written as the sum of two components: the expected replacement cost of the current assets in place and the present value of expected future economic profits. That is,

$$P_t = E_t[K_{t+1}^o] + E_t \left[\sum_{\tau=1}^{\infty} \gamma^\tau \pi_{t+\tau}^o \right], \tag{11}$$

where $K_{t+1}^o \equiv k_{t+1}^o \Delta_{t+1}$ denotes the *realized* value of capital stock in period $t + 1$ under the first-best investment policy. For our analysis, however, it will be convenient to express the market price P_t as follows:¹²

$$P_t = \gamma E_t[CF_{t+1}] + \gamma(1 - \delta) E_t[K_{t+1}^o] + E_t \left[\sum_{\tau=2}^{\infty} \gamma^\tau \pi_{t+\tau}^o \right]. \tag{12}$$

Equation (12) reveals that the firm’s market price can be written as the sum of three terms. The first term, $\gamma E_t[CF_{t+1}]$, is the expected discounted value of one-period-ahead operating cash flow. The second term, $\gamma(1 - \delta) E_t[K_{t+1}^o]$, is the discounted value of expected replacement cost that the assets currently in place will have at the end of the following period. Lastly, the third component of equity value is the present value of expected economic profits in period $t + 2$ and thereafter. We will refer to the second term in (12) as the *future replacement cost* of assets in place and to the third term as *over-the-horizon economic profits*.

The market conditions its expectations of the operating cash flow CF_{t+1}^o and the capital stock K_{t+1}^o in (12) on the accounting report R_t . Let

$$h \equiv \frac{\sigma_\delta^2}{\sigma_\delta^2 + \sigma_s^2}$$

denote the signal-to-noise ratio of the accounting signal. When h is equal to one, the signal is perfect and R_t reveals the precise value of K_{t+1} . The other polar case of $h = 0$ corresponds to the scenario in which the signals R_t are completely uninformative about K_{t+1} . Calculating the expectations in (12), Proposition 1 shows that the equilibrium market price at date t can

¹² It can be checked that $K_{t+1}^o + \gamma \pi_{t+1}^o = \gamma CF_{t+1} + \gamma(1 - \delta) K_{t+1}^o$. Substituting this in (11) yields the expression in (12).

be written as follows:

$$P_t = \gamma \cdot (E_{t-}[CF_{t+1}])^{1-h} (\overline{GX}_t R_t^\alpha)^h + \gamma(1-\delta) (k_{t+1}^o)^{1-h} R_t^h + E_{t-} \left[\sum_{\tau=2}^{\infty} \gamma^\tau \pi_{t+\tau}^o \right], \tag{13}$$

where

$$E_{t-} \left[\sum_{\tau=2}^{\infty} \gamma^\tau \pi_{t+\tau}^o \right] = C_1 X_t^{1-\alpha},$$

and C_1 is a constant that does not depend on X_t and K_t . We summarize the above discussion as follows:

PROPOSITION 1. *Suppose that investments I_t are directly observable.*

- i. *The firm’s market price is given by (13).*
- ii. *The firm follows the first-best investment policy as characterized by (9).*

As observed earlier, the firm’s market price is given by the discounted sum of one-period-ahead operating cash flow, the future replacement cost of assets in place, and over-the-horizon economic profits. Equation (13) shows that these three components of the market price respond differently to the information contained in the accounting report. Specifically, the accounting report R_t conveys useful information only about the first two components of this decomposition.

The first term of equation (13) is simply equal to the discounted value of period t expected operating cash flow with the market expectation based on all the information released up to date t ; that is, $E_t(CF_{t+1}) = [E_{t-}(CF_{t+1})]^{1-h} [\overline{GX}_t R_t^\alpha]^h$. When the accounting report R_t perfectly reveals the value of one-period-ahead capital stock K_{t+1} , the market’s conditional expectation of CF_{t+1} is simply equal to $\overline{GX}_t R_t^\alpha$. With an imprecise accounting signal, the conditional expectation of one-period-ahead operating cash flow is equal to the weighted geometric mean of its pre-report expectation (i.e., $E_{t-}[CF_{t+1}]$) and the expected value of CF_{t+1} calculated based on R_t alone (i.e., $\overline{GX}_t R_t^\alpha$). As one would expect, the weight on the pre-report expectation is decreasing and the weight on the implied value based on R_t is increasing in the informativeness of the accounting reports, h .

We note that the last term in equation (13) does not depend on R_t . Though the capacity shocks are persistent in our model, the information about the capital stock in period $t + 1$ does not alter the investors’ expectations of economic profits to be earned in periods $t + 2$ and thereafter. The reason is that the investors rationally anticipate that the firm will completely offset the effect of any economic depreciation shock Δ_{t+1} on over-the-horizon economic profits by adjusting its investment amount in period $t + 1$. For example, if the realization of R_t turns out to be low, the firm will make a larger investment in period $t + 1$ so that the expected economic

profit of period $t + 2$ remains unaffected. In contrast, the expected operating cash flow of period $t + 1$ depends on R_t because the capital stock is fixed in the short run; that is, K_{t+1} cannot be changed by I_{t+1} .

We are now ready to characterize the equilibrium when the firm’s investment choices are not directly observed by the market. In forming expectations about the firm’s future capital stocks and cash flows, the stock market relies on its conjecture \hat{I}_t in interpreting the information contained in the firm’s financial reports. As a consequence, the firm’s market price will depend on both the conjectured investment level, \hat{I}_t as well as the firm’s actual investment choice, I_t .

The proof of Proposition 2 shows that the firm’s equilibrium investment policy is to choose I_t^* so as to maximize the expected difference between the operating cash flow in period $t + 1$ and an *adjusted* user cost of capital employed in that period. Specifically, the equilibrium investment amount is given by

$$I_t^* = \operatorname{argmax}_I E_{t-}[CF_{t+1}] - c^* E_{t-}[K_{t+1}], \tag{14}$$

where

$$c^* \equiv h^{-1}(1 + r) - (1 - \delta) \tag{15}$$

denotes the *adjusted* user cost of capital. We note that the adjusted user cost of capital, c^* , is monotonically decreasing in the precision of accounting signals. For very imprecise signals (h close to zero), c^* tends to infinity and the firm’s investments approach zero. For very informative signals (characterized by h close to one), c^* approaches the standard Jorgensonian user cost of capital, $r + \delta$, and the firm’s investments approach first-best.

The maximization problem in (14) implies that the equilibrium target capacity level is given by (see the proof of Proposition 2 for details)

$$k_{t+1}^* = c^{*-\frac{1}{1-\alpha}} (\alpha \overline{G\Delta^\alpha} X_t)^{\frac{1}{1-\alpha}}. \tag{16}$$

Let $\pi_{t+\tau}^*$ denote the economic profit in period $t + \tau$ under the investment policy I_t^* , calculated relative to the standard Jorgensonian (i.e., *unadjusted*) user cost of capital c :

$$\pi_{t+\tau}^* \equiv CF_{t+\tau} - cK_{t+\tau}.$$

Proposition 2 shows that the firm’s market price is given by

$$P_t = \gamma \cdot (E_{t-}[CF_{t+1}])^{1-h} (\overline{GX}_t R_t^\alpha)^h + \gamma(1 - \delta) (k_{t+1}^*)^{1-h} R_t^h + E_{t-} \left[\sum_{\tau=2}^{\infty} \gamma^\tau \pi_{t+\tau}^* \right], \tag{17}$$

where

$$E_{t-} \left[\sum_{\tau=2}^{\infty} \gamma^\tau \pi_{t+\tau}^* \right] = C_2 X_t^{\frac{1}{1-\alpha}},$$

and C_2 is a constant that does not depend on X_t , K_t , or R_t .

PROPOSITION 2. *Suppose that investments I_t are unobservable.*

- i. *The equilibrium market price at date t is given by (17).*
- ii. *In equilibrium, the firm's investment policy is characterized by (16) with the adjusted user cost of capital given by (15).*
- iii. *In equilibrium, the firm underinvests as long as accounting reports are imprecise (i.e., $I_t^* < I_t^o$ for $h < 1$). The equilibrium investment policy becomes more efficient as accounting reports become more informative (i.e., as h increases).*

A comparison of Propositions 1 and 2 reveals that the valuation equation in (17) corresponds exactly to equation (13) from Proposition 1 with the first-best capacity levels, $k_{t+\tau}^o$, replaced by the equilibrium capacity levels, $k_{t+\tau}^*$. The real effects of disclosures about capital stock are thus fully captured by the adjusted user cost of capital in (15). Specifically, a comparison of expressions (9) and (16) reveals that the equilibrium capacity level k_{t+1}^* is given by the same expression as the first-best target capacity level k_{t+1}^o with the user cost of capital replaced by its adjusted value. Since $c^* \geq c$, the firm underinvests in equilibrium; that is, $k_{t+1}^* \leq k_{t+1}^o$ and $I_t^* \leq I_t^o$. Furthermore, the equilibrium investment amounts I_t^* monotonically increase in the precision of accounting report, h , and approach the first-best levels as the accounting reports become perfectly informative (i.e., $h = 1$).

The intuition behind the underinvestment result is the same as the one highlighted by Kanodia and Mukherji [1996] in their static setting. Recall that generation t shareholders choose investment I_t to maximize the expected resale price of the firm's stock net of the cost of investment:

$$\max_{I_t} E_{t-}[P_t(\hat{I}_t, R_t)] - I_t.$$

The firm's actual investment choice affects the market price $P_t(\hat{I}_t, R_t)$ only through the accounting report R_t because the firm takes the market's conjecture, \hat{I}_t , as given. The market uses the financial report R_t to update its expectations about the first two components of the firm's equity price; that is, one-period-ahead operating cash flow and replacement cost of assets in place. These are the same components that determined the firm's optimal investment in the first-best setting. However, the firm now rationally anticipates that the conditional expectations of these two components will be partly based on the market's conjecture \hat{I}_t . The expectations of these components are therefore less sensitive to the firm's actual investment choice, I_t . Hence, the firm's investment incentives are weaker than those in the first-best case.

We note that while the firm's equilibrium investment policy is determined by the *adjusted* user cost of capital, its economic profits included in the price of its equity in equation (17) are calculated relative to the *unadjusted* user cost of capital. Since economic profits calculated relative to

the unadjusted user cost of capital are maximized under the first-best investment policy, I_t^o , we have

$$E_{t-} [\pi_{t+\tau}^*] \leq E_{t-} [\pi_{t+\tau}^o].$$

As one would expect, the firm’s economic profits are lower when its investment choices are not directly observed by the market.

The proof of Proposition 2 shows that the pre-report expectation of the firm’s economic profit in period $t + 1$ is given by

$$E_{t-} [\pi_{t+1}^*] = \alpha^{\frac{\alpha}{1-\alpha}} [c^* - \alpha c] c^{*-\frac{1}{1-\alpha}} \{ \overline{G\Delta^\alpha X_t} \}^{\frac{1}{1-\alpha}}.$$

It is easy to verify that the quantity above is decreasing in c^* , and hence increasing in the precision of the accounting information, h . When the accounting reports are perfectly informative (i.e., $h = 1$), the adjusted cost of capital c^* becomes equal to c , and the expression above reduces to the one for $E_{t-} [\pi_{t+1}^o]$ in (10). On the other hand, $c^* \rightarrow \infty$ when $h = 0$, and hence $E_{t-} [\pi_{t+1}^*]$ approaches zero. To summarize, the firm’s expected economic profits are monotonically increasing in the precision of accounting signals, approach first-best when the accounting reports become perfectly informative, and go to zero in the case of uninformative reports.

We now investigate disclosure preferences of different generations of the firm’s owners. Specifically, suppose that before the firm’s new investment is chosen in period t , there is an exogenous shock to the mandated disclosure regime as characterized by a new value of h . It is common knowledge that the new disclosure policy h will stay in place for all future periods. Several earlier papers have shown that the current shareholders’ disclosure preferences may be different from those of the *future* ones (e.g., Dye [1990] and Dutta and Nezlobin [2016]). This divergence of preferences arises because the purchase price of the firm’s stock is a sunk cost for the current generation of shareholders but not for the future generations. Therefore, while the firm’s future owners are concerned about how the new disclosure regime affects both the purchase and resale prices of the firm’s stock, the current owners’ welfare is affected only through its effect on the resale price.

In our setting with risk-neutral investors, future shareholders are indifferent between all disclosure regimes. The no-arbitrage condition in equation (5) ensures that all future generations will get exactly “what they pay for”; that is, the price that generation $t + \tau$ pays is equal to the present value of cash flows that generation is expected to receive. The following result demonstrates that the firm’s *current* owners prefer the most informative accounting signals.

COROLLARY 1. *When accounting reports convey information about the firm’s capital stock, the current shareholders of the firm prefer the most informative accounting regime.*

The corollary above follows directly from the observation that the firm's expected economic profits increase in the precision of accounting system, h . We recall that the pre-report expectation of the firm's price at date t can be written as the sum of the replacement cost of its assets and the discounted sum of future economic profits:

$$E_{t-}[P_t] = k_{t+1}^* + E_{t-} \left[\sum_{\tau=1}^{\infty} \gamma^{\tau} \pi_{t+\tau}^* \right].$$

The expected payoff to the firm's current owners is equal to the sum of net dividends in period t and the expected resale price of the firm:

$$\begin{aligned} X_t K_t - I_t^* + E_{t-}[P_t] &= X_t K_t + k_{t+1}^* - I_t^* + E_{t-} \left[\sum_{\tau=1}^{\infty} \gamma^{\tau} \pi_{t+\tau}^* \right] \\ &= X_t K_t + (1 - \delta) K_t + E_{t-} \left[\sum_{\tau=1}^{\infty} \gamma^{\tau} \pi_{t+\tau}^* \right]. \end{aligned}$$

Since the first two terms in the right-hand side of the expression above do not depend on the new value of h , it follows that the current generation of shareholders prefers disclosure regimes that result in a higher value of the discounted sum of expected future economic profits. As discussed earlier, the expected value of future economic profits monotonically increases in the precision of accounting disclosures.

4. Accounting Reports About Future Operating Cash Flows

The previous section investigated a setting in which accounting disclosures revealed information about the firm's future capital stock (i.e., balance sheet disclosures). Accounting disclosures also convey information about future cash flows (i.e., earnings). Such disclosures can be potentially informative about the future demand for the firm's output; for example, increases in the reported order backlogs or deferred revenues may signal improving output market conditions. In this section, we consider a setting in which the accounting reports convey information about future demand for the firm's output. We will show that disclosures about future capital stocks and demands have fundamentally different implications on efficiency of the firm's investment decisions and market prices. We conclude this section by examining the case in which accounting disclosures contain information about both future capital stocks and demand conditions.

Consider first the scenario in which the accounting report, R_t , conveys information only about future demand through a forecast of the firm's forthcoming operating cash flows. We recall that the operating cash flow in period $t + 1$ is affected by shocks to both the productive capacity of assets and demand for the firm's output. To isolate the effect of information about future demand, we consider accounting reports of the following form:

$$R_t = S_{t+1} X_{t+1} \{ (1 - \delta) K_t + I_t \}^{\alpha} \overline{\Delta}^{\alpha}. \quad (18)$$

The accounting reports of the above form convey information about the demand parameter X_{t+1} in the next period, but not about the depreciation shock Δ_{t+1} . As before, we assume that $\ln S_{t+1}$ is normally distributed with mean 0 and variance σ_s^2 , and that G_i , Δ_j , and S_k are mutually independent for all i, j, k . In this setting, the signal-to-noise ratio of accounting signals is given by

$$h \equiv \frac{\sigma_g^2}{\sigma_g^2 + \sigma_s^2},$$

which takes its minimum value of zero when the accounting report, R_t , is completely uninformative about the next period demand, X_{t+1} , and is equal to its maximum value of one when R_t is perfectly informative.

We recall that $\overline{G} - 1$ denotes the expected growth rate in the demand parameter, that is, $\overline{G} = \frac{E(X_{t+1})}{E(X_t)}$. For the analysis in this section, it will be convenient to define a corresponding growth rate, $\mu < r$, for the expected over-the-horizon *first-best* economic profits. We show in the appendix that μ and \overline{G} are related as follows:

$$1 + \mu = \overline{G^{\frac{1}{1-\alpha}}}. \tag{19}$$

To understand the intuition for (19), we recall that the present value of over-the-horizon economic profits under the first-best investment policy is proportional to $X_t^{\frac{1}{1-\alpha}}$ and

$$E_{t-} \left[X_{t+1}^{\frac{1}{1-\alpha}} \right] = \overline{G^{\frac{1}{1-\alpha}}} X_t^{\frac{1}{1-\alpha}}.$$

We recall from the previous section that when investments are observable and the accounting reports are completely uninformative (i.e., $h = 0$), the firm’s value at date t can be written as

$$P_t = \gamma(1 - \delta)k_{t+1}^o + \gamma \cdot E_{t-}[CF_{t+1}] + C_1 X_t^{\frac{1}{1-\alpha}}.$$

In this section, it will be convenient to rewrite the equity price as follows:

$$P_t = \gamma(1 - \delta)k_{t+1}^o + \gamma \cdot E_{t-}[CF_{t+1}] + C_3 E_{t-} \left[X_{t+1}^{\frac{1}{1-\alpha}} \right], \tag{20}$$

where

$$C_3 \equiv C_1 / (1 + \mu).$$

Before describing the equilibrium market price and investment policy, it is again helpful to examine a benchmark setting in which the market can directly observe the firm’s investment choices and the accounting reports provide useful information about the forthcoming operating cash flow (i.e., $h > 0$). In our next proposition, we show that the price of the firm’s equity is then given by

$$P_t = \gamma(1 - \delta)k_{t+1}^o + \gamma \cdot E_t[CF_{t+1}] + C_3 E_t \left[X_{t+1}^{\frac{1}{1-\alpha}} \right].$$

The only difference from (20) is that the pre-report expectations of CF_{t+1} and $X_{t+1}^{\frac{1}{1-\alpha}}$ are replaced with their expectations conditional on all information available by date t , including the report R_t . We further show that the expectation of CF_{t+1} conditional on R_t is equal to the weighted geometric mean of its pre-report expectation and the report itself; that is,

$$E_t[CF_{t+1}] = E_{t-}[CF_{t+1}]^{1-h} R_t^h, \tag{21}$$

where

$$E_{t-}[CF_{t+1}] = [G\Delta^\alpha X_t (k_{t+1}^o)^\alpha]^{1-h}.$$

Consistent with our results in the previous section, the weight on R_t is equal to the signal-to-noise ratio of the accounting report, h .

Recall that the accounting reports about the *capital stock* are uninformative about the expected present value of over-the-horizon economic profits, since the firm could offset any shocks to its capital stock by adjusting its investment in the subsequent period. In contrast, the reports about one-period-ahead *operating cash flow* do provide useful information about the present value of over-the-horizon economic profits. When the accounting report R_t is informative about X_{t+1} , it is also informative about all future demand shock parameters $X_{t+\tau}$ for $\tau \geq 2$. While the firm can adjust its investment process to the changing product market conditions, it cannot completely negate the effect of demand shocks on its economic profits. Therefore, the expected value of over-the-horizon economic profits at date t , which is proportional to $X_{t+1}^{\frac{1}{1-\alpha}}$, depends on R_t .

To understand how the market draws inferences about $X_{t+1}^{\frac{1}{1-\alpha}}$ from the accounting report R_t , suppose first that the accounting reports are perfectly informative (i.e., S_{t+1} is nonstochastic and equal to one). Equation (18) then implies that $X_{t+1}^{\frac{1}{1-\alpha}}$ is given by

$$R_t^{\frac{1}{1-\alpha}} [(k_{t+1}^o)^\alpha \overline{\Delta}^\alpha]^{-\frac{1}{1-\alpha}}.$$

When the accounting reports are imprecise, the expectation of $X_{t+1}^{\frac{1}{1-\alpha}}$ is equal to the weighted geometric mean of its pre-report expectation and the value of $X_{t+1}^{\frac{1}{1-\alpha}}$ calculated based on the report; that is,

$$E_t \left[X_{t+1}^{\frac{1}{1-\alpha}} \right] = E_{t-} \left[X_{t+1}^{\frac{1}{1-\alpha}} \right]^{1-h} \left[R_t^{\frac{1}{1-\alpha}} \{ (k_{t+1}^o)^\alpha \overline{\Delta}^\alpha \}^{-\frac{1}{1-\alpha}} \right]^h. \tag{22}$$

We have the following results:

PROPOSITION 3. *Assume that investments I_t are observable and the accounting reports R_t provide information about CF_{t+1} .*

i. The firm's date t market price is given by

$$P_t = \gamma(1 - \delta)k_{t+1}^o + \gamma E_t[CF_{t+1}] + C_3 E_t \left[X_{t+1}^{\frac{1}{1-\alpha}} \right], \tag{23}$$

where $E_t[CF_{t+1}]$ and $E_t[X_{t+1}^{\frac{1}{1-\alpha}}]$ are as given by equations (21) and (22), respectively.

ii. The firm follows the first-best investment policy as characterized by (9).

We are now ready to investigate the equilibrium for our main setting with unobservable investments. The proof of Proposition 4 shows that the equilibrium investment policy is characterized by the adjusted user cost of capital, c^* , which is given by the following expression:

$$c^* = \frac{(r - \mu)(1 - \alpha)(1 + r) + h\alpha(1 + \mu)(r + \delta)}{h\{(r - \mu)(1 - \alpha) + (1 + \mu)\}}. \tag{24}$$

The equilibrium investment in period t is then given by

$$I_t^* = \operatorname{argmax}_{I_t} \{E_{t-}[CF_{t+1}] - c^* E_{t-}[K_{t+1}]\}.$$

The first-order condition yields the following expression for the equilibrium target capacity:

$$k_{t+1}^* = c^{*-\frac{1}{1-\alpha}} \{\alpha \overline{G\Delta^\alpha} X_t\}^{\frac{1}{1-\alpha}} \tag{25}$$

with $I_t^* = k_{t+1}^* - (1 - \delta)K_t$. Comparing the equation above to (9), one can see that, in equilibrium, the firm underinvests (overinvests) when $c^* > c$ ($c^* < c$).¹³ We discuss the intuition for this result after providing a complete characterization of the equilibrium in Proposition 4.

As in the previous section, let $\pi_{t+\tau}^*$ denote the firm’s economic profit in period $t + \tau$ calculated relative to the unadjusted user cost of capital, c , under the equilibrium investment policy:

$$\pi_{t+\tau}^* \equiv CF_{t+\tau} - cK_{t+\tau}.$$

We obtain the following result.

PROPOSITION 4. *Assume that investments I_t are unobservable and the accounting reports R_t are informative about CF_{t+1} . In equilibrium, the adjusted user cost of capital is given by (24), the firm’s investment policy is characterized by (25), and the firm’s price at date t is given by*

$$P_t = \gamma(1 - \delta)k_{t+1}^* + \gamma E_{t-}[CF_{t+1}]^{1-h} R_t^h + C_4 E_{t-} \left[X_{t+1}^{\frac{1}{1-\alpha}} \right]^{1-h} \left[R_t^{\frac{1}{1-\alpha}} (\{k_{t+1}^*\}^\alpha \overline{\Delta^\alpha})^{-\frac{1}{1-\alpha}} \right]^h, \tag{26}$$

where

$$E_{t-}[CF_{t+1}] = \overline{G\Delta^\alpha} X_t (k_{t+1}^*)^\alpha,$$

¹³ It is also useful to note that while c^* determines the equilibrium investment levels, the growth rate of expected future capacity levels is unaffected and equal to μ ; that is, $k_{t+\tau+1}^* = (1 + \mu)k_{t+\tau}^*$.

$$E_{t-} \left[X_{t+1}^{\frac{1}{1-\alpha}} \right] = (1 + \mu) X_t^{\frac{1}{1-\alpha}},$$

$$E_{t-} \left[\sum_{\tau=2}^{\infty} \gamma^{\tau} \pi_{t+\tau}^* \right] = C_4 E_{t-} \left[X_{t+1}^{\frac{1}{1-\alpha}} \right],$$

and C_4 is a constant that does not depend on X_t, K_t, R_t .

The equilibrium market prices in the settings with observable and unobservable investments, as given by equations (23) and (26), share the same functional form and differ only with respect to the underlying investment levels. The adjusted user cost of capital, as given by equation (24), summarizes the real effects of accounting disclosures on the firm’s investment levels. Recall that the firm underinvests when c^* exceeds c and overinvests when c^* is less than c . The result below characterizes how the adjusted cost of capital varies with the precision of accounting system h and growth rate μ .¹⁴

COROLLARY 2. *The adjusted user cost of capital as given in equation (24)*

- *monotonically decreases in h , with $c^* \rightarrow \infty$ as $h \rightarrow 0$,*
- *monotonically decreases in μ , with $c^* = h^{-1}(1 + r)$ at $\mu = -1$ and $c^* \rightarrow \alpha c$ as $\mu \rightarrow r$,*
- *is equal to the unadjusted user cost, c , if $\mu > -\delta$ and the precision of the firm’s signal is given by*

$$h^* = \frac{r - \mu}{r + \delta},$$

- *is equal to the unadjusted user cost, c , if the growth rate of the firm’s economic profits is given by*

$$\mu^* = r - h(r + \delta).$$

The above result shows that when the accounting reports convey information about the forthcoming operating cash flows, the adjusted user cost of capital that determines the equilibrium investment amounts is monotonically decreasing in h and μ . Depending on the values of these two parameters, the adjusted user cost of capital can be above or below the unadjusted user cost of capital. Therefore, the equilibrium investment levels are increasing in h and μ and can be above or below the first-best levels. The result below characterizes the circumstances under which the equilibrium investment policy entails under- or overinvestment.

¹⁴ Corollary 2 can be confirmed by straightforward algebra, so we do not provide a separate proof for it.

COROLLARY 3. *In equilibrium with unobservable investments, the firm underinvests relative to the first-best levels if*

$$\mu < r - h(r + \delta)$$

and overinvests if the opposite inequality holds.

The above result shows that if investments are unobservable and accounting reports convey information about future operating cash flows, low growth firms underinvest and high growth firms overinvest. To understand the intuition for this result, we recall that the current shareholders choose I_t to maximize the difference between the expected resale price and investment costs; that is, $E_{t-}[P_t] - I_t$. As discussed earlier, the firm's market price is the expected discounted sum of three components: one-period-ahead operating cash flows, the replacement cost of assets in place, and over-the-horizon economic profits. Accounting information combined with unobservability of the firm's investment choices has three distinct effects on the equilibrium investment policy. First, since the accounting report provides no useful information about the future capital stocks, the expected discounted value of the future replacement cost of assets in place, $\gamma(1 - \delta)k_{t+1}^*$, is based solely on the market's conjecture about I_t^* , and is unaffected by the firm's actual choice of I_t . This generates an *underinvestment* bias to the firm's investment choice. The strength of this effect is independent of the precision of accounting reports, h .

Second, the conditional expectation of the one-period-ahead operating cash flow,

$$E_t[CF_{t+1}] = E_{t-}[CF_{t+1}]^{1-h} R_t^h,$$

is the weighted geometric mean of its pre-report expectation, $E_{t-}[CF_{t+1}]$, and the accounting report, R_t . As expected, the weight on the accounting report increases in its precision h . While R_t depends directly on the firm's actual investment choice I_t , the market's pre-report expectation of the firm's one-period-ahead operating cash flow, $E_{t-}[CF_{t+1}]$, is based only on its conjecture about I_t^* . Hence $E_t[CF_{t+1}]$ is less sensitive to the firm's actual investment choice, I_t , than it is in the first-best case. This effect also results in *underinvestment* incentives, which decline in the precision of accounting system, h . In the limiting case of $h = 1$, $E_t[CF_{t+1}]$ becomes just as sensitive to I_t as in the first-best setting, and hence this particular underinvestment effect vanishes.

Third, note from equation (26) that the market's expectation of the present value of over-the-horizon economic profits depends on R_t , and hence on the firm's actual investment choice I_t . The current shareholders rationally anticipate that the market will use the accounting report, R_t , to infer over-the-horizon economic profits. In particular, the market interprets a higher value of R_t as an indication of higher demand for the firm's output in future periods. As a consequence, the current shareholders have incentives to favorably influence the market's expectations of future demand by

increasing the likelihood of higher R_t through *overinvestment*.¹⁵ However, as in the signal-jamming model of Stein [1989], the current shareholders do not benefit from such an overinvestment strategy in equilibrium because the buying investors price the firm perfectly anticipating its equilibrium investment choice.

The strength of these signal-jamming incentives for overinvestment increases in both the precision of accounting system, h , and the growth rate of expected over-the-horizon economic profits, μ . Depending on the values of h and μ , the net effect of these three forces described above can be either positive or negative; that is, the equilibrium investment levels can be either higher or lower than the first-best levels. We note, however, that the equilibrium investment levels are unequivocally increasing in both the growth rate, μ , and the quality of accounting disclosures, h .

We now turn to characterizing the optimal disclosure regime from the perspective of the firm's shareholders. As in the previous section, we presume that a new disclosure regime, as characterized by a new value of h , takes effect in period t before the firm chooses its new investment. This new disclosure regime governs all future reports issued by the firm. As discussed earlier, the firm's *future* shareholders are indifferent between all possible values of h because the no-arbitrage condition on the firm's equity price ensures that the purchase price of the stock is equal to the present value of dividends and the stock's resale price in each period. The following corollary characterizes the optimal precision of disclosures from the perspective of the firm's *current* owners.

COROLLARY 4. *When accounting reports convey information about the next period's operating cash flow, the optimal precision of accounting disclosures from the perspective of the firm's current shareholders is given by*

$$h^* = \frac{r - \mu}{r + \delta}$$

if $\mu \geq -\delta$, and $h^ = 1$ otherwise.*

As discussed at the end of the previous section, the current shareholders prefer the disclosure regime that maximizes the expected present value of future economic profits. This expected value is maximized when the adjusted user cost of capital is equal to the unadjusted user cost, $r + \delta$. Corollary 4 shows that, *ceteris paribus*, shareholders of high-growth firms prefer less informative accounting disclosures. The higher is the expected product market growth, the more sensitive is the expected present value of over-the-horizon economic profits to the accounting report R_t . The increased sensitivity of the market price P_t to the accounting report R_t leads, in turn,

¹⁵ Recall that in the first-best case, the expected value of over-the-horizon economic profits is not affected by the choice of I_t .

to stronger overinvestment incentives for the current and all future generations of shareholders. Accordingly, the current shareholders prefer a less informative accounting regime (a lower value of h) to offset the effect of the higher value of μ on the sensitivity of the market price P_t to the accounting report R_t .

Corollary 4 highlights that more transparent financial reports do not necessarily result in higher investor welfare. Kanodia, Singh, and Spero [2005] also show that investor welfare can decline with more precise accounting reports. In contrast to our model, however, they examine a setting in which the firm has *private* information about the profitability of its investment. Since the market seeks to infer the firm's private information from its observation of the firm's accounting report, this results in a noisy signaling equilibrium with overinvestment. These overinvestment incentives become stronger with more precise financial reports. Thus, while overinvestment is a consequence of private information and the associated signaling equilibrium in Kanodia, Singh, and Spero [2005], it arises from a "signal jamming" equilibrium effect in our model. Put differently, our analysis shows that overinvestment incentives can arise (and hence imprecise accounting disclosures can be efficient) in dynamic settings *even* in the absence of private information.

Taken together, our results in sections 3 and 4 generate several novel implications about the effects of accounting disclosures on investment efficiency and investor welfare. Much of the prior empirical research on the link between disclosure quality and investment efficiency (see, e.g., Biddle and Hilary [2006], Biddle, Hilary, and Verdi [2009], Bushman and Smith [2001], and Goodman et al. [2014]) does not distinguish between the balance sheet and earnings disclosures. However, our analysis shows that the link between disclosure quality and investment efficiency crucially depends on this distinction. Specifically, we find that while the investment efficiency ambiguously improves in the precision of disclosures about future capital stock (i.e., balance sheet disclosures), it is maximized at an intermediate level of precision for disclosures of future cash flows (i.e., earnings disclosures). Our theory also characterizes conditions under which under- or overinvestment will arise in equilibrium. Specifically, we show that firms with high expected growth in demand overinvest, whereas firms whose output markets are expected to grow at slow rates underinvest relative to the efficient investment levels.

Our analysis highlights that the relationship between disclosure quality and investor welfare also critically hinges on whether such disclosures provide information about capital stock or future cash flows. While shareholders prefer the most informative disclosures about future capital stocks, their welfare is generally maximized at an intermediate level of precision for disclosures about future cash flows. Our theory also predicts that all else equal, shareholders of high- (low-) growth firms prefer fewer (more) informative accounting reports about future cash flows. These results are potentially testable and can be used to design more refined empirical tests of the

relationship between disclosure quality and investment efficiency and investor welfare.

To conclude this section, we consider a scenario in which the firm’s financial reports are informative about both the next period’s capital stock and operating cash flow. Specifically, suppose the firm releases two accounting reports, R_t^k and R_t^{cf} , at the end of each period. The first report, R_t^k , informs investors about the one-period-ahead capital stock, K_{t+1} , and is given by

$$R_t^k = S_{t+1}^k K_{t+1}.$$

The second accounting disclosure, R_t^{cf} , provides information about the one-period-ahead operating cash flow, CF_{t+1} , and takes the following form:

$$R_t^{cf} = S_{t+1}^{cf} \frac{\overline{\Delta}^\alpha}{\Delta_{t+1}^\alpha} CF_{t+1}.$$

The measurement error terms, S_{t+1}^k and S_{t+1}^{cf} , are assumed to be mutually and serially independent. As before, we assume that $\ln S_{t+1}^k$ and $\ln S_{t+1}^{cf}$ are both normally distributed with means of zero and variances of σ_k^2 and σ_{cf}^2 , respectively. Let h_k and h_{cf} denote the corresponding signal-to-noise ratios of the two signals:

$$h_k \equiv \frac{\sigma_\delta^2}{\sigma_\delta^2 + \sigma_k^2}; \quad h_{cf} \equiv \frac{\sigma_g^2}{\sigma_g^2 + \sigma_{cf}^2}.$$

Lastly, we impose the condition that $\mu > -\delta$; that is, the output market does not decline at a rate faster than the rate at which the expected capacity of the firm’s assets decline over time. Corollary 4 shows that under this condition, the firm’s current owners prefer an intermediate level of precision for disclosures about future cash flows.

In our earlier results, we have shown that if $h_k = 0$, the firm will follow the first-best investment policy in equilibrium if $h_{cf} = \frac{r-\mu}{r+\delta}$. On the other hand, if $h_k = 1$, the first-best policy will be implemented in equilibrium if $h_{cf} = 0$. More generally, for a given level of precision of capital stock disclosures h_k , let $h_{cf}^*(h_k)$ denote the precision of cash flow disclosures at which the firm’s equilibrium investment levels are first-best. Any disclosure regime of the form $\{h_k, h_{cf}^*(h_k)\}$ is optimal from the perspective of the firm’s current owners because the expected value of future economic profits achieves its maximum value in equilibrium under such a disclosure regime. The two “corner” cases considered above suggest that $h_{cf}^*(h_k)$ is decreasing in h_k . Our next result confirms this intuition.¹⁶

PROPOSITION 5. *The optimal precision of forthcoming cash flow disclosures, $h_{cf}^*(h_k)$, decreases in the precision of disclosures about next period’s capital stock, h_k , and vice versa.*

¹⁶ See the proof of Proposition 5 for a complete characterization of the equilibrium and the adjusted user cost of capital in the setting with two signals.

The result above shows that the two types of disclosures act as substitutes. Among the optimal regimes, investors prefer to have a lower level of precision for the second disclosure as the precision of the first disclosure increases. In particular, the result in Corollary 3 implies that if the disclosures about capital stock are less than fully revealing, the firm's owners will prefer the firm to provide informative signals about next period's operating cash flow. Furthermore, as long as the firm's accounting reports provide *some* information about next period's cash flow, the optimal precision of capital stock disclosures will take on an intermediate value. In fact, we show in the proof of Proposition 5 that the optimal disclosure regimes are characterized by the following linear functions:

$$h_{cf}^*(h_k) = \frac{r - \mu}{r + \delta} (1 - h_k),$$

and

$$h_k^*(h_{cf}) = 1 - \frac{r + \delta}{r - \mu} h_{cf}.$$

To see why the two types of disclosures act as substitutes, recall that in both "pure" settings considered above, the amount of investment in equilibrium monotonically increases in the precision of accounting signals. It is therefore impossible to have two optimal disclosure regimes one of which requires more precise disclosures along both dimensions than the second one.

5. Conclusion

In this paper, we have examined the effects of different types of information disclosure on the firm's investment decisions. When disclosures are informative only about the firm's capital stock (i.e., balance sheet), the equilibrium outcome is characterized by underinvestment and the extent of underinvestment is decreasing in the precision of accounting disclosures. In contrast, when disclosures convey information only about future cash flow, both under- and overinvestment can emerge in equilibrium. When the firm reports both types of information to investors, the capital stock and cash flow disclosures act as substitutes. Specifically, the optimal precision of capital stock disclosures decreases in the precision of cash flow disclosures. Our results demonstrate that efficient investment decisions can be implemented in equilibrium even when both types of disclosures are less than perfectly informative.

Our analysis assumes that the investors are risk-neutral, which implies that marginal utilities of consumption are constant and simply equal to the risk-free discount rate. This assumption ensures that the effects of accounting disclosures on the equilibrium investment policy can be succinctly described in terms of distortions in the "user cost of capital." In future research, it would be interesting to develop a tractable modeling framework that allows for risk aversion on the part of investors. Though it

might no longer be possible to characterize equilibrium investment policies in terms of the user cost of capital, such an analysis has the potential to generate interesting insights on how risk aversion and accounting disclosures interact to influence the equilibrium investment choices and investor welfare.

APPENDIX

Proof of Proposition 1. As a function of investment I_t , suppose that the firm’s equity price at date t is given by

$$P_t = \gamma \cdot \{ \overline{G\Delta^\alpha} X_t (k_{t+1})^\alpha \}^{1-h} \{ \overline{GX_t R_t^\alpha} \}^h + \gamma(1 - \delta) \{ k_{t+1} \}^{1-h} R_t^h + C_1 X_t^{\frac{1}{1-\alpha}}, \tag{A.1}$$

where $k_{t+1} = (1 - \delta)K_t + I_t$. Recall that I_t is assumed to be directly observable for the setting considered in Proposition 1. Hence, the market’s pre-report expectation of K_{t+1} , k_{t+1} , is based on the firm’s actual investment choice I_t . We verify that i) if the firm’s price is given by the expression above, then the optimal investment from the perspective of generation t is given by equation (8), and ii) the price process in (A.1) and investments in (8) satisfy the no-arbitrage condition:

$$P_t (I_t^o, R_t) = \gamma \{ E_t [CF_{t+1} + P_{t+1} (I_t^o, R_{t+1}) - I_{t+1}^o] \}. \tag{A.2}$$

First, let us determine the optimal investment from the perspective of generation t assuming that P_{t+1} is given by (A.1). Generation t chooses investment I_t^o to maximize the difference between the expected resale price of the firm and the cost of investment; that is,

$$I_t^o = \operatorname{argmax}_{I_t} \{ E_{t-} [P_t] - I_t \}.$$

Given the price conjecture in (A.1), $E_{t-} [P_t]$ is given by

$$E_{t-} [P_t] = \gamma \{ \overline{GX_t \Delta^\alpha} (k_{t+1})^\alpha \}^{1-h} \{ \overline{GX_t (k_{t+1})^\alpha} \}^h \overline{\Delta^{\alpha h} S^{\alpha h}} + \gamma(1 - \delta) \{ k_{t+1} \}^{1-h} \{ k_{t+1} \}^h \overline{\Delta^h S^h} + C_1 X_t^{\frac{1}{1-\alpha}}. \tag{A.3}$$

Since Δ_{t+1} and S_{t+1} are lognormally distributed, we have

$$\begin{aligned} \overline{\Delta^{\alpha h} S^{\alpha h}} &= \exp \left\{ -\frac{1}{2} \alpha h \sigma_\delta^2 + \frac{1}{2} (\sigma_\delta^2 + \sigma_s^2) (\alpha h)^2 \right\} \\ &= \exp \left\{ -\frac{1}{2} \alpha h \sigma_\delta^2 + \frac{1}{2} \sigma_\delta^2 \alpha^2 h \right\} \end{aligned}$$

and

$$\begin{aligned} \overline{\Delta^h S^h} &= \exp \left\{ -\frac{1}{2} h \sigma_\delta^2 + \frac{1}{2} (\sigma_\delta^2 + \sigma_s^2) h^2 \right\} \\ &= \exp \left\{ -\frac{1}{2} h \sigma_\delta^2 + \frac{1}{2} \sigma_\delta^2 h \right\} = 1. \end{aligned} \tag{A.4}$$

Therefore,

$$\begin{aligned} \overline{\Delta^\alpha}^{1-h} \cdot \overline{\Delta^{\alpha h} S^{\alpha h}} &= \exp \left\{ (1-h) \left\{ -\frac{1}{2} \alpha \sigma_\delta^2 + \frac{1}{2} \sigma_\delta^2 \alpha^2 \right\} \right. \\ &\quad \left. - \frac{1}{2} \alpha h \sigma_\delta^2 + \frac{1}{2} \sigma_\delta^2 \alpha^2 h \right\} \\ &= \exp \left\{ -\frac{1}{2} \alpha \sigma_\delta^2 + \frac{1}{2} \sigma_\delta^2 \alpha^2 \right\} = \overline{\Delta^\alpha}. \end{aligned} \tag{A.5}$$

Using equations (A.4–A.5), the expression for the firm’s expected resale price in (A.3) simplifies to

$$E_{t-}[P_t] = \gamma \overline{G} X_t (k_{t+1})^\alpha \overline{\Delta^\alpha} + \gamma (1 - \delta) k_{t+1} + C_1 X_t^{\frac{1}{1-\alpha}}. \tag{A.6}$$

Note that $I_t = k_{t+1} - (1 - \delta) K_t$. It follows that

$$\begin{aligned} I_t^o &= \operatorname{argmax}_{I_t} \{ E_{t-}[P_t] - k_{t+1} + (1 - \delta) K_t \} \\ &= \operatorname{argmax}_{I_t} \left\{ \gamma \overline{G} X_t (k_{t+1})^\alpha \overline{\Delta^\alpha} + \gamma (1 - \delta) k_{t+1} \right. \\ &\quad \left. + C_1 X_t^{\frac{1}{1-\alpha}} - k_{t+1} + (1 - \delta) K_t \right\} \\ &= \operatorname{argmax}_{I_t} \gamma \left\{ \overline{G} X_t (k_{t+1})^\alpha \overline{\Delta^\alpha} - (r + \delta) k_{t+1} \right\}. \end{aligned}$$

We have shown that the optimal investment from the perspective of generation t is indeed given by equation (8) and $c = r + \delta$ is the firm’s effective user cost of capital. Furthermore, it is straightforward to check that the maximization problem above implies that

$$k_{t+1}^o = c^{-\frac{1}{1-\alpha}} \{ \alpha \overline{G} \overline{\Delta^\alpha} X_t \}^{\frac{1}{1-\alpha}} \tag{A.7}$$

and

$$\begin{aligned} E_{t-} [\pi_{t+1}^o] &= \{ \overline{G} X_t (k_{t+1}^o)^\alpha \overline{\Delta^\alpha} - c k_{t+1}^o \} \\ &= a(\alpha) \cdot c^{-\frac{\alpha}{1-\alpha}} \{ \overline{G} \overline{\Delta^\alpha} X_t \}^{\frac{1}{1-\alpha}}, \end{aligned} \tag{A.8}$$

where $a(\alpha) \equiv (1 - \alpha) \alpha^{\frac{\alpha}{1-\alpha}}$.

Let us now verify that under the conjectured pricing function and the optimal investment policy, the no-arbitrage condition in (A.2) holds. Substituting the price conjecture into the left-hand side of (A.2), we can rewrite the no-arbitrage condition as

$$\begin{aligned} &\gamma \cdot \{\overline{G\Delta^\alpha} X_t (k_{t+1}^o)^\alpha\}^{1-h} \{\overline{GX_t R_t^\alpha}\}^h + \gamma(1-\delta) \{k_{t+1}^o\}^{1-h} R_t^h + C_1 X_t^{\frac{1}{1-\alpha}} \\ &= \gamma \{E_t[CF_{t+1} + P_{t+1}(I_t^o, R_{t+1}) - I_{t+1}^o]\}. \end{aligned} \tag{A.9}$$

Let us now check that

$$\{\overline{G\Delta^\alpha} X_t (k_{t+1}^o)^\alpha\}^{1-h} \{\overline{GX_t R_t^\alpha}\}^h = E_t[CF_{t+1}] \tag{A.10}$$

and

$$\{k_{t+1}^o\}^{1-h} R_t^h = E_t[K_{t+1}]. \tag{A.11}$$

First note that

$$E_t[CF_{t+1}] = E_t[\overline{GX_t \Delta_{t+1}^\alpha} (k_{t+1}^o)^\alpha]$$

and recall that $R_t = S_{t+1} \Delta_{t+1} k_{t+1}^o$. Therefore, to prove (A.10), we need to check that

$$\{\overline{G\Delta^\alpha} X_t (k_{t+1}^o)^\alpha\}^{1-h} \{\overline{GX_t} (S_{t+1} \Delta_{t+1} k_{t+1}^o)^\alpha\}^h = E_t[\overline{GX_t \Delta_{t+1}^\alpha} (k_{t+1}^o)^\alpha],$$

or, equivalently,

$$\{\overline{\Delta^\alpha}\}^{1-h} \{(S_{t+1} \Delta_{t+1})^\alpha\}^h = E_t[\Delta_{t+1}^\alpha]. \tag{A.12}$$

Since $\ln \Delta_{t+1}$ is normally distributed with mean $-\frac{\sigma_\delta^2}{2}$ and variance σ_δ^2 , $\ln S_{t+1}$ is normally distributed with mean 0 and variance σ_s^2 , and $\ln \Delta_{t+1}$ and $\ln S_{t+1}$ are independent, it follows from the standard signal extraction problem for normal distributions that the conditional distribution of $\ln \Delta_{t+1}$ given $\{\ln \Delta_{t+1} + \ln S_{t+1}\}$ is normal with mean

$$-\frac{\sigma_\delta^2}{2}(1-h) + \{\ln \Delta_{t+1} + \ln S_{t+1}\} h$$

and variance $\sigma_\delta^2(1-h)$. Therefore,

$$\begin{aligned} E_t[\Delta_{t+1}^\alpha] &= \exp \left\{ \alpha \left(-\frac{\sigma_\delta^2}{2}(1-h) + \{\ln \Delta_{t+1} + \ln S_{t+1}\} h \right) \right. \\ &\quad \left. + \frac{1}{2} \alpha^2 \sigma_\delta^2 (1-h) \right\} \\ &= (S_{t+1} \Delta_{t+1})^{\alpha h} \exp \left\{ -\alpha \frac{\sigma_\delta^2}{2} (1-h) + \frac{1}{2} \alpha^2 \sigma_\delta^2 (1-h) \right\} \\ &= \{\overline{\Delta^\alpha}\}^{1-h} (S_{t+1} \Delta_{t+1})^{\alpha h}, \end{aligned}$$

and we have shown that (A.10) holds. Equation (A.11) is established by the same argument.

Using (A.10–A.11), the no-arbitrage condition in (A.9) can be rewritten as

$$\gamma(1-\delta) E_t[K_{t+1}] + C_1 X_t^{\frac{1}{1-\alpha}} = \gamma \{E_t[P_{t+1}(I_{t+1}^o, R_{t+1}) - I_{t+1}^o]\}. \tag{A.13}$$

Given the conjecture for P_{t+1} in (A.1) and equations (A.10–A.11), we can write $E_t[P_{t+1}(I_{t+1}^o, R_{t+1})]$ as

$$E_t [P_{t+1} (I_{t+1}^o, R_{t+1})] = E_t \left[\gamma CF_{t+2} + \gamma(1 - \delta)K_{t+2} + C_1 X_{t+1}^{\frac{1}{1-\alpha}} \right].$$

Substituting the expression above into the right-hand side of (A.13), we can further simplify the no-arbitrage condition as follows:

$$\begin{aligned} & \gamma(1 - \delta)E_t[K_{t+1}] + C_1 X_t^{\frac{1}{1-\alpha}} \\ & = \gamma \left\{ E_t \left[\gamma CF_{t+2} + \gamma(1 - \delta)K_{t+2} + C_1 X_{t+1}^{\frac{1}{1-\alpha}} - I_{t+1}^o \right] \right\}. \end{aligned} \tag{A.14}$$

Now observe that

$$\gamma(1 - \delta)E_t[K_{t+1}] + \gamma E_t [I_{t+1}^o] = \gamma E_t [K_{t+2}]$$

and

$$E_t \left[C_1 X_{t+1}^{\frac{1}{1-\alpha}} \right] = C_1 \overline{G^{\frac{1}{1-\alpha}}} X_t.$$

Using these two observations, equation (A.14) simplifies to

$$C_1 \left(1 - \gamma \overline{G^{\frac{1}{1-\alpha}}} \right) X_t^{\frac{1}{1-\alpha}} = \gamma^2 E_t [CF_{t+2} - (r + \delta)K_{t+2}],$$

or

$$C_1 \left(1 - \gamma \overline{G^{\frac{1}{1-\alpha}}} \right) X_t^{\frac{1}{1-\alpha}} = \gamma^2 E_t [\pi_{t+2}^o]. \tag{A.15}$$

Applying (A.8) yields

$$\begin{aligned} E_t [\pi_{t+2}^o] & = E_t \left[a(\alpha) \cdot c^{-\frac{\alpha}{1-\alpha}} \{ \overline{G\Delta^\alpha} X_{t+1} \}^{\frac{1}{1-\alpha}} \right] \\ & = a(\alpha) \cdot c^{-\frac{\alpha}{1-\alpha}} \overline{G^{\frac{1}{1-\alpha}}} \{ \overline{G\Delta^\alpha} X_t \}^{\frac{1}{1-\alpha}}. \end{aligned}$$

Therefore, the no-arbitrage condition in (A.15) is satisfied for C_1 given by

$$C_1 = \frac{\gamma^2 a(\alpha) \cdot c^{-\frac{\alpha}{1-\alpha}} \overline{G^{\frac{1}{1-\alpha}}} \{ \overline{G\Delta^\alpha} \}^{\frac{1}{1-\alpha}}}{1 - \gamma \overline{G^{\frac{1}{1-\alpha}}}}. \tag{A.16}$$

It remains to check that, for C_1 calculated above, $C_1 X_t^{\frac{1}{1-\alpha}}$ can indeed be interpreted as the present value of the expected over-the-horizon economic profits. Note that (A.8) implies that for $\tau \geq 2$

$$E_t [\pi_{t+\tau+1}^o] = \overline{G^{\frac{1}{1-\alpha}}} \cdot E_t [\pi_{t+\tau}^o],$$

that is, the expected over-the-horizon economic profits increase at rate of $G^{\frac{1}{1-\alpha}}$ on the first-best investment path. Therefore,

$$E_t \left[\sum_{\tau=2}^{\infty} \gamma^\tau \pi_{t+\tau}^o \right] = \frac{\gamma^2}{1 - \gamma G^{\frac{1}{1-\alpha}}} E_t [\pi_{t+2}^o] = C_1 X_t^{\frac{1}{1-\alpha}},$$

where the last equality follows from (A.15). □

Proof of Proposition 2. As a function of the market’s conjecture \hat{I}_t , suppose that the firm’s equity price at date t is given by

$$P_t(\hat{I}_t, R_t) = \gamma \cdot \{ \overline{G\Delta}^\alpha X_t (\hat{k}_{t+1})^\alpha \}^{1-h} \{ \overline{GX}_t R_t^\alpha \}^h + \gamma(1 - \delta) \{ \hat{k}_{t+1} \}^{1-h} R_t^h + C_2 X_t^{\frac{1}{1-\alpha}}, \tag{A.17}$$

where $\hat{k}_{t+1} = (1 - \delta)K_t + \hat{I}_t$. Taking this pricing function as given, the firm chooses its optimal investment policy I_t^* . We will then verify that if the market’s conjectures are rational (i.e., $I_t^* = \hat{I}_t$ for all t), the price process in (A.17) satisfies the following no-arbitrage condition:

$$P_t(I_t^*, R_t) = \gamma E_t \left[CF_{t+1} + P_{t+1}(\hat{I}_{t+1}^*, R_{t+1}) - I_{t+1}^* \right]. \tag{A.18}$$

The firm’s optimal investment choice I_t^* is given by

$$I_t^* = \operatorname{argmax}_{I_t} E_{t-} \left[P_t(\hat{I}_t, R_t) \right] - I_t. \tag{A.19}$$

The price conjecture in (A.17) yields

$$E_{t-} \left[P_t(\hat{I}_t, R_t) \right] = \gamma \{ \overline{GX}_t \overline{\Delta}^\alpha (\hat{k}_{t+1})^\alpha \}^{1-h} \{ \overline{GX}_t (k_{t+1})^\alpha \}^h \overline{\Delta^{\alpha h} S^{\alpha h}} + \gamma(1 - \delta) \{ \hat{k}_{t+1} \}^{1-h} (k_{t+1})^h \overline{\Delta^h S^h} + C_2 X_t^{\frac{1}{1-\alpha}}.$$

Using equations (A.4–A.5) from the proof of Proposition 1 and simplifying, the expression above reduces to

$$E_{t-} \left[P_t(\hat{I}_t, R_t) \right] = \gamma \overline{GX}_t \overline{\Delta}^\alpha (\hat{k}_{t+1})^{\alpha(1-h)} (k_{t+1})^{\alpha h} + \gamma(1 - \delta) \{ \hat{k}_{t+1} \}^{1-h} (k_{t+1})^h + C_2 X_t^{\frac{1}{1-\alpha}}.$$

Substituting the expression above into (A.19) and taking the first-order condition with respect to k_{t+1} yields

$$\gamma \alpha h \overline{GX}_t \overline{\Delta}^\alpha (\hat{k}_{t+1})^{\alpha(1-h)} (k_{t+1}^*)^{\alpha h-1} + \gamma(1 - \delta) h \{ \hat{k}_{t+1} \}^{1-h} (k_{t+1}^*)^{h-1} = 1,$$

where $k_{t+1}^* \equiv (1 - \delta)K_t + I_t^*$. Imposing the rationality condition that $I_t^* = \hat{I}_t$, and hence $k_{t+1}^* = \hat{k}_{t+1}$, the above first-order condition simplifies to

$$\gamma \alpha h \overline{GX}_t \overline{\Delta}^\alpha (k_{t+1}^*)^{\alpha-1} + \gamma(1 - \delta) h = 1,$$

or, equivalently,

$$\alpha \overline{GX}_t \overline{\Delta}^\alpha (k_{t+1}^*)^{\alpha-1} = c^*,$$

where we recall that $c^* \equiv h^{-1}(1+r) - (1-\delta)$ denotes the adjusted user cost of capital. The above equation implies

$$k_{t+1}^* = c^{*-\frac{1}{1-\alpha}} \left\{ \alpha \overline{G\Delta^\alpha} X_t \right\}^{\frac{1}{1-\alpha}}. \tag{A.20}$$

It can be easily checked that the above optimal target capacity is the same that maximizes period $t+1$ economic profit calculated using the adjusted user cost of capital c^* ; that is, k_{t+1}^* maximizes $E_t[\pi_{t+1}] = E_{t-}[CF_{t+1}] - c^* E_{t-}[K_{t+1}]$. The maximized value of period $t+1$ expected economic profit is then given by

$$\begin{aligned} E_{t-}[\pi_{t+1}^*] &\equiv \max_{I_t} \left\{ E_{t-}[CF_{t+1}] - c^* \cdot E_{t-}[K_{t+1}] \right\} \\ &= \left\{ \overline{G} X_t (k_{t+1}^*)^\alpha \overline{\Delta^\alpha} - c k_{t+1}^* \right\} \\ &= \alpha^{\frac{\alpha}{1-\alpha}} \{c^* - \alpha c\} c^{*-\frac{1}{1-\alpha}} \left\{ \overline{G\Delta^\alpha} X_t \right\}^{\frac{1}{1-\alpha}}. \end{aligned} \tag{A.21}$$

It remains to verify that the conjectured price process and the optimal investment policy jointly satisfy the no-arbitrage condition in (A.13). This part of the proof follows exactly the same steps as the proof of Proposition 1 from equation (A.9) to equation (A.15) with k_{t+1}^o replaced by k_{t+1}^* , I_{t+1}^o replaced by I_{t+1}^* , π_{t+2}^o replaced by π_{t+2}^* , and C_1 replaced by C_2 . Implementing the same steps, one can verify that the no-arbitrage condition holds if C_2 satisfies

$$C_2 \left(1 - \gamma \overline{G^{\frac{1}{1-\alpha}}} \right) X_t^{\frac{1}{1-\alpha}} = \gamma^2 E_t[\pi_{t+2}^*]. \tag{A.22}$$

Applying (A.21), we obtain

$$E_t[\pi_{t+2}^*] = \alpha^{\frac{\alpha}{1-\alpha}} \{c^* - \alpha c\} c^{*-\frac{1}{1-\alpha}} \overline{G^{\frac{1}{1-\alpha}}} \left\{ \overline{G\Delta^\alpha} X_t \right\}^{\frac{1}{1-\alpha}}.$$

Therefore, C_2 is given by

$$C_2 = \frac{\gamma^2 \alpha^{\frac{\alpha}{1-\alpha}} \{c^* - \alpha c\} c^{*-\frac{1}{1-\alpha}} \overline{G^{\frac{1}{1-\alpha}}} \left\{ \overline{G\Delta^\alpha} \right\}^{\frac{1}{1-\alpha}}}{1 - \gamma \overline{G^{\frac{1}{1-\alpha}}}}. \tag{A.23}$$

Lastly, it follows from (A.21) that for $\tau \geq 2$

$$E_t[\pi_{t+\tau+1}^*] = \overline{G^{\frac{1}{1-\alpha}}} \cdot E_t[\pi_{t+\tau}^*],$$

that is, the expected over-the-horizon economic profits increase at rate $\overline{G^{\frac{1}{1-\alpha}}}$ on the equilibrium investment path. Therefore,

$$E_t \left[\sum_{\tau=2}^{\infty} \gamma^\tau \pi_{t+\tau}^* \right] = \frac{\gamma^2}{1 - \gamma \overline{G^{\frac{1}{1-\alpha}}}} E_t[\pi_{t+2}^*] = C_2 X_t^{\frac{1}{1-\alpha}},$$

where the last equality follows from (A.22). Therefore, the last term of the equity pricing function, $C_2 X_t^{\frac{1}{1-\alpha}}$, can indeed be interpreted as the present

value of the expected over-the-horizon economic profits. This proves the first two parts of Proposition 2.

Equations (9) and (A.20) show that the equilibrium target capacity k_{t+1}^* is given by the same expression as the first-best target capacity k_{t+1}^o with the user cost of capital c replaced by its adjusted value c^* . Also, notice from equations (7) and (15) that c^* is greater than c for $h < 1$, equal to c for $h = 1$, and monotonically decreasing in h . It thus follows that $k_{t+1}^* < k_{t+1}^o$, and hence $I_t^* < I_t^o$, for $h < 1$. Since the optimal target capital k_{t+1}^* decreases in the adjusted user cost of capital c^* which, in turn, decreases in h , it follows that k_{t+1}^* increases, and hence becomes more efficient, as h increases. This proves the last two parts. \square

DERIVATION OF EQUATION (19)

Equations (9–10) show that the first-best target capacity level in period $t + 1$, k_{t+1}^o , as well as the expected optimized economic profit in that period, $E_{t-}[\pi_{t+1}^o]$, are both proportional to $X_t^{\frac{1}{1-\alpha}}$. From the perspective of date t , therefore, the expected over-the-horizon economic profits are growing at rate μ , since

$$\begin{aligned} E_{t-}[\pi_{t+\tau+1}^o] &= E_{t-}[E_{t+\tau-}[\pi_{t+\tau+1}^o]] = E_{t-}\left[A \cdot X_{t+\tau}^{\frac{1}{1-\alpha}}\right] \\ &= (1 + \mu) E_{t-}\left[A \cdot X_{t+\tau-1}^{\frac{1}{1-\alpha}}\right] = (1 + \mu) E_{t-}[\pi_{t+\tau}^o], \end{aligned}$$

where $A = a(\alpha) \cdot c^{-\frac{\alpha}{1-\alpha}} \{\overline{G\Delta^\alpha}\}^{\frac{1}{1-\alpha}}$.

Proof of Proposition 3. For a given investment level I_t , we conjecture that the firm’s price at date t is given by

$$\begin{aligned} P_t &= \gamma(1 - \delta)k_{t+1} + \gamma E_{t-}[\overline{G\Delta^\alpha} X_t k_{t+1}]^{1-h} R_t^h \\ &\quad + C_3 E_{t-}\left[X_{t+1}^{\frac{1}{1-\alpha}}\right]^{1-h} \left\{R_t^{\frac{1}{1-\alpha}} (k_{t+1} \overline{\Delta^\alpha})^{-\frac{1}{1-\alpha}}\right\}^h, \end{aligned} \tag{A.24}$$

where $k_{t+1} = (1 - \delta)K_t + I_t$. First, let us verify that generation t will choose the first-best investment level. The representative investor of generation t will choose I_t to maximize

$$\{E_{t-}[P_t] - I_t\}.$$

It is easy to verify that, given the price conjecture in (A.24),

$$E_{t-}[P_t] = \gamma(1 - \delta)k_{t+1} + \gamma \overline{G\Delta^\alpha} X_t k_{t+1} + C_3(1 + \mu) X_t^{\frac{1}{1-\alpha}}. \tag{A.25}$$

Indeed, consider, for example, the $E_{t-}[\cdot]$ -expectation of the last term in (A.24):

$$\begin{aligned}
 E_{t-} & \left[C_3 E_{t-} \left[X_{t+1}^{\frac{1}{1-\alpha}} \right]^{1-h} \left\{ R_t^{\frac{1}{1-\alpha}} (k_{t+1} \overline{\Delta}^\alpha)^{-\frac{1}{1-\alpha}} \right\}^h \right] \\
 & = E_{t-} \left[C_3 X_t^{\frac{1}{1-\alpha}} (1 + \mu)^{1-h} (S_{t+1} G_{t+1})^{\frac{h}{1-\alpha}} \right]. \tag{A.26}
 \end{aligned}$$

Recall that $1 + \mu = \overline{G}^{\frac{1}{1-\alpha}}$. By the same argument as was used to prove equation (A.5), one can verify that

$$\overline{G}^{\frac{1}{1-\alpha} 1-h} \cdot S^{\frac{h}{1-\alpha}} \overline{G}^{\frac{h}{1-\alpha}} = \overline{G}^{\frac{1}{1-\alpha}}.$$

Therefore, we indeed have

$$E_{t-} \left[C_3 X_t^{\frac{1}{1-\alpha}} (1 + \mu)^{1-h} (S_{t+1} G_{t+1})^{\frac{h}{1-\alpha}} \right] = C_3 (1 + \mu) X_t^{\frac{1}{1-\alpha}}.$$

We obtain the expression for $E_{t-}[P_t]$ in (A.25) is exactly the same as in expression (A.6) in the proof of Proposition 1. Therefore, by the same steps as in the proof of Proposition 1, we conclude that the first-best investment level I_t^o maximizes the payoff to generation t shareholders.

It remains to verify that the price process conjecture in (A.24) in conjunction with the first-best investment policy jointly satisfy the no-arbitrage condition:

$$P_t(I_t^o, R_t) = \gamma \{ E_t [CF_{t+1} + P_{t+1}(I_{t+1}^o, R_{t+1}) - I_{t+1}^o] \}. \tag{A.27}$$

Let us show that

$$\gamma E_{t-} [CF_{t+1}]^{1-h} R_t^h = E_t [CF_{t+1}]. \tag{A.28}$$

Since R_t is independent of Δ_{t+1} ,

$$E_t [CF_{t+1}] = E_t [G_{t+1} X_t \overline{\Delta}_{t+1}^\alpha (K_{t+1}^o)^\alpha].$$

The left-hand side of (A.28) can be rewritten as

$$\begin{aligned}
 \gamma E_{t-} [CF_{t+1}]^{1-h} R_t^h & = \{ \overline{G} \overline{\Delta}^\alpha X_t (k_{t+1}^o)^\alpha \}^{1-h} \{ G_{t+1} S_{t+1} \overline{\Delta}^\alpha X_t (k_{t+1}^o)^\alpha \}^h \\
 & = \overline{\Delta}^\alpha X_t (k_{t+1}^o)^\alpha \overline{G}^{1-h} \{ G_{t+1} S_{t+1} \}^h.
 \end{aligned}$$

To prove (A.28), it remains to check that

$$\overline{G}^{1-h} \{ G_{t+1} S_{t+1} \}^h = E_t [G_{t+1}].$$

This equation is verified by the same argument as equation (A.12) in the proof of Proposition 1. Similarly,

$$E_{t-} \left[X_{t+1}^{\frac{1}{1-\alpha}} \right]^{1-h} \left\{ R_t^{\frac{1}{1-\alpha}} (k_{t+1}^o \overline{\Delta}^\alpha)^{-\frac{1}{1-\alpha}} \right\}^h = E_t \left[X_{t+1}^{\frac{1}{1-\alpha}} \right] \tag{A.29}$$

follows from the observation that

$$\overline{G}^{\frac{1}{1-\alpha} 1-h} \{ G_{t+1} S_{t+1} \}^{\frac{h}{1-\alpha}} = E_t \left[G_{t+1}^{\frac{1}{1-\alpha}} \right],$$

which, in turn, is established by the same argument as (A.12).

Using (A.28) and (A.29), the no-arbitrage condition (A.27) can be simplified as

$$\gamma(1 - \delta)k_{t+1}^o + C_3 E_t \left[X_{t+1}^{\frac{1}{1-\alpha}} \right] = \gamma \left\{ E_t \left[P_{t+1} (I_{t+1}^o, R_{t+1}) - I_{t+1}^o \right] \right\}.$$

Substituting the conjecture for $P_{t+1}(I_{t+1}^o, R_{t+1})$ into the right-hand side of the equation above and applying (A.28) and (A.29) yields

$$\begin{aligned} & \gamma(1 - \delta)k_{t+1}^o + C_3 E_t \left[X_{t+1}^{\frac{1}{1-\alpha}} \right] \\ &= \gamma E_t \left[\gamma(1 - \delta)k_{t+2}^o + \gamma C F_{t+2} + C_3 X_{t+2}^{\frac{1}{1-\alpha}} - I_{t+1}^o \right]. \end{aligned} \tag{A.30}$$

Now recall that

$$(1 - \delta)k_{t+1}^o + E_t \left[I_{t+1}^o \right] = E_t \left[k_{t+2}^o \right].$$

Applying the equation above, the no-arbitrage condition (A.30) can be rewritten as

$$\begin{aligned} C_3 E_t \left[X_{t+1}^{\frac{1}{1-\alpha}} \right] &= \frac{\gamma^2}{1 - \gamma G^{\frac{1}{1-\alpha}}} E_t \left[\pi_{t+2}^o \right] \\ &= \frac{\gamma}{r - \mu} E_t \left[\pi_{t+2}^o \right]. \end{aligned}$$

From equation (10), we have

$$E_t \left[\pi_{t+2}^o \right] = E_t \left[X_{t+1}^{\frac{1}{1-\alpha}} \right] \cdot a(\alpha) c^{-\frac{\alpha}{1-\alpha}} \{ \overline{G\Delta^\alpha} \}^{\frac{1}{1-\alpha}}.$$

Therefore, the no-arbitrage condition is satisfied for C_3 given by

$$C_3 = \frac{\gamma}{r - \mu} a(\alpha) c^{-\frac{\alpha}{1-\alpha}} \{ \overline{G\Delta^\alpha} \}^{\frac{1}{1-\alpha}},$$

which is equal to $C_1/(1 + \mu)$. □

Proof of Proposition 4. As a function of the market conjecture \hat{I}_t , suppose that the firm's price at date t is given by

$$\begin{aligned} P_t &= \gamma(1 - \delta)\hat{k}_{t+1} + \gamma (\overline{G\Delta^\alpha} X_t \hat{k}_{t+1})^{1-h} R_t^h \\ &+ C_4 E_{t-} \left[X_{t+1}^{\frac{1}{1-\alpha}} \right]^{1-h} \left\{ R_t^{\frac{1}{1-\alpha}} (\hat{k}_{t+1} \overline{\Delta^\alpha})^{-\frac{1}{1-\alpha}} \right\}^h, \end{aligned} \tag{A.31}$$

where $\hat{k}_{t+1} = (1 - \delta)K_t + \hat{I}_t$,

$$C_4 = \frac{\gamma}{r - \mu} \alpha^{\frac{\alpha}{1-\alpha}} \{ c^* - \alpha c \} c^{*-\frac{1}{1-\alpha}} \{ \overline{G\Delta^\alpha} \}^{\frac{1}{1-\alpha}}, \tag{A.32}$$

and

$$c^* = \frac{(r - \mu)(1 - \alpha)(1 + r) + h\alpha(1 + \mu)(r + \delta)}{h \{ (r - \mu)(1 - \alpha) + (1 + \mu) \}}. \tag{A.33}$$

We first verify that if P_t is given by (A.31), the optimal investment from the perspective of generation t , I_t^* , is such that

$$k_{t+1}^* = c^{*-\frac{1}{1-\alpha}} \{ \alpha \overline{G\Delta^\alpha} X_t \}^{\frac{1}{1-\alpha}}, \tag{A.34}$$

where $k_{t+1}^* = (1 - \delta)K_t + I_t^*$ denotes the optimal target capacity. Using the same steps as in the derivation of equation (A.25) in the proof of Proposition 3, one can verify that

$$\begin{aligned} E_{t-}[P_t(\hat{I}_t, R_t)] &= \gamma(1 - \delta)\hat{k}_{t+1} + \gamma \overline{G\Delta^\alpha} X_t \cdot (\hat{k}_{t+1})^{\alpha(1-h)} \cdot (k_{t+1})^{\alpha h} \\ &\quad + C_4(1 + \mu) X_t^{\frac{1}{1-\alpha}} \cdot (\hat{k}_{t+1})^{-\frac{\alpha h}{1-\alpha}} \cdot (k_{t+1})^{\frac{\alpha h}{1-\alpha}}. \end{aligned}$$

Generation t chooses k_{t+1} (which is equivalent to choosing I_t) to maximize

$$E_{t-}[P_t(\hat{k}_{t+1}, R_t)] - [k_{t+1} - (1 - \delta)K_t].$$

Substituting for $E_{t-}[P_t(\hat{k}_{t+1}, R_t)]$ into the above objective function, the first-order condition for k_{t+1}^* yields

$$\begin{aligned} \gamma \alpha h \overline{G\Delta^\alpha} X_t \cdot (\hat{k}_{t+1})^{\alpha(1-h)} (k_{t+1}^*)^{\alpha h - 1} \\ + \frac{\alpha h}{1 - \alpha} C_4(1 + \mu) X_t^{\frac{1}{1-\alpha}} \cdot (\hat{k}_{t+1})^{-\frac{\alpha h}{1-\alpha}} \cdot (k_{t+1}^*)^{\frac{\alpha h}{1-\alpha} - 1} = 1. \end{aligned}$$

Imposing the market rationality condition $\hat{k}_{t+1} = k_{t+1}^*$, the above simplifies to

$$\gamma \alpha h \overline{G\Delta^\alpha} X_t \cdot (k_{t+1}^*)^{\alpha - 1} + \frac{\alpha h}{1 - \alpha} C_4(1 + \mu) X_t^{\frac{1}{1-\alpha}} (k_{t+1}^*)^{-1} = 1.$$

This yields the optimal target capacity k_{t+1}^* as given by (A.34). To verify that this is indeed the case, substituting (A.34) into the above condition gives

$$\gamma h c^* + \frac{\alpha h}{1 - \alpha} C_4(1 + \mu) c^{*\frac{1}{1-\alpha}} (\alpha \overline{G\Delta^\alpha})^{-\frac{1}{1-\alpha}} = 1.$$

Now substituting for C_4 from (A.32), the expression above becomes

$$\gamma h c^* + \frac{\gamma h(1 + \mu)(c^* - \alpha c)}{(1 - \alpha)(r - \mu)} = 1.$$

It is straightforward to check that the equation above holds for c^* given by (A.33). Therefore, the optimal investment for generation t is indeed characterized by (A.34). It is also easy to verify that the optimal target capacity level k_{t+1}^* is the same that maximizes the expected value of economic profit calculated using c^* as the user cost of capital. That is, k_{t+1}^* maximizes $E_{t-}[\pi_{t+1}] = E_{t-}[CF_{t+1}] - c^*E_{t-}[K_{t+1}]$.

It now remains to verify that the price process conjecture in (A.31) and the optimal investments (A.34) jointly satisfy the no-arbitrage condition for equity prices. By the same argument as in the proof of Proposition 3, we can check that

$$P_t = \gamma(1 - \delta)k_{t+1}^* + \gamma E_t[CF_{t+1}] + C_4 E_t \left[X_{t+1}^{\frac{1}{1-\alpha}} \right].$$

Therefore, the no-arbitrage condition can be written as

$$\begin{aligned} & \gamma(1 - \delta)k_{t+1}^* + \gamma E_t[CF_{t+1}] + C_4 E_t \left[X_{t+1}^{\frac{1}{1-\alpha}} \right] \\ & = \gamma \left\{ E_t [CF_{t+1} + P_{t+1} (I_{t+1}^*, R_{t+1}) - I_{t+1}^*] \right\}, \end{aligned}$$

or, substituting for the conjectured value of $E_t[P_{t+1}(I_{t+1}^*, R_{t+1})]$ and canceling equal terms,

$$\begin{aligned} & \gamma(1 - \delta)k_{t+1}^* + C_4 E_t \left[X_{t+1}^{\frac{1}{1-\alpha}} \right] \\ & = \gamma E_t \left[\gamma(1 - \delta)k_{t+2}^* + \gamma CF_{t+2} - I_{t+1}^* + C_4 X_{t+2}^{\frac{1}{1-\alpha}} \right]. \end{aligned} \tag{A.35}$$

The expression above can be further simplified by recalling that

$$\gamma(1 - \delta)k_{t+1}^* + \gamma E_t [I_{t+1}^*] = \gamma E_t [k_{t+2}^*]$$

and

$$E_t \left[C_4 X_{t+2}^{\frac{1}{1-\alpha}} \right] = (1 + \mu) E_t \left[X_{t+1}^{\frac{1}{1-\alpha}} \right].$$

Specifically, (A.35) is equivalent to

$$(r - \mu) C_4 E_t \left[X_{t+1}^{\frac{1}{1-\alpha}} \right] = \gamma E_t [CF_{t+2} - ck_{t+2}^*]. \tag{A.36}$$

Now observe that

$$\begin{aligned} E_t [CF_{t+2}] & = E_t [X_{t+2} \{ \Delta_{t+2} k_{t+2}^* \}^\alpha] \\ & = \overline{G\Delta}^\alpha E_t [X_{t+1} \{ k_{t+2}^* \}^\alpha] \\ & = \alpha^{\frac{\alpha}{1-\alpha}} c^{*-\frac{\alpha}{1-\alpha}} \{ \overline{G\Delta}^\alpha \}^{\frac{1}{1-\alpha}} E_t \left[X_{t+1}^{\frac{1}{1-\alpha}} \right], \end{aligned}$$

where the last equality follows from (A.34). Therefore, equation (A.36) can be rewritten as

$$(r - \mu) C_4 = \gamma \alpha^{\frac{\alpha}{1-\alpha}} c^{*-\frac{\alpha}{1-\alpha}} \{ \overline{G\Delta}^\alpha \}^{\frac{1}{1-\alpha}} - \gamma c \cdot c^{*-\frac{1}{1-\alpha}} \{ \alpha \overline{G\Delta}^\alpha \}^{\frac{1}{1-\alpha}},$$

which holds if C_4 is given by (A.32). □

Proof of Proposition 5. As a function of the market conjecture \hat{I}_t , we posit that the firm’s price at date t is given by

$$\begin{aligned} P_t & = \gamma(1 - \delta) \{ \hat{k}_{t+1} \}^{1-h_k} (R_t^k)^{h_k} \\ & + \gamma (\overline{G\Delta}^\alpha X_t \hat{k}_{t+1})^{1-h_k-h_{cf}} \{ \overline{G} X_t (R_t^k)^\alpha \}^{h_k} (R_t^{cf})^{h_{cf}} \\ & + C_5 E_{t-} \left[X_{t+1}^{\frac{1}{1-\alpha}} \right]^{1-h_{cf}} \left\{ (R_t^{cf})^{\frac{1}{1-\alpha}} (\hat{k}_{t+1} \overline{\Delta}^\alpha)^{-\frac{1}{1-\alpha}} \right\}^{h_{cf}}, \end{aligned} \tag{A.37}$$

where $\hat{k}_{t+1} \equiv (1 - \delta)K_t + \hat{I}_t$,

$$C_5 = \frac{\gamma}{r - \mu} \alpha^{\frac{\alpha}{1-\alpha}} \{c^* - \alpha c\} c^{*-\frac{1}{1-\alpha}} \{\overline{G\Delta^\alpha}\}^{\frac{1}{1-\alpha}}, \tag{A.38}$$

and

$$c^* = \frac{(r - \mu)(1 - \alpha)(1 + r - (1 - \delta)h_k) + h_{cf}\alpha(1 + \mu)(r + \delta)}{h_{cf}\{(r - \mu)(1 - \alpha) + (1 + \mu)\} + (1 - \alpha)(r - \mu)h_k}. \tag{A.39}$$

The price conjecture in (A.37) has a form similar to those of price conjectures in the proofs of Propositions 2 and 4 with the following differences. As in the proof of Proposition 2, R_t^k is used to update expectations of K_{t+1} and CF_{t+1} . Report R_t^{cf} is used to update expectations of CF_{t+1} and over-the-horizon economic profits.

We will first show that, given the pricing functions in (A.37–A.39), the optimal investment amount is characterized by

$$k_{t+1}^* = c^{*-\frac{1}{1-\alpha}} \{\alpha \overline{G\Delta^\alpha} X_t\}^{\frac{1}{1-\alpha}}. \tag{A.40}$$

To show this, one can follow the same steps as used in the proof of Proposition 4. First, observe that

$$\begin{aligned} E_{t-}[P_t(\hat{I}_t, R_t)] &= \gamma(1 - \delta)(\hat{k}_{t+1})^{1-h_k}(k_{t+1})^{h_k} \\ &\quad + \gamma \overline{G\Delta^\alpha} X_t \cdot (\hat{k}_{t+1})^{\alpha(1-h_{cf}-h_k)} \cdot (k_{t+1})^{\alpha(h_{cf}+h_k)} \\ &\quad + C_5(1 + \mu) X_t^{\frac{1}{1-\alpha}} \cdot (\hat{k}_{t+1})^{-\frac{\alpha h_{cf}}{1-\alpha}} \cdot (k_{t+1})^{\frac{\alpha h_{cf}}{1-\alpha}}. \end{aligned}$$

Generation t chooses I_t (equivalently k_{t+1}) to maximize $E_{t-}[P_t(\hat{I}_t, R_t)] - I_t$. Substituting the above expression into the objective function, the first-order condition yields

$$\begin{aligned} &\gamma(1 - \delta)h_k(\hat{k}_{t+1})^{1-h_k}(k_{t+1}^*)^{h_k-1} \\ &\quad + \gamma\alpha(h_{cf} + h_k)\overline{G\Delta^\alpha} X_t \cdot (\hat{k}_{t+1})^{(1-h_{cf}-h_k)}(k_{t+1}^*)^{\alpha(h_{cf}+h_k)-1} \\ &\quad + \frac{\alpha h_{cf}}{1-\alpha} C_5(1 + \mu) X_t^{\frac{1}{1-\alpha}} \cdot (\hat{k}_{t+1})^{-\frac{\alpha h_{cf}}{1-\alpha}}(k_{t+1}^*)^{\frac{\alpha h_{cf}}{1-\alpha}-1} = 1. \end{aligned}$$

Imposing the market rationality condition $\hat{k}_{t+1} = k_{t+1}^*$, the above simplifies to

$$\gamma(1 - \delta)h_k + \gamma\alpha(h_{cf} + h_k)\overline{G\Delta^\alpha} X_t \cdot k_{t+1}^* + \frac{\alpha h_{cf}}{1-\alpha} C_5(1 + \mu) X_t^{\frac{1}{1-\alpha}} \cdot k_{t+1}^* = 1.$$

Substituting for k_{t+1}^* from (A.40) and then for C_5 from (A.38), the expression above becomes

$$\gamma(1 - \delta)h_k + \gamma(h_{cf} + h_k)c^* + \frac{\gamma h_{cf}(1 + \mu)(c^* - \alpha c)}{(1 - \alpha)(r - \mu)} = 1,$$

which holds if c^* is given by (A.39). The remaining steps that are needed to confirm that (A.37–A.40) defines an equilibrium are exactly the same as in the proof of Proposition 4.

To find $h_{cf}^*(h_k)$, one can equate the adjusted user cost of capital in (A.39) to $r + \delta$. This yields

$$h_{cf}^*(h_k) = \frac{r - \mu}{r + \delta}(1 - h_k).$$

Conversely,

$$h_k^*(h_{cf}) = 1 - \frac{r + \delta}{r - \mu}h_{cf}.$$

The first-best investment policy can be implemented in equilibrium for a given level of h_k if $h_{cf}^*(h_k)$ is between zero and one. If $\mu \geq -\delta$, then $1 \geq h_{cf}^*(h_k) \geq 0$ for all values of h_k . The first-best investment policy can be implemented in equilibrium for a given level of h_{cf} if $h_{cf} \leq \frac{r - \mu}{r + \delta}$. It is straightforward to see that both $h_{cf}^*(h_k)$ and $h_k^*(h_{cf})$ are decreasing in their arguments. \square

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