R&D investment, Disclosure and the Horizon Problem

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Abstract

Contrary to the conventional view that voluntary disclosures improve investment efficiency, this study indicates that managers' ability to selectively disclose information about their firms' future can adversely affect investment decisions. Specifically, we show in the context of R&D that when CEOs manipulate stock prices by strategically disclosing favorable information and withholding unfavorable information pertaining to future prospects of R&D, reducing R&D spending reins in such manipulation. Such manipulation is especially expensive for long term projects such as R&D, because maintaining a facade for an ongoing project requires real manipulations that lead to suboptimal outcomes. Because a retiring CEO cannot be disciplined by the effects of his decisions on future compensation, R&D spending cuts just prior to his retirement become necessary to preserve shareholder wealth. Thus, our study provides a new explanation for the empirical regularity of R&D spending cuts preceding CEO retirements.

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1 Introduction

Substantial evidence exists that CEOs reduce their firms' research and development (R&D) spending as they approach retirement (e.g., see Dechow and Sloan 1991). While moral hazard is often appealed to as the explanation for this result, that interpretation may lack theoretical foundation, since R&D expenditures remain publicly observable and therefore not subject to moral hazard. A recent study by Cheng (2004) raises further doubt on the moral hazard argument by providing evidence that compensation committees deter opportunistic R&D spending cuts by appropriately adjusting executive compensation contracts when the CEO approaches retirement. Thus the question remains: why do we observe R&D reductions at the end of a CEO's tenure. In this study we show that an answer to this question may lie in the CEO's disclosure practices. When a CEO strategically discloses favorable information and withholds unfavorable information pertaining to the firm's R&D prospects, reining in R&D spending enhances firm value.

R&D projects require long periods of gestation, during which time there exists high levels of uncertainty (e.g., Chan et al. 2001; Kothari et al. 2002) and information asymmetry (e.g., Clinch 1991; Aboody and Lev 2000) regarding their potential outcomes. Firms meet investors' demand for R&D related information during this period by voluntarily disclosing information (Merkley 2011). For example, towards the end of 2007, Eli Lilly released favorable information pertaining to the progress of its R&D activity, including details of six drugs that it had planned to launch between then and 2011.[1] Shortly after this disclosure, the firm's then CEO Sidney Taurel retired, having already scaled back R&D spending.[2] The central determinants of our theory - disclosure of favorable information and curtailment of R&D spending, both occurring prior to the CEO's imminent retirement - are evident in this illustration. In what follows, we present a general model that explains how disclosure incentives influence R&D spending choices when a CEO approaches retirement.

[1] See *USA today* article titled "Taurel to retire as Eli Lilly CEO" dated December 18, 2007 for information about the firm's R&D disclosures.

[2] R&D investments in Eli Lilly declined gradually from 20.75% of revenue in 2005 to just 18.76% of revenue in 2007, at the time of Taurel's retirement. Tellingly, the ratio rose immediately to 21.13% under the leadership of Taurel's successor.

The main insight of our model is that voluntary disclosure choices induce a CEO approaching retirement to scale back R&D spending. All CEOs hold the "option" of selective disclosure. Disclosing positive information and withholding negative information pertaining to R&D leads to a transient manipulation of stock price. This is particularly valuable to a retiring CEO, as his exposure to the firm terminates before the withheld information eventually becomes public. Furthermore, withholding information for an ongoing project to maintain a facade leads to costly distortions, either by the CEO himself, or his successor, at the cost of long-term firm value. For example, when a CEO privately learns that a drug is not viable, pulling the plug on its development is efficient, but such an action reveals his private information. Whereas, allocating further resources to its development reduces long-term firm value but preserves the impression in the short-term that the drug may succeed. A long-horizon CEO may be unwilling to engage in these costly distortions because the associated costs realize during his tenure in the firm. In contrast, a retiring CEO's incentives to engage in these perverse actions increase with the scale of the R&D project.[3] In order to mitigate these incentives, shareholders seek reduced R&D spending from a CEO close to retirement.

Our analysis also makes other predictions that underlie the main result. We predict that a retiring CEO has better knowledge about the firm's future than a (possibly younger and less experienced) CEO earlier in his tenure. We do not attribute the superior wisdom at the time of retirement to exogenous factors such as age or experience. In our model, the superior knowledge arises endogenously. A retiring CEO derives an "option value" from information due to the option of selective disclosure. This makes information acquisition more valuable to him than to a long-horizon CEO. Thus, he actively devotes greater time and resources to acquire knowledge as he approaches retirement.

The incentives of a retiring CEO to acquire knowledge also lends to a comparison of his disclosure policy vis-a-vis the policy of a long-horizon CEO earlier in his tenure. We predict that his frequency of favorable (unfavorable) R&D related disclosures is greater (smaller) than that of a long-horizon CEO. This follows naturally from his incentives to influence stock price, even at the cost of long term firm value.

[3] Disclosing unfavorable information for a larger scale project has a bigger price impact than the release of the same information for a smaller scale project. Thus, incentives to withhold unfavorable information and engage in inefficient decisions increase with the project's scale.

It bears pointing out that R&D reductions in our model occur not because of moral hazard, but because of adverse selection associated with strategic disclosure. Thus, stock-ownership does not solve the R&D problem. Indeed, we show that even if the CEO were granted 100% stock ownership, R&D spending declines at the time of his retirement. Moreover, because stock ownership by the CEO motivates price manipulation through selective disclosure, granting him 100% ownership does not maximize firm value. Separation of ownership and management control helps to mitigate disclosure related inefficiencies. In contrast to the usual predictions of agency theory, a carefully constructed agency contract with reduced dependence on stock price and increased reliance on explicit R&D based measures enhances firm value. Thus, we predict that compensation contracts of CEOs approaching retirement are more sensitive to explicit R&D based measures and less sensitive to stock price than those of long-horizon CEOs. However, as long as a retiring CEO receives some stock based compensation, an incentive to manipulate stock price remains, making R&D reductions unavoidable.

Our study contributes to the literature in several ways. First, it adds to the debate on the "horizon Problem" (Smith and Watts 1982), which deals with the issues arising from a CEO's impending retirement. Dechow and Sloan (1991), in their seminal study, establish that a CEO's motivation to spend on R&D diminishes during his final years in office. This result has been revisited by Murphy and Zimmerman (1993), Barker and Mueller (2002), Lundstrum (2002), Cheng (2004), Naveen (2006), Demers and Wang (2010), and Xu (2011), among others. Much of this work examines the problem through the lens of moral hazard and the issues of incentive pay. Cheng (2004) indicates that moral hazard might not be at play, since firms succeed in motivating the desired level of R&D spending through compensation contracts that explicitly link CEO pay to the level of R&D spending. Likewise, Murphy and Zimmerman (1993) suggest that moral hazard is unlikely to explain the R&D investment choices of a retiring CEO. They find that R&D investments merely mirror a general decline in firm performance just prior to CEO retirements and predict that the forces contributing to the decline of both are likely the same. These studies imply that one needs to look beyond moral hazard to fully understand the horizon problem. We predict that R&D investments decline prior to CEO retirements due to incentives of selective disclosure.

Second, our study contributes to the literature that relates a firm's performance with how its manager exercises disclosure discretion. Prior studies focus on the effect of firm performance on voluntary disclosure practices. Verrecchia (1983), Dye (1985), Miller (2002), and Kothari, Shu and Wysocki (2008), among others, suggest that managers seeking to maximize stock price disclose favorable firm performance and conceal unfavorable performance. Teoh and Hwang (1991), Skinner (1994), Aboody and Kasznik (2000), and Cheng and Lo (2006) identify other situations in which managers prefer to disclose bad financial performance. Our study indicates that firm performance not only affects, but is also affected by discretionary disclosure choices. Specifically, we show that disclosure discretion adversely affects the underlying performance measure considered for disclosure.

Third, our study contributes to the understanding of how disclosure efficiency can improve through the process of contracting. Prior studies typically examine disclosure inefficiencies in the context of an owner managed firm (e.g., Verrecchia 1983, Shavell 1994, etc.). We extend this literature by investigating the role of contracting in disclosure decisions. We show that since disclosure inefficiencies arise from stock ownership, separation of ownership and control can help mitigate those inefficiencies through a well-designed compensation contract.

The rest of the paper is organized as follows. Section 2 introduces the model and characterizes a firm's benchmark information and R&D policy under a long-horizon manager. Section 3 identifies distortions in R&D and information policies arising from a CEO's impending retirement. Section 4 examines alternate solutions for the horizon problem. Section 5 concludes.

2 Model

Consider an infinitely lived R&D oriented firm that initiates the development of a new R&D project in each period. We incorporate the long gestational nature of R&D projects by assuming that the life cycle of each project encompasses two time periods. R&D commences in the first period. Development is completed and revenues realize in the second period. We refer to a project spanning time periods t and $t+1$ as project t.

Project t requires an initial R&D investment $X_t \geq 0$ in the beginning of period t and a subsequent follow-up action m_{t+1} in the beginning of period $t+1$. The kind of follow up actions we envisage include, among other things, product design choices, clinical trial decisions, patent applications, marketing strategies, etc. The R&D investment reduces the firm's resources by X_t, whereas the follow-up action incurs a personal cost of effort $\frac{m_{t+1}^2}{2}$ for the manager (henceforth "CEO").

These inputs generate revenues Y_{t+1} at the end of period $t+1$, given by:

$$Y_{t+1} = \tilde{\theta}_t \left[G\left(X_t\right) + m_{t+1} \right],$$

where $G(\bullet)$ represents an increasing and concave payoff function of R&D investment and satisfies $G(X_t) \geq 0$ for all $X_t \geq 0$, $G'(X_t) \to \infty$ for $X_t \to 0$, and $G'(X_t) \to 0$ for $X_t \to \infty$. The random variable $\tilde{\theta}_t \in [0, \infty)$ reflects the uncertain prospects of long-term R&D projects. We denote the expected value of θ_t by $\bar{\theta}$ and let Φ symbolize θ_t's cumulative distribution function (CDF), which we assume to be an increasing and differentiable function.

At the time of the initial R&D investment, the project's prospects (i.e., θ_t) are uncertain. But the uncertainty resolves with time, and a good manager can use his expertise and diligence to reassess conditions for the follow-up decision. Assume that at the end of period t, the CEO can privately acquire information about θ_t if he devoted the required time and effort. The ease of extracting information for decision making varies with the firm's and the project's characteristics. We account for these differences by assuming that there is some uncertainty in the input required to learn the project's prospects. We let the random variable $\tilde{\gamma}_t \in [0, \infty)$ denote the CEO's personal cost of time and effort needed to become informed. Although the CDF of γ_t, represented by the function F, is common knowledge, the CEO alone observes the realization of γ_t before determining if expending the required time and effort for information acquisition is worthwhile. If he chooses to exert effort and incur cost γ_t, then he privately observes θ_t.[4] This information becomes valuable in determining the follow-up effort m_{t+1}. With this set-up we capture the dynamic nature of long-term projects, in which decisions in later stages can be tailored to incorporate available information.

A horizon problem in the model arises, because a CEO only serves the firm for a single period due to life cycle reasons. We refer to the manager who serves in time period t as CEO$_t$. Thus, while CEO$_t$ makes the R&D investment and information acquisition decisions for project t, the benefits of his decisions realize only after his retirement. Meanwhile, he inherits and follows-up on project $t-1$, whose benefits he realizes on his clock.

The firm's performance during his tenure is measured by earnings e_t:

[4] The assumption that the CEO acquires a precise signal of θ_t is inessential to any of the results that follow. The economics of this model equally apply to signals of lower precision.

$$e_t = Y_t - X_t - W_t.$$

The earnings incorporate revenues Y_t from product $t-1$, net of R&D expense X_t for product t, and net of compensation cost W_t for CEO$_t$. Shareholders can base a CEO's compensation on the observable measures - earnings e_t; each component Y_t, X_t and W_t of earnings; and the firm's market price P_t (which we will describe shortly). The compensation cost W_t realizes based on this contract.[5] For simplicity, we assume that the reservation payoff for the CEO equals zero. Thus, in equilibrium, the expected compensation payment for the CEO must exceed the expected monetary costs of his efforts.

The focus of the model is on information sharing by the exiting CEO and its impact on other decisions. Implementing the follow-up effort m_{t+1} requires efficient information acquisition about θ_t as well as its disclosure. Since an incoming CEO does not arrive with private information about the firm's projects, he has to rely on his predecessor to acquire and share knowledge. It is well known that early in his tenure a new CEO finds it difficult to access reliable information (e.g., see Porter et al. 2004). Thus, if outgoing CEO$_t$ has knowledge about θ_t, his successor will have access to it in a timely manner only if CEO$_t$ chooses to disclose it. Thus, the compensation contract of CEO$_t$ must motivate R&D investment X_t, follow-up effort m_t, efficient information acquisition, and its disclosure.

Since the actual realization of cost γ_t or the CEO's information acquisition decision is not publicly known, the CEO retains complete discretion over whether to disclose θ_t if he observes it. As is standard in the disclosure literature, we assume that disclosure, when made, is honest. We denote the public information set by I_t so that $I_t \equiv \{e_t, X_t, Y_t, \theta_t\}$ with disclosure and $I_t \equiv \{e_t, X_t, Y_t\}$ with no disclosure. Following the CEO's disclosure or lack thereof, the stock market prices the firm. What gets priced is the expected value of future dividends. Dividends are declared and paid at the beginning of each period, and equals the earnings from the previous period. Thus, earnings e_t gets distributed as dividends at the beginning of period $t+1$. We denote the price formed at the end of period t by P_t. Based on the public information set I_t, the market prices the firm as follows:

[5] With slight abuse of notation, we use W_t to represent both the compensation cost and the contract itself.

Variable	Definition
t	Representative time period
X_t	Initial R&D investment in time period t
m_t	Follow-up effort in period t for product $t-1$
Y_t	Revenues in period t from product $t-1$
θ_t	Measure of the prospects of product t
$G(X_t)$	Payoff function for R&D investment
$\Phi(\theta_t)$	CDF of θ_t
σ_θ^2	Variance of θ_t
γ_t	CEO's uncertain cost of time and effort to acquire information
$F(\gamma_t)$	CDF of γ_t
e_t	Earnings for period t
W_t	CEO's compensation payment for period t
P_t	Stock price of the firm at the end of period t
I_t	Public information set for period t

Table 1: Notations

$$P_t = E\left[\sum_{\tau=0}^{\infty}\frac{e_{t+\tau}}{(1+r)^{\tau}}|I_t,\right] + \tilde{\varepsilon}_t, \tag{1}$$

where $r > 0$ represents the discount rate of the stock. The variable $\tilde{\varepsilon}_t$ has an expected value of zero and represents random market fluctuations around the intrinsic value of the firm.

As soon as the market price forms, the incumbent CEO retires and consumes the payoff granted by his compensation contract W_t. Each period is identical in its structure and gets repeated infinitely. The model description is now complete. The time line in figure 1 summarizes the sequence of events in each period and table 1 summarizes the notations used.

To identify the strategies that would arise in the absence of the horizon-problem, we now determine the benchmark strategies of a long-horizon CEO (i.e., a CEO who is willing to continue serving in the next period and thus does not face the horizon problem). In any time period, a long-horizon CEO can be motivated to choose strategies that maximize expected cash flows (net of costs) over the remainder of the firm's life. This is achieved by the standard solution of granting him firm ownership. The following lemma describes the resulting strategies in a given period t.

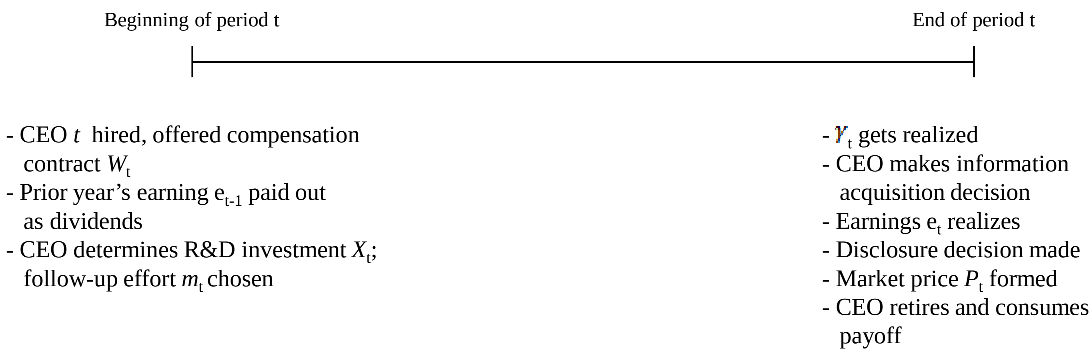

Figure 1: Time-line of activities in any time period t

Lemma 1 *A long-horizon CEO's benchmark strategies X_t^B, m_t^B and γ^B in period t are given by:*

R&D investment satisfies $G'\left(X_t^B\right) = \dfrac{(1+r)}{\bar{\theta}}$;

information is acquired when $\gamma_t < \gamma^B = \dfrac{\sigma_\theta^2}{2(1+r)}$;

$m_t^B = \theta_{t-1}$ *when* θ_{t-1} *is known;* $m_t^B = \bar{\theta}$ *when* θ_{t-1} *is not known; and*

the CEO fully discloses any information acquired.

The above R&D investment follows directly from the optimization of its net expected payoff. The follow-up action maximizes the payoff based on knowledge about prospects θ_{t-1} of the project. Information is acquired as long as cost γ_t of time and effort remains lower than the value of improved efficiency of the follow-up action. Finally, since the CEO has no particular incentive to influence short-term stock prices, he has no incentive to withhold any acquired information. Thus, full disclosure occurs.

In the analysis that follows, we compare these strategies with those of a CEO approaching retirement.

3 Horizon problem

Before proceeding with the analysis, we delineate the distinction between a long-horizon and a retiring CEO. A long-horizon CEO's interests are directly aligned with the firm's future. Since he remains employed with the firm when the future arrives, his (future) payoff and incentives can be made sensitive to the firm's future performance. Whereas, a CEO approaching retirement is not around when the future arrives. Thus, his motivation to contribute to the firm's future arises from the sensitivity of his payoff to stock price. In this section, we describe how disclosure incentives limit the extent to which a firm can use stock based compensation for motivating forward looking decisions from a CEO.

To emphasize the notion that the horizon problem persists independent of moral hazard issues arising from the separation of ownership and control, we initially conduct the analysis for a CEO who owns 100% of the firm. We subsequently extend the analysis to a CEO under a formal agency arrangement.

Consider the setting in which the retiring CEO owns 100% of the firm. The strategies in this game are determined by a sequential equilibrium. Since each period is identical in this infinitely repeated game, we envisage an equilibrium with identical strategies in each of the infinite periods.

In each period, the CEO begins with the R&D investment decision. Next, he chooses the follow-up effort for the project developed by his predecessor. Then, at the end of the period, he decides whether to become privately informed about the prospects of the R&D project. After that, he determines whether to voluntarily disclose any information that he possesses. Finally, once a competitive equity market sets the price contingent on his disclosure (or lack thereof), he transfers firm ownership to the next generation CEO. Since each period is identical, we consider a representative period t, for which we establish an equilibrium through the process of backward induction.

3.1 Managerial follow-up action

Although, the follow-up action does not occur last in period t, we consider it first to determine CEO_{t+1}'s choice m_{t+1}, which bears relevance to the other actions of CEO_t. The efficiency of this action hinges on information about future prospects θ_t. If CEO_t discloses information about θ_t, CEO_{t+1} makes an informed decision pertaining to the follow-up action m_{t+1}. Else, he makes a rational inference about prospects of the project and determines follow-up action accordingly. Solving for the follow-up action under both circumstances, we obtain:

$$\begin{aligned} m_{t+1} &= \theta_t \text{ if } \theta_t \text{ was disclosed; and} \\ &= \theta^{ND} \text{ if } \theta_t \text{ was not disclosed.} \end{aligned}$$

where $\theta^{ND} = E[\theta|\text{no disclosure}]$ (derived in the following sub-sections).

3.2 Equity price formation

Next, we deriving the stock price formed at the end of period t. This requires us to consider the impact of each feasible disclosure policy on stock value. To this end, first suppose that the CEO discloses θ_t. Based on this disclosure and all other public information, the stock price evolves as follows:

$$P_t(\theta_t) = e_t + E\left[\sum_{\tau=1}^{\infty} \frac{e_{t+\tau}}{(1+r)^{\tau}} | I_t\right] + \tilde{\varepsilon}_t.$$

Since we consider 100% CEO-ownership, compensation W_t that the CEO pays himself is largely inconsequential for his total payoff. For expositional convenience, we assume that the compensation always equals his *ex ante* expected effort cost.[6] Enhancing compensation beyond this level reduces current earning e_t and stock price by an equal amount, and the next CEO's immediate dividend falls by the same amount, leaving all parties completely unaffected.

The above expression expands to:

$$P_t(\theta_t) = e_t + \frac{Y_{t+1}(\theta_t) - E[X_{t+1} + W_{t+1}]}{(1+r)} + E\left[\sum_{\tau=2}^{\infty} \frac{e_{t+\tau}}{(1+r)^{\tau}}\right] + \tilde{\varepsilon}_t, \tag{2}$$

This pricing rule takes into account that the market learns future revenues $Y_{t+1}(\theta_t)$ from the disclosure. The market estimates other components of firm value by assuming that future CEOs will rationally follow the equilibrium path.

Next, suppose that CEO$_t$ makes no disclosure. Then, the market cannot distinguish between whether the CEO is not informed or whether he is informed but is strategically withholding his

[6] This assumption simply allows us to represent stock price purely as a function of future earnings. Absent compensation payments, stock prices will represent future cash flows net of expected managerial costs, leading to the exact same valuation.

information. In either case, the market values the firm at $P_t\left(ND\right)$ as follows:

$$P_t\left(ND\right) = e_t + \frac{Y_{t+1}\left(\theta^{ND}\right) - E\left[X_{t+1} + W_{t+1}\right]}{(1+r)} + E\left[\sum_{\tau=2}^{\infty} \frac{e_{t+\tau}}{(1+r)^{\tau}}\right] + \tilde{\varepsilon}_t, \tag{3}$$

where θ^{ND} is the market's assessment of the expected value of θ_t given that no disclosure occurs. This assessment rationally takes into account that no disclosure can mean either that the incumbent CEO lacks information, or that he possesses information that he chose to withhold.

The pricing functions in (2) and (3) differ only in their assessments of next period revenues Y_{t+1}. All other components of firm value remain identical.

3.3 Discretionary disclosure

Expressions (2) and (3) fully characterize the firm's stock price as a function of the CEO's disclosure strategy. We now derive this strategy.

If the CEO has not acquired any information from the previous decision node, naturally the question of disclosure does not arise. But if he has already acquired information about future prospects θ_t, then he discloses strategically, aiming to maximize price P_t. He only discloses signals θ_t that satisfy $P_t\left(\theta_t\right) > P_t\left(ND\right)$. Since price $P_t\left(\theta_t\right)$ increases with the disclosed signal θ_t, there exists a threshold θ^*, such that for all signals $\theta_t > \theta^*$, disclosure occurs. Any signal that satisfies $\theta_t < \theta^*$ will not be disclosed. When the signal θ_t equals θ^*, the CEO is indifferent between withholding and disclosing. Our convention assumes that he discloses the signal $\theta_t = \theta^*$. Given the pricing functions in (2) and (3), we solve for the CEO's disclosure threshold θ^* to obtain:

$$\theta^* = \theta^{ND}.$$

This disclosure threshold suggests that if the CEO believes that non-disclosure leads the market to estimate future prospects at θ^{ND}, then he would not disclose any information that guides the market's estimate any lower.

For the market's estimate to be rational, it must correctly anticipate the CEO's disclosure threshold θ^*, form a rational belief about the CEO's likelihood of being informed, and then determine θ^{ND}. Letting p denote the market's belief of the probability with which the CEO is informed, we obtain:[7]

$$\theta^{ND} = \frac{(1-p)\,\bar{\theta} + p\int_0^{\theta^*} \theta_t d\Phi(\theta_t)}{(1-p) + p\int_0^{\theta^*} d\Phi(\theta_t)}.$$

Of course, in equilibrium, the market's assessment θ^{ND} is identical to the CEO's belief θ^* of the market's assessment, so we have:

$$\theta^* = \frac{(1-p)\,\bar{\theta} + p\int_0^{\theta^*} \theta_t d\Phi(\theta_t)}{(1-p) + p\int_0^{\theta^*} d\Phi(\theta_t)}.$$

Some simple manipulations of the above equation yield:[8]

$$\theta^* = \bar{\theta} - \frac{p}{(1-p)} \int_0^{\theta^*} \Phi(\theta_t)\, d(\theta_t)\,. \tag{4}$$

3.4 Information acquisition

Having characterized the disclosure strategy, we can now examine the CEO's information acquisition decision. A long-horizon CEO acquires information to improve the efficiency of the follow-up action m_{t+1}, whereas a retiring CEO acquires information to maximize stock price.

The first step in determining the strategy of a retiring CEO entails estimating the expected stock price he commands when he becomes informed:

$$E\left[P_t|\text{Information is acquired}\right] = \int_0^{\theta^*} P_t(ND)\, d\Phi(\theta_t) + \int_{\theta^*}^{\infty} P_t(\theta_t)\, d\Phi(\theta_t)\,.$$

This expression follows from the expectation that the equilibrium disclosure strategy θ^* will be adhered to.

The next step involves evaluating the stock value he can command from remaining uninformed. Of course, being uninformed precludes any disclosure, and so results in stock price $P_t(ND)$.

The final step, for any given realization of γ_t, involves weighing the payoffs of the two possible

[7] The market's belief about p has to be rational. We derive its value subsequently in section 3.4.
[8] The determination of this threshold follows Jung and Kwon (1988) and Shavell (1994).

strategies with the cost γ_t of becoming informed. He becomes informed if and only if:

$$\int_0^{\theta^*} P_t\left(ND\right) d\Phi\left(\theta_t\right) + \int_{\theta^*}^{\infty} P_t\left(\theta_t\right) d\Phi\left(\theta_t\right) - \gamma_t \geq P_t\left(ND\right).$$

We solve for the cost threshold γ^* below which he becomes informed, obtaining:[9]

$$\gamma^* = \int_{\theta^*}^{\infty} \left\{ \frac{\left(\theta_t - \theta^*\right) G\left(X_t\right)}{\left(1+r\right)} \right\} d\Phi\left(\theta_t\right) + \int_{\theta^*}^{\infty} \left\{ \frac{\theta_t^2 - \left(\theta^*\right)^2}{2\left(1+r\right)} \right\} d\Phi\left(\theta_t\right) \tag{5}$$

The RHS of equation (5) represents the CEO's incremental benefit from becoming informed.[10] The first term directly relates to R&D investment X_t and represents the CEO's "option value" of acquiring information. This term represents the expected higher valuation that the CEO can receive for his initial investment X_t through selective disclosure. The second term reflects the expected value from efficiency gains by sharing the information for follow-up action m_{t+1}. Proposition 1 examines how this maps into the CEO's propensity to acquire information.

Proposition 1 *A retiring CEO is better informed about the firm's future prospects than a benchmark long-horizon CEO, i.e.,* $\gamma^* > \gamma^B$.

Proposition 1 establishes that a retiring CEO has better knowledge about the future than a (possibly younger and less experienced) long-horizon CEO. The superior wisdom is usually attributed to exogenous factors such as age and experience. Whereas, proposition 1 indicates that this advantage arises endogenously through his willingness to actively acquire information. As indicated earlier, relative to a long-horizon CEO, he derives additional value from information due to the option of selective disclosure (the option value of information), so he also acquires more information. It is important to note that although he has a lot of knowledge about the future, it is not always used in the best interests of the firm. Rather, it is used to bolster stock price through strategic disclosure.

[9] This follows from taking other equilibrium strategies as given, substituting for $P_t\left(\theta_t\right)$ and $P_t\left(ND\right)$ from (2) and (3), and solving for the largest value of γ_t which satisfies the preceding expression.

[10] Since the market rationally anticipates the CEO's incentives, it anticipates the threshold γ^*. Thus, in equilibrium the market's belief p pertaining to the likelihood of the CEO being informed satisfies $p = F\left(\gamma^*\right)$.

Proposition 2 *A retiring CEO is more likely than a long-horizon CEO to disclose favorable news (i.e., signals $\theta_t \geq \theta^*$), but less likely than a long-horizon CEO to disclose unfavorable news (i.e., signals $\theta_t < \theta^*$).*

Proposition 2 predicts how a retiring CEO's disclosure policy deviates from that of a long-horizon CEO. A retiring CEO is better informed than a long-horizon CEO, so he is naturally more likely to be informed of a favorable signal (i.e., a signal $\theta_t \geq \theta^*$). Since he fully discloses all favorable signals, the frequency of favorable disclosures heighten when the CEO approaches retirement.

Although a retiring CEO is also more likely to be informed of unfavorable signals than a long-horizon CEO, he strategically withholds those signals, whereas a long-horizon CEO has no incentive to disclose selectively. Thus, the likelihood of a retiring CEO disclosing an unfavorable signal is lower than that of a long-horizon CEO.

3.5 R&D investment

Finally, we consider the R&D investment choice X_t. The CEO takes as given the optimal strategies in other decision nodes and chooses the investment that maximizes his expected payoff, i.e., he solves:

$$\underset{X_t}{Max} \left[F(\gamma^*) \left\{ \int_0^{\theta^*} P_t^{ND} d\Phi(\theta_t) + \int_{\theta^*}^{\infty} P_t(\theta_t) d\Phi(\theta_t) \right\} + (1 - F(\gamma^*)) P_t^{ND} \right] - E\left[\frac{m_t^2}{2}\right] - \int_0^{\gamma^*} \gamma dF(\gamma).$$

The first expression in square brackets represents the expected market value of the firm assuming that the equilibrium strategies are adhered to in subsequent decision nodes. The remaining expressions represent the CEO's expected personal cost from his managerial efforts. The following proposition describes the solution to this maximization problem.

Proposition 3 *The level of R&D investment that maximizes firm value is below the benchmark investment of a long-horizon CEO, i.e., $X_t < X_t^B$.*

Although with 100% stock ownership, a retiring CEO fully internalizes the effect of R&D investment on the firm's future cash flows, he finds curtailing R&D investment to be optimal.

The best way to see why R&D investment is scaled back is to note that it elicits more disclosures. The CEO withholds unfavorable information only because it has an adverse effect on stock price.

As the scale of the R&D project decreases, disclosure of a given unfavorable signal causes a smaller impact on stock price. This makes withholding information less attractive for the CEO. As more information gets disclosed, the efficiency of the follow-up action improves, contributing to firm value. Moreover, the CEO's incentive to over acquire information for its option value is also curtailed. The value of these twin benefits more than compensates for the diminished payoff from scaling back R&D investment.

Remark 1 *If disclosure is either prohibited, or the CEO is forced to fully disclose his information, then R&D investment equals the benchmark* X_t^B.

R&D reductions encourage the CEO to disclose more information. But when a certain disclosure policy can be enforced, R&D investment plays no incentive role in the CEO's disclosure, so R&D reductions become unnecessary. R&D investment efficiency is achieved under both extremes - full disclosure as well as no-disclosure. Since the objective of scaling back R&D is to motivate more disclosures, naturally there is no need for R&D reductions if full disclosure can be enforced. What is interesting is that R&D investment efficiency is achieved even in a no-disclosure regime. This is because reducing R&D cannot motivate a change in disclosure policy in this regime. Disclosures never occur.

This remark highlights the idea that R&D reductions arise when CEOs hold disclosure discretion, and not necessarily when public information is limited. Once the discretion is taken away, R&D reductions become unnecessary. Thus, the key to improving R&D spending efficiency is to limit the CEO's option value from discretionary disclosure. Proposition 3 demonstrates that scaling back R&D investment is one way to dilute his option. The CEO derives his option from stock ownership, and his incentive to manipulate stock price arises from his payoff being sensitive to stock price. This observation raises an important question: can an agency arrangement with reduced dependence on stock based measures provide better motivation to invest in R&D than offering him full ownership of the firm?

3.6 Agency arrangement

To answer the preceding question, consider an agency arrangement where shareholders hire a new manager for each period. As before, we consider a representative period t. Before proceeding further, we define the ex-dividend price $P_t^{ex} = P_t - e_t$ (recall that all earnings are paid out as dividends at the beginning of the following period). It is more convenient to use the ex-dividend price in the compensation contract than the cum-dividend price, which decreases with the compensation payment W_t. Using the ex-dividend price avoids the circularity of the compensation payment being a function of a variable that changes with the compensation payment itself.[11]

To motivate the CEO, let shareholders rely on compensation contract W_t of the following form:

$$W_t = \alpha + \beta_1 G(X_t) + \beta_2 X_t + \beta_3 P_t^{ex} + \beta_4 Y_t$$

With this compensation contract, the firm's shareholders have enough degrees of freedom to induce any level of investment X_t, effort m_t, and information acquisition threshold γ^*. However, they do not have full control over the manager's disclosure threshold θ^*. In this contract, weights β_1 and β_2 jointly determine the R&D investment X_t. Given that X_t remains directly contractible, any R&D investment choice can easily be motivated. Information acquisition (or, in other words, the threshold γ^*) is motivated by the stock based incentive weight β_3, and follow up effort m_t is motivated through incentive weight β_4 on revenues.

Now, the shareholders' problem in period t can be formulated as follows:

[11] A contract using the cum-dividend price can easily deal with this circularity, but the incentive weights of such a contract become difficult to interpret.

$$\underset{W_t}{Max} E\left[\sum_{\tau=0}^{\infty}\frac{e_{t+\tau}}{(1+r)^{\tau}}|W_t\right] \tag{6}$$

Subject to:

$$X_t \in \underset{\hat{X}_t}{\arg\max} E\left[W_t - \frac{m_t^2}{2} - \int_0^{\gamma^*}\gamma dF(\gamma)\,|\hat{X}_t, m_t, \gamma^*, \theta_t^*\right] \tag{7}$$

$$m_t \in \underset{\hat{m}_t}{\arg\max} E\left[W_t - \frac{\hat{m}_t^2}{2} - \int_0^{\gamma^*}\gamma dF(\gamma)\,|X_t, \hat{m}_t, \gamma^*, \theta_t^*\right] \tag{8}$$

$$\theta_t^* \in \underset{\hat{\theta}^*}{\arg\max} E\left[W_t - \frac{m_t^2}{2} - \int_0^{\gamma^*}\gamma dF(\gamma)\,|X_t, m_t, \gamma^*, \hat{\theta}^*\right] \tag{9}$$

$$\gamma_t^* \in \underset{\hat{\gamma}^*}{\arg\max} E\left[W_t - \frac{m_t^2}{2} - \int_0^{\hat{\gamma}^*}\gamma dF(\gamma)\,|X_t, m_t, \hat{\gamma}^*, \theta^*\right] \tag{10}$$

$$E\left[W_t - \frac{m_t^2}{2} - \int_0^{\gamma^*}\gamma dF(\gamma)\,|X_t, m_t, \gamma_t^*, \theta_t^*\right] \geq 0, \tag{11}$$

where (6) describes the shareholders' compensation contract choice that maximizes the firm's expected future cash flows. (7) to (10) describe the CEO's individual action choices in response to the compensation contract. Finally, (11) represents the manager's participation constraint that the expected compensation payment implied by the contract exceed the expected personal costs of his efforts.

Now, we formally establish that the separation of ownership and managerial control implied by the above contract strictly dominates owner-management in motivating better efficiency.

Proposition 4 *When the CEO has a limited tenure, the value of a firm under an agency arrangement exceeds that of a firm that is owner-managed.*

Stock based compensation provides incentives for R&D investments, but the drawback is that it also motivates selective disclosures for manipulating stock prices. The R&D investment that gets motivated by 100% stock ownership can equally be motivated by a contract with a smaller incentive weight on stock price, but accompanied by a positive weight on a direct R&D based measure. Such a contract reduces the CEO's incentive to manipulate stock price and leads to efficiency gains in the follow-up action.

This proposed agency arrangement finds empirical support with Cheng (2004), who finds that compensations of CEOs close to retirement are made sensitive to actual R&D investments, whereas those of long-horizon CEOs' are not. He argues that this arrangement brings about R&D investment efficiency from CEOs approaching retirement. Through proposition 4 we show that the improved efficiency is achieved from curtailing CEO incentives to manipulate stock prices.

Interestingly, proposition 4 also refutes the general belief that 100% management ownership maximizes firm value. This conventional wisdom does not ring true when stock price can be manipulated by the CEO. The firm is better served by separating ownership and management control, for allowing a manager with less than 100% ownership share in the firm to perform disclosure duties mitigates the incentives for selective disclosure.

Our result relates to Fershtman and Judd (1987), who were the first to show that agency can contribute to firm value. In their study, the negative effects of oligopolistic competition on a firm's profits are mitigated by hiring managers and strategically manipulating their incentives through an agency contract. Fershtman, Judd and Kalai (1991) also discuss a general case in an oligopolistic setting where the delegation of decision power to agents can achieve a Pareto improvement. Our result contributes to this literature, which identifies conditions under which agency enhances firm value.

The above discussion brings us to the next logical question. Since R&D investment is now explicitly contractible, can the benchmark long-horizon R&D investment be enforced through a forcing contract? Proposition 5 answers this question.

Proposition 5 *Even though R&D investment X_t is directly contractible, R&D investment remains below the choice of a long-horizon manager.*

Information acquisition is valuable and is motivated by the presence of a market price based measure in the compensation contract. And, a compensation contract that includes a market-price based measure leads to price manipulation through selective disclosure. As we have already seen, reductions in R&D spending becomes necessary to mitigate these perverse incentives.

4 Other possible solutions

In this section, we consider other possible solutions to mitigate the horizon problem.

4.1 Outgoing CEO choosing the follow-up action

The main inefficiency from the horizon problem is that the outgoing CEO is not forthcoming with his private information to further his successor's follow-up decision. But the outgoing CEO himself is equipped to perform the follow-up action, so we examine if asking him to perform the follow-up action rather than allowing his successor to do so would result in better use of information. Admittedly, some follow up actions are not publicly observable, so motivating the outgoing CEO to perform them raises serious difficulties. But many other actions, such as marketing decisions, clinical trials decisions,[12] patent applications, etc., are publicly observable. The outgoing CEO can be motivated to perform them.

To determine the effect of the same CEO acquiring information and following-up on the project, assume that CEO$_t$ performs the follow up effort just prior to the end of period t, rather than CEO$_{t+1}$ in the beginning of period $t+1$. For consistency label this action as m_{t+1}, even though, it is performed at the end of period t. In this case, CEO$_t$'s follow up action given a private signal is identical to that his successor chooses in section 3.1 (except to the extent that timing differences lead to differences in discounting).

The point is - the efficiency of follow up effort m_{t+1} hinges not on what information CEO$_t$ possesses, but on what he ultimately discloses. Any information he does not disclose is ignored for the follow-up action; he chooses the same follow-up action an uninformed CEO would. This is to avoid revealing the adverse private information through his actions. Only information that he discloses is used for guiding the follow-up action.

To illustrate the point, consider a situation where a CEO privately learns that the project is not viable and that abandoning it is desirable. Disclosing this news has an adverse effect on stock price, so the CEO will not disclose it. Equally, the CEO will not abandon the project, for it reveals his private information. He will, instead choose a follow up action that continues to develop the

[12] Pharmaceutical and biotechnology firms are legally required by the The FDA Modernization Act of 1997 to register and publicly list all ongoing clinical trials, as well as provide details, such as, about the scale of the trial, including the number of participants, etc. These details are publicly available at clinicalTrials.gov.

project - to signal to the market that the project may succeed.

Proposition 6 (a) *The disclosure threshold when CEO$_t$ performs the follow-up action is* θ^*, *the same as that derived in section 3.*

(b) *CEO$_t$'s follow-up actions are given by:*

$$\begin{aligned} m_{t+1} &= \frac{\theta_t}{1+r} \text{ when } \theta_t \text{ is disclosed.} \\ &= \frac{\theta_t^{ND}}{1+r} \text{ when } \theta_t \text{ is not disclosed.} \end{aligned}$$

(c) *R&D investments are below that chosen by a benchmark long-horizon CEO.*

The central message is that asking the same CEO to perform the follow-up action and the information disclosure decision does not lead to any improvement in the follow-up action. Crucially, he will tailor the follow-up action to align with his disclosure policy, rather than with his private information.

This leads to an empirical prediction. A CEO approaching retirement is more likely than at other stages in his tenure to throw good money after bad to highlight the future in a positive light. This prediction receives empirical support from a recent study by Xu and Yan (2011) in the context of patent applications. This study finds that patents filed during a CEO's terminal year in office receive fewer subsequent citations than those filed earlier in his tenure.

This result is also related to Kanodia, Bushman and Dickaut (1989). They argue that a CEO may similarly escalate an earlier commitment without switching to a better alternative because switching may reveal private information about his human capital. The CEO does not switch to maintain his reputation. In our setting, the CEO chooses a sub-optimal follow-up action to maintain stock value.

4.2 Deferred compensation contracts

In principle, the CEO's horizon can be extended by linking his pay to future firm performance. A popular method of implementing this is to defer the CEO's compensation payments into the future.[13] In our model, consider offering the retiring CEO$_t$ 100% firm ownership, with the restriction

[13] See Eaton and Rosen (1983) for a general discussion of employing deferred compensation to mitigate managerial incentives for investing in short-term projects.

that he cannot sell his stake in the firm until after the end of period $t+1$, when the outcome of R&D investment X_t during his tenure is fully resolved. With this contract, the benchmark long-horizon outcomes can be achieved. However, such a deferred compensation contract is not without cost. First, the postponement of compensation payments into the future is valued less by the manager due to time value of money considerations. Thus, he may have to be compensated through other fixed payments. Second, such an arrangement eliminates the horizon problem only when the *entire* compensation payments get deferred. Such a restriction becomes impractical due to the effect it has on the manager's immediate consumption. As a result, we see deferment applied in practice only to a fraction of a manager's total compensation payment.[14] The effect of such deferment on the horizon problem is limited. For instance, if the CEO were allowed to sell 75% of his stock-ownership at the time of retirement and the sale of the balance 25% were deferred, the horizon problem is partially mitigated, but not completely resolved. Finally, since deferring any compensation puts a strain on the manager's immediate consumption, he may demand additional fixed payments as compensation, entailing further costs for the firm. These costs and limitations on deferred compensation reduces the extent to which it can be applied in practice, implying that the horizon problem is never completely defeated.

5 Conclusions

In this paper, we address the issue that CEOs curtail R&D investments during their final years in office. We show that such reductions in R&D spending arise not due to moral hazard, but due to the CEO's ability to manipulate stock prices through selective disclosure. Greater the R&D investment, greater the ability of CEOs to manipulate stock prices through selective disclosure. Thus, curtailing R&D investment happens to be in the best interest of shareholders, for it limits the extent to which CEOs manipulate stock prices.

6 References

[14] For example, a recent study by Cen (2011) finds that during the years 2006 to 2008, the mean deferred compensation, defined as the present value of total deferred compensation, for CEOs in S&P composite 1500 firms was only $2.2 million, out of the mean annual total compensation of $5.66 million.

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7 Appendix

7.1 Proof of lemma 1

The optimization problem in any period t can be written as:

$$\underset{X_t, m_t, \gamma_t^*}{Max} \; E\left[e_t\right] - E\left[W_t\right] + \frac{E\left[e_{t+1}\right]}{1+r} + \sum_{\tau=2}^{\infty} \frac{E\left[e_{t+\tau}\right]}{(1+r)^{\tau}}$$

Expanding,

$$\underset{X_t, m_t, \gamma_t^*}{Max} \; E\left[Y_t\right] - X_t - E\left[W_t\right] + E\left[\frac{Y_{t+1} - X_{t+1} - K_{t+1}}{1+r}\right] + \sum_{\tau=2}^{\infty} \frac{E\left[e_{t+\tau}\right]}{(1+r)^{\tau}}$$

Ignoring the terms independent of the actions in period t, the above reduces to:

$$\underset{X_t, m_t, \gamma_t^*}{Max} \; E\left[Y_t\right] - X_t - E\left[W_t\right] + E\left[\frac{Y_{t+1}}{1+r}\right]$$

Expanding further,

$$\underset{X_t, m_t, \gamma_t^*}{Max} \; E\left[\tilde{\theta}_{t-1}\left\{G\left(X_{t-1}\right) + m_t\right\}\right] - X_t - E\left[W_t\right] + E\left[\frac{\tilde{\theta}_t\left\{G\left(X_t\right) + m_{t+1}\right\}}{1+r}\right]$$

The first order conditions with respect to X_t yields:

$$\frac{\bar{\theta} G'\left(X_t^{FB}\right)}{1+r} = 1.$$

Similarly, the first order condition w.r.t. m_t gives (after considering the cost $\frac{m_t^2}{2}$ included in W_t):

$$\begin{aligned} m_t^{FB} &= \theta_{t-1} \text{ if } \theta_{t-1} \text{ is known;} \\ &= \bar{\theta} \text{ otherwise.} \end{aligned}$$

Next, we solve for γ^*. Informatuion about θ_t is acquired if the cost of acquiring the information is less than the expected benefit. Without information, the next period effort m_{t+1} will equal $\bar{\theta}$. Thus, the net payoff from effort in the next period will be: $\frac{(\bar{\theta})^2}{2}$. If information is acquired, the next period effort m_{t+1} will equal θ_t. Thus, the net payoff from the effort in the next period will equal $\frac{E[\theta_t^2]}{2}$. Thus, information will be acquired when $\gamma_t < \frac{E[\theta_t^2]-(\bar{\theta})^2}{2(1+r)}$. Thus, $\gamma^{FB} = \frac{\sigma_\theta^2}{2(1+r)}$. ■

7.2 Proof of proposition 1

First, observe that $\theta^* > 0$ (follows from (4))

Next, notice that $\theta^{ND} = \theta^* < \bar{\theta}$ (again, follows from (4). $\theta^{ND} = \bar{\theta}$ if and only if there is full disclosure)

$$\text{Thus, } \theta^* G(X_t) + \frac{(\theta^*)^2}{2} < \bar{\theta} G(X_t) + \frac{(\bar{\theta})^2}{2} (\text{since } G(X_t) \geq 0 \text{ for all } X_t)$$

This implies, and is implied by:

$$\int_0^\infty \left[\left\{ \theta_t G(X_t) + \frac{\theta_t^2}{2} \right\} - \left\{ \theta^* G(X_t) + \frac{(\theta^*)^2}{2} \right\} \right] d\Phi(\theta_t) > \int_0^\infty \left[\left\{ \theta_t G(X_t) + \frac{\theta_t^2}{2} \right\} - \left\{ \bar{\theta} G(X_t) + \frac{(\bar{\theta})^2}{2} \right\} \right] d\Phi(\theta_t)$$

Multiplying both sides by $\frac{1}{1+r}$ and simplifying the RHS,

$$\frac{1}{1+r} \int_0^\infty \left[\left\{ \theta_t G(X_t) + \frac{\theta_t^2}{2} \right\} - \left\{ \theta^* G(X_t) + \frac{(\theta^*)^2}{2} \right\} \right] d\Phi(\theta_t) > \int_0^\infty \left[\frac{\theta_t^2 - (\bar{\theta})^2}{2(1+r)} \right] d\Phi(\theta_t) = \frac{\sigma_\theta^2}{2(1+r)} = \gamma^{FB}$$

Again, since $\left\{ \theta G(X_t) + \frac{\theta^2}{2} \right\}$ increases in θ, we have:

$$\begin{aligned} \gamma^* &= \frac{1}{1+r} \int_{\theta^*}^\infty \left[\left\{ \theta_t G(X_t) + \frac{\theta_t^2}{2} \right\} - \left\{ \theta^* G(X_t) + \frac{(\theta^*)^2}{2} \right\} \right] d\Phi(\theta_t) \\ &> \frac{1}{1+r} \int_0^\infty \left[\left\{ \theta_t G(X_t) + \frac{\theta_t^2}{2} \right\} - \left\{ \theta^* G(X_t) + \frac{(\theta^*)^2}{2} \right\} \right] d\Phi(\theta_t) > \gamma^{FB} \end{aligned}$$

The equality follows from the definition of γ^* in (5). The first inequality follows because $\left\{ \theta_t G(X_t) + \frac{\theta_t^2}{2} \right\} - \left\{ \theta^* G(X_t) + \frac{(\theta^*)^2}{2} \right\} < 0$ for all values of $\theta_t \in [0, \theta^*)$. The second inequality is carried forward from the previous equation. Thus, we have shown that $\gamma^* > \gamma^{FB}$, proving the claim. ■

7.3 Proof of proposition 2

That the frequency of good news disclosures is greater than in the benchmark setting follows from $F(\gamma^*) > F(\gamma^B)$. That frequence of bad news disclosures is less than the benchmark follows from the observation that such news is always witheld by a short-horizon manager. ■

7.4 Proof of proposition 3

First, observe from (5) that γ^* increases with X_t. Thus, we have:

$$\frac{d\gamma^*}{dX_t} > 0. \tag{12}$$

Next, consider the owner-manager's optimization problem for determining investment X_t. He is maximizing the expected market price net of his expected costs K_t, i.e.,

$$\underset{X_t}{Max}\ F(\gamma^*)\left[\int_0^{\theta^*} P_t^{ND} d\Phi(\theta_t) + \int_{\theta^*}^{\infty} P_t(\theta_t)\, d\Phi(\theta_t)\right] + (1 - F(\gamma^*))\, P_t^{ND} - \frac{m_t^2}{2} - \int_0^{\gamma^*} \gamma dF(\gamma)$$

Expanding the pricing functions (i.e., expanding the e_t and e_{t+1} terms embedded in the pricing function) and applying the law of iterated expectations (i.e., because the market is rational, we have $F(\gamma^*)\left[\int_0^{\theta^*} \theta^* d\Phi(\theta_t) + \int_{\theta^*}^{\infty} \theta_t d\Phi(\theta_t)\right] + (1 - F(\gamma^*)) \int_0^{\infty} \theta^* d\Phi(\theta_t) = \bar{\theta}$. The first term in the second line below directly follows from this equality.)

$$\underset{X_t}{Max}\ Y_t - X_t - \frac{m_t^2}{2} - \int_0^{\gamma^*} \gamma_t dF(\gamma_t) +$$
$$\frac{1}{1+r}\left[\bar{\theta}G(X_t) + F(\gamma^*)\left\{\int_0^{\theta^*} \frac{(\theta^*)^2}{2} df(\theta_t) + \int_{\theta^*}^{\infty} \frac{\theta_t^2}{2} df(\theta_t)\right\} + (1 - F(\gamma^*))\frac{(\theta^*)^2}{2} - X_{t+1} - E[W_{t+1}]\right]$$
$$+E\left[\sum_{\tau=2}^{\infty} \frac{e_{t+\tau}}{(1+r)^{\tau}}\right]$$

Observe that each of Y_t, m_t, X_{t+1}, K_{t+1}, and $E\left[\sum_{\tau=2}^{\infty} \frac{e_{t+\tau}}{(1+r)^{\tau}}\right]$ are independent of X_t and hence drop out of the maximization problem. Thus, the above problem is equivalent to (after some rearrangement):

$$\underset{X_t}{Max}\ \left[\frac{\bar{\theta}G(X_t)}{(1+r)}\right]+F(\gamma^*)\left\{\int_0^{\theta^*}\frac{(\theta^*)^2}{2(1+r)}df(\theta_t)+\int_{\theta^*}^{\infty}\frac{\theta_t^2}{2(1+r)}df(\theta_t)\right\}+(1-F(\gamma^*))\frac{(\theta^*)^2}{2(1+r)}-X_t-\int_0^{\gamma^*}\gamma_t dF(\gamma_t)$$

The first order condition yields:

$$\frac{\bar{\theta}G'(X_t)}{(1+r)}+\frac{d\gamma^*}{dX_t}\cdot\frac{d}{d\hat{\gamma}_{|\hat{\gamma}=\gamma^*}}\left[F(\hat{\gamma})\left\{\int_0^{\theta^*}\frac{(\theta^*)^2}{2(1+r)}d\Phi(\theta_t)+\int_{\theta^*}^{\infty}\frac{\theta_t^2}{2(1+r)}d\Phi(\theta_t)\right\}+\frac{(1-F(\hat{\gamma}))(\theta^*)^2}{2(1+r)}-\int_0^{\hat{\gamma}}\gamma dF(\gamma)\right]=1 \tag{13}$$

Taking the derivative,

$$\frac{\bar{\theta}G'(X_t)}{(1+r)}+\frac{d\gamma^*}{dX_t}\cdot\left[dF(\gamma^*)\left\{\int_0^{\theta^*}\frac{(\theta^*)^2}{2(1+r)}d\Phi(\theta_t)+\int_{\theta^*}^{\infty}\frac{\theta_t^2}{2(1+r)}d\Phi(\theta_t)-\frac{(\theta^*)^2}{2(1+r)}-\gamma^*\right\}\right]=1$$

Simplifying,

$$\frac{\bar{\theta}G'(X_t)}{(1+r)}+\frac{d\gamma^*}{dX_t}\cdot\left[dF(\gamma^*)\left\{\int_{\theta^*}^{\infty}\frac{\theta_t^2-(\theta^*)^2}{2(1+r)}d\Phi(\theta_t)-\gamma^*\right\}\right]=1$$

It follows from (5) that:

$$\int_{\theta^*}^{\infty}\frac{\theta_t^2-(\theta^*)^2}{2(1+r)}d\Phi(\theta_t)-\gamma^*<0 \tag{14}$$

(14), taken together with (12) implies that:

$$\frac{\bar{\theta}G'(X_t)}{1+r}>1 \text{ or } G'(X_t)>\frac{1+r}{\bar{\theta}}.$$

Since G is an increasing and concave function, under-investment (i.e., $X_t < X^{FB}$) occurs if and only if $G'(X_t) > G'\left(X^{FB}\right) = \frac{(1+r)}{\bar{\theta}}$. This completes the proof. ■

7.5 Proof of proposition 4

To prove the proposition it is sufficient to show that there exists one contract W_t for which the expected value of the firm exceeds that under a compensation contract that offers 100% ownership.

Let the equilibrium strategies chosen by the CEO under 100% ownership be denoted by X_t^o, m_t^o and γ_t^{*o}.

Claim: Firm value under a contract that motivates m_t^o, X_t^o and $(\gamma_t^{*o} - \varepsilon)$ where $\varepsilon \to 0$ is higher than with 100% CEO ownership.

Proof: That value increases by motivating a level of information acquisition lower than γ^* follows directly from (14) above.

The above Claim establishes the proposition. ■

7.6 Proof of proposition 5

In solving the shareholders' problem, first consider the manager's response to any compensation contract W_t, i.e., consider (8) to (10) and the investment X_t.

(i) His choice of X_t is dictated by the shareholders. He simply chooses the investment X_t demanded by the shareholders.

(ii) His effort m_t is the solution to the maximization problem (8), which after expanding and dropping all variables unrelated to effort m_t reduces to :

$$\underset{m_t}{Max} E\left[\beta_2 \theta_{t-1} m_t\right] - \frac{m_t^2}{2}.$$

Depending on whether or not information about θ_{t-1} is available, the effort choice will equal:

$$\begin{aligned} m_t &= \beta_2 \theta_{t-1} \text{ when } \theta_{t-1} \text{ is disclosed by his predecessor; and} \\ &= \beta_2 \theta^{ND} \text{ when } \theta_{t-1} \text{ is not disclosed by his predecessor,} \end{aligned}$$

where, θ^{ND} is the expected value of θ given no disclosure by the predecessor. Again, as in the full ownership case, θ^{ND} will equal θ^*, the equilibrium disclosure threshold.

(iii) Next, consider his disclosure threshold θ^*. For any given compensation contract, as long as $\beta_1 > 0$, the manager has an incentive to maximize the market price of the firm. Then, it is obvious that there will not be full disclosure. Thus, $\theta^* > 0$. (That $\theta^* > 0$ is sufficient to establish the proposition. We do not need to derive the actual value of θ^*).

(iv) Finally consider his information acquisition cost threshold γ^*. Taking as given his own choice of θ^*, the solution to his optimization problem (10) yields:

$$\gamma^* = \beta_1 \int_{\theta^*}^{\infty} \left\{ \frac{(\theta_t - \theta^*) G(X_t)}{(1+r)} \right\} d\Phi(\theta_t) + \beta_1 \int_{\theta^*}^{\infty} \left\{ \frac{\theta_t^2 - (\theta^*)^2}{2(1+r)} \right\} d\Phi(\theta_t) \tag{15}$$

Now, consider the shareholders contracting problem in (7), namely of choosing α, β_1 and β_2.

(a)The choice of α merely ensures that constraint (11) holds with equality, and this choice does not directly affect the action choices of the manager.

(b) It is easy to see that β_2 takes the value 1 in order to motivate the optimal level of follow-up effort m_t.

(c) Now consider the choice of β_1.

Claim: $\beta_1 \in (0,1)$.

Proof of claim: If $\beta_1 = 0$, there is no information acquisition. It is easy to see that at least some information acquisition is valuable. Thus, we will have $\beta_1 > 0$.

Now, we need to show that $\beta_1 < 1$ in equilibrium.

For a given choice of X_t and an induced level of m_t, the optimal choice of β_1 for the shareholders should satisfy:

$$\frac{d}{d\beta_1} E\left[\sum_{\tau=0}^{\infty} \frac{e_{t+\tau}}{(1+r)^{\tau}} | X_t, m_t \right] = 0$$

Expanding,

$$\frac{d}{d\beta_1} \left\{ E\left[Y_t - X_t - W_t\right] + E\left[\frac{Y_{t+1} - X_{t+1} - W_{t+1}}{(1+r)} \right] + \sum_{\tau=2}^{\infty} \frac{e_{t+\tau}}{(1+r)^{\tau}} \right\} = 0$$

Removing the terms whose derivative with respect to β_1 equal zero,

$$\frac{d}{d\beta_1} \left\{ E\left[-W_t\right] + E\left[\frac{Y_{t+1} - W_{t+1}}{(1+r)} \right] \right\} = 0$$

Since (11) holds with equality, we have $E[W_t] = \frac{m_t^2}{2} + \int_0^{\gamma^*} \gamma dF(\gamma)$. Substituting above, expanding the remaining terms, and removing the terms whose derivative equals zero,

$$\frac{d}{d\beta_1} \left\{ -\int_0^{\gamma^*} \gamma dF(\gamma) + F(\gamma^*) \left(\int_0^{\theta^*} \frac{(\theta^*)^2}{2(1+r)} df(\theta_t) + \int_{\theta^*}^{\infty} \frac{\theta_t^2}{2(1+r)} df(\theta_t) \right) + (1 - F(\gamma^*)) \frac{(\theta^*)^2}{2(1+r)} \right\} = 0$$

Or,

$$\frac{d\gamma^*}{d\beta_1}.\frac{d}{d\gamma^*}\left\{-\int\limits_0^{\gamma^*}\gamma dF(\gamma)+F(\gamma^*)\left(\int\limits_0^{\theta^*}\frac{(\theta^*)^2}{2(1+r)}df(\theta_t)+\int\limits_{\theta^*}^{\infty}\frac{\theta_t^2}{2(1+r)}df(\theta_t)\right)+(1-F(\gamma^*))\frac{(\theta^*)^2}{2(1+r)}\right\}=0$$

Simplifying and rearranging,

$$\frac{d\gamma^*}{d\beta_1}.\frac{d}{d\gamma^*}\left\{F(\gamma^*)\int\limits_{\theta^*}^{\infty}\frac{\theta_t^2-(\theta^*)^2}{2(1+r)}df(\theta_t)+\frac{(\theta^*)^2}{2(1+r)}-\int\limits_0^{\gamma^*}\gamma dF(\gamma)\right\}=0$$

Expanding the derivative,

$$\frac{d\gamma^*}{d\beta_1}.\frac{dF(\gamma^*)}{d\gamma^*}\left\{\int\limits_{\theta^*}^{\infty}\frac{\theta_t^2-(\theta^*)^2}{2(1+r)}d\Phi(\theta_t)-\gamma^*\right\}=0$$

That is, (since $\frac{d\gamma^*}{d\beta_1}\neq 0$ and $\frac{dF(\gamma^*)}{d\gamma^*}\neq 0$),

$$\gamma^*=\int\limits_{\theta^*}^{\infty}\frac{\theta_t^2-(\theta^*)^2}{2(1+r)}d\Phi(\theta_t)$$

Equating the above with (15), we have:

$$\beta_1\int\limits_{\theta^*}^{\infty}\left\{\frac{(\theta_t-\theta^*)G(X_t)}{(1+r)}\right\}d\Phi(\theta_t)+\beta_1\int\limits_{\theta^*}^{\infty}\left\{\frac{\theta_t^2-(\theta^*)^2}{2(1+r)}\right\}d\Phi(\theta_t)=\int\limits_{\theta^*}^{\infty}\frac{\theta_t^2-(\theta^*)^2}{2(1+r)}d\Phi(\theta_t)$$

Simplifying,

$$\beta_1\int\limits_{\theta^*}^{\infty}\left\{\frac{(\theta_t-\theta^*)G(X_t)}{(1+r)}\right\}d\Phi(\theta_t)+(\beta_1-1)\int\limits_{\theta^*}^{\infty}\left\{\frac{\theta_t^2-(\theta^*)^2}{2(1+r)}\right\}d\Phi(\theta_t)=0$$

If $\beta_1\geq 1$, then the LHS is strictly greater than 0, a contradiction. Thus, we must have $\beta_1<1$. This establishes the claim.

Finally, consider the shareholders' problem in (6), namely of what investment level X_t to enforce.

Taking as given the choices (7) to (10) and expanding (6), gives

$$\underset{X_t}{Max} E\left[Y_t - X_t - W_t\right] + E\left[\frac{Y_{t+1} - X_{t+1} - W_{t+1}}{1+r}\right] + E\left[\sum_{\tau=2}^{\infty} \frac{e_{t+\tau}}{(1+r)^{\tau}}\right]$$

The choice of α implies that the constraint (11) is satisfied with equality, i.e., $E\left[W_t\right] = \frac{m_t^2}{2} + \int_0^{\gamma^*} \gamma dF(\gamma)$. Substituting in the above, we have:

$$\underset{X_t}{Max} E\left[Y_t - X_t - \frac{m_t^2}{2} - \int_0^{\gamma^*} \gamma dF(\gamma)\right] + E\left[\frac{Y_{t+1} - X_{t+1} - W_{t+1}}{1+r}\right] + E\left[\sum_{\tau=2}^{\infty} \frac{e_{t+\tau}}{(1+r)^{\tau}}\right]$$

Expanding Y_{t+1} and dropping all terms unrelated to X_t from the maximization problem, we have:

$$\underset{X_t}{Max} - X_t - \int_0^{\gamma^*} \gamma_t dF(\gamma_t) + E\left[\frac{\theta_t G(X_t) + \theta_t m_{t+1} - \frac{m_{t+1}^2}{2}}{1+r}\right]$$

Taking as given the current manager's information acquisition threshold γ^*, disclosure threshold θ^* and the successor CEO's choices for m_t, the above can be rewritten as:

$$\underset{X_t}{Max} - X_t - \int_0^{\gamma^*} \gamma_t dF(\gamma_t) + \frac{\bar{\theta} G(X_t)}{1+r} + F(\gamma^*)\left\{\int_0^{\theta^*} \frac{(\theta^*)^2}{2(1+r)} df(\theta_t) + \int_{\theta^*}^{\infty} \frac{\theta_t^2}{2(1+r)} df(\theta_t)\right\} + (1 - F(\gamma^*)) \frac{(\theta^*)^2}{2(1+r)}.$$

Grouping together the terms involving $F(\gamma^*)$ and simplifying,

$$\underset{X_t}{Max} - X_t - \int_0^{\gamma^*} \gamma_t dF(\gamma_t) + \frac{\bar{\theta} G(X_t)}{1+r} + F(\gamma^*) \int_{\theta^*}^{\infty} \frac{\theta_t^2 - (\theta^*)^2}{2(1+r)} df(\theta_t) + \frac{(\theta^*)^2}{2(1+r)}.$$

The first order condition yields:

$$-1 + \frac{\bar{\theta} G'(X_t)}{1+r} + \frac{d\gamma^*}{dX_t} . \frac{d}{d\gamma^*}\left[-\int_0^{\gamma^*} \gamma_t dF(\gamma_t) + F(\gamma^*) \int_{\theta^*}^{\infty} \frac{\theta_t^2 - (\theta^*)^2}{2(1+r)} df(\theta_t) + \frac{(\theta^*)^2}{2(1+r)}\right] = 0.$$

Taking the derivative,

$$\frac{\bar{\theta}G'(X_t)}{(1+r)}+\frac{d\gamma^*}{dX_t}\cdot\left[dF(\gamma^*)\left\{-\gamma^*+\int\limits_{\theta^*}^{\infty}\frac{\theta_t^2-(\theta^*)^2}{2(1+r)}d\Phi(\theta_t)\right\}\right]=1$$

Since $\frac{d\gamma^*}{dX_t}>0$ and $\left\{-\gamma^*+\int\limits_{\theta^*}^{\infty}\frac{\theta_t^2-(\theta^*)^2}{2(1+r)}d\Phi(\theta_t)\right\}<0$ (follows from (15) because $\beta_1<1$), it follows that $G'(X_t)>\frac{1+r}{\bar{\theta}}$. Comparing this expression for $G'(X_t)$ with the expression for $G'\left(X_t^{FB}\right)$ in lemma 1, it follows that $X_t<X_t^{FB}$ (since G is an increasing and concave function). ■

7.7 Proof of proposition 6

The proof is identical to the main analysis. ■