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Abstract

We study a situation in which a manager, whose ability to select good projects is unknown a priori, proposes a project for funding. The manager's superior can observe the information about project quality generated by the manager, but cannot observe the resources devoted by the manager to generate that information. We show that a reputation-conscious manager will overinvest in information about the project, relative what the firm's shareholders would like, and that this leads to an excessively long product-development cycle time. Possible organizational responses to this distortion are discussed and empirical implications drawn out.

1 Introduction

Much has been written and said about "time-based" competition whereby an element of competitive strategy is product-development cycle time (see, for example, Stalk (1988)).[1] Over the last two decades, the market share gains of Japanese firms in various industries have been attributed to their shorter cycle times (see Ohmae (1988)). For example, Sony's domination of the personal stereo market with its "Walkman" has been linked to the fact that Sony pioneered the product and has successfully introduced improved versions of the product. Another example is the much-publicized success of Japanese automakers in gaining market share from their American rivals in the U.S. marketplace; the average cycle time of Japanese automakers has been 18 months, half that of the average U.S. automaker.

While the management strategy literature has emphasized the competitive significance of cycle time through examples such as these, it leaves many important questions unanswered:

- Why do cycle times vary cross-sectionally when the virtues of beating one's competition to market are presumably well known?

- What are the costs of shortening cycle time? That is, are there any organizational tradeoffs in determining cycle time?

- In instances where cycle times are longer than optimal for the firm's shareholders, what can be done organizationally to improve the situation?

Our goal in this paper is to address these questions. Our perspective is that cycle time is an outcome of the firm's capital budgeting system, which is itself a corporate response to the need to collect and analyze information about the project before deciding whether to invest in it. Launching a new product or modifying an existing product represents a tangible commitment of capital, and most of the activities that help the firm to determine whether the capital should be committed are part of capital budgeting. To understand cycle time, therefore, we should understand those aspects of capital budgeting that affect cycle time.

We treat cycle time as a conscious managerial decision in capital budgeting. What determines cycle time is how much information the manager wishes to collect before making a decision about

[1] Product-development cycle time refers to the amount of time it takes a firm to develop a product from the time the idea is first generated to the time production commences. This should be distinguished from production cycle time which refers to how long it takes for a product to be manufactured. Our concern in this paper is exclusively with product-development cycle time.

whether to invest capital; increased information collection lengthens cycle time. If one views information collection as a way to learn more about the project before deciding whether to invest in it, then the manager's choice of cycle time is essentially a choice of how much learning is optimal. Now, if the reputation of the manager depends on whether the chosen project is good or bad, the manager's choice of how much to invest in learning about the project will be affected by (reputational) career concerns. Our goal is to study how managerial career concerns could distort cycle time away from what is optimal for shareholders.

The basic intuition underlying our analysis is as follows. Lengthening cycle time allows the manager to learn more about the project. This reduces the probability that the manager will erroneously pass up a good (positive net present value) project as well as the probability that he will erroneously invest in a bad project. Investing in a project that is discovered ex post to be good is valuable to the manager because it has a favorable impact on his perceived ability (reputation). By the same token, investing in a project that is discovered ex post to be bad adversely affects the manager's reputation. Of course, the manager can eschew the project altogether and avoid collecting any information, pretending to be like those who simply did not get a project to evaluate. But in equilibrium he is then pooled with those who declined projects they received negative information about. This hurts the manager's reputation since more talented managers are more likely to have good projects, conditional on having a project. The consequence of this is a personal desire in the manager to collect as much information as possible before making an accept/reject decision on the project. Tempering this desire is the fact that collecting project information consumes organizational resources and lowers firm value, and the manager cares both about his personal reputation and firm value. But since the manager's personal reputation enters his utility function and not firm value, the manager's investment in information collection exceeds first best.

We also examine the effect of heterogeneity across managers within the firm on each manager's choice of cycle time, and find that an increase in the this heterogeneity tends to increase the cycle-time distortion. This helps us address our first question regarding cross-sectional differences in cycle times. For example, if intrafirm heterogeneity in perceived managerial ability is lower in Japan than in the U.S., our analysis would predict shorter cycle times in Japan.

As for the second question regarding organizational tradeoffs in determining cycle time, our analysis points out that while shortening cycle time conserves organizational resources and improves speed to market, it also increases errors in project choice. However, as the probability of competitors investing in the same project goes up, the tradeoff shifts in favor of a shorter cycle time.

In response to the third question regarding possible remedies, we discuss a variety of organizational responses to the cycle-time distortion. In particular, we explore the effectiveness of capital rationing, hard product-development budgets, rewards to managers for fast cycle times, redesign of managerial compensation to increase its dependence on total firm value, and better screening and training of managers. Each of these potential resolutions can diminish the problem we study, but each also has costs associated with it. Discussing the costs and benefits of these organizational responses sheds light on the rich interaction between capital budgeting, managerial career concerns, project risk, cross-sectional differences in product-development cycle times, and organizational talent assessment processes.

The rest of the paper is organized as follows. Section 2 contains a literature review. Section 3 has a description of the model. Section 4 is devoted to the formal analysis of the model. Section 5 addresses organizational resolutions of the problem. Finally, Section 6 concludes with a summary of the empirical implications of the paper. All proofs are in the Appendix.

2 Review of the Related Literature

There have been numerous interesting papers on intrafirm capital allocation to which our paper is related. These papers can broadly be classified as falling in one of three groups: overinvestment, capital rationing, and distortions in the nature of investments. Consider the overinvestment problem first. Holmstrom and Ricart i Costa (1986) show how the career concerns of risk-averse managers could induce them to overinvest in projects. This happens because the optimal managerial wage contract in their model is downward rigid and hence the manager views the opportunity to invest as an option on his human capital; the value of this option is enhanced by the risky strategy of investing in a project with a random payoff rather than the safe strategy of avoiding investment. Harris and Raviv (1996) assume that managers have an innate preference for capital to show that overinvestment will occur.

In both papers, the efficient organizational response is capital rationing in some circumstances. However, the group of papers that show that capital rationing can sometimes be optimal for the shareholders includes those that do not deal with it as a way to combat overinvestment. In Thakor (1990), the firm rations capital to positive-NPV projects in order to conserve internally-generated cash for future projects that would otherwise require higher-cost external financing.

The third group of papers, those examining distortions in the types of projects chosen by managers, include those that ask why managers may sometimes be too short-term oriented or myopic, and those that investigate the conditions under which managers may choose projects that are too safe or too risky from the shareholders' standpoint. Narayanan (1985) shows that short-termism may arise from the career concerns of managers who prefer projects that throw off high cash flows early rather than late.[2] Stein (1988) argues that short-term projects may be used by managers as a signal to elevate the firm's market value and thereby deter unwanted takeover attempts.

On the issue of whether self-interested managers will choose projects that are too risky or too safe from the shareholders' standpoint, the finding seems to be that the distortion could go either way, depending on the parameters. Hirshleifer and Suh (1992) show that the manager's risk preference depends on the curvature of his compensation contract. Hirshleifer and Thakor (1992) show that managers may invest in excessively-safe projects to protect their human capital against conspicuous and early project failure. Lambert (1986) develops a model in which effort-averse managers must be incented to expend effort to gather information about project profitability and also to choose the right project, conditional on the information gathered. Depending on the parameters, the manager's project choice may be safer or riskier than what the shareholders would like. More recently, Prendergast and Stole (1996) study the investment distortions that occur when managers are concerned with (market) perceptions of their ability to *learn*. In their model, a manager must make a sequence of investment decisions based on his information about the project's profitability. They find that a manager's desire to appear as a quick learner induces him to exaggerate his information initially. Later in his career, the same manager responds too conservatively to new information in an attempt to hide his previous (investment) errors. Thus, managerial career concerns with respect to the ability to learn can lead to a firm's investment portfolio being either too risky or too safe.

The most important difference between these papers and ours is that none of them examines the product-development cycle time issue that we do. The similarity is that, like some of these papers, we also examine the capital budgeting ramifications of managerial career concerns. But whereas managerial career concerns in these models are reflected in distortions in project choice – overinvestment, myopia or projects that are too risky or too safe – they are reflected in excessively-

[2]Thakor (1990) suggests that short-term projects may be attractive to *shareholders* because the early cash they generate provides internal capital for investing in future projects, so that reliance on more expensive external capital is minimized.

long cycle times *prior* to project choice in our model. That is, our paper focuses on the generation of information before a project is chosen rather than on the choice of the project itself.[3]

3 The Model

3.1 Agents and Investment Opportunities

We consider a two-period model of a firm in which there is a CEO overseeing many managers. These managers are of varying ability, which is unobservable to everyone, including the managers themselves. The CEO, who acts in the shareholders' best interests, is entrusted with the task of allocating capital to managers who bring forward project ideas.[4] Managers are responsible for generating project ideas at date $t = 0$ and investigating them during the first period which ends at date $t = 1$. They screen their project ideas (when they arise) by investing in information at date $t = 0$ which reveals an informative signal at date $t = 1$. To obtain project funding, managers must submit a capital appropriation request to the CEO at $t = 1$.

Projects arise randomly at $t = 0$. We assume that a manager[5] generates a project idea at $t = 0$ with probability (w.p.) $q \in (0, 1)$, which is *independent* of the manager's ability. This implies that w.p. $1 - q$, the manager will not have a project to investigate. Conditional on generating a project idea, there are two types of projects, good (G) and bad (B), each requiring investment I at $t = 1$. Conditional on knowing a project's type, there is no uncertainty at $t = 1$ in the payoffs of the projects at $t = 2$. A type-G project has a payoff (at date $t = 2$) of V_G, and a type-B project has a payoff of V_B, where $V_G > I > V_B$. The project payoff is observed by the CEO at $t = 2$.

While the probability with which a manager generates a project idea is independent of managerial ability, the average *quality* of the project idea is not. The likelihood of a given project idea being of type G or B depends on a manager's ability, given by $p \in [0, 1]$. That is, we assume that the $\Pr(G \mid \text{project idea}) = p, \forall p \in [0, 1]$. Ability p, which is unknown to everyone, is randomly

[3] In that regard, it is similar to Lambert (1986), the key difference being that the manager in Lambert's model wants to invest too little in generating information, whereas our manager wants to invest too much. This happens because Lambert studies the moral hazard created by lazy managers, while we study the reputational motives of career-conscious managers.

[4] We assume that the CEO does not face any capital constraints, and can therefore finance every project that she believes will contribute positively to shareholders' wealth.

[5] Since managers do not know their own ability, we consider the equilibrium behavior of a representative manager for the remainder of the paper.

distributed with a continuous probability density function $f(p)$.[6] Thus, we denote

$$E(p) = \int_0^1 pf(p)dp \equiv \overline{p} \tag{1}$$

$$Var(p) = \int_0^1 p^2 f(p)dp - \overline{p}^2 = \sigma^2. \tag{2}$$

Consequently, when the manager succeeds in generating a project idea, the unconditional probability that he will draw a good project is:

$$\Pr(G) = E(p) = \overline{p}. \tag{3}$$

Conditional on having a project idea, the expected NPV of the project is thus given by

$$E(NPV \mid \text{project idea}) = \overline{p}V_G + [1-\overline{p}]V_B - I, \tag{4}$$

where $\overline{p}$ is given by (1). We assume that the firm is *a priori indifferent* to this project, that is,

$$E(NPV \mid \text{project idea}) = 0. \tag{5}$$

The manager's decision to propose a project (or not) at $t = 1$ is observable to the CEO. However, when the CEO doesn't see a project proposal, she does not know whether a project idea was investigated and ultimately rejected, or if the manager simply didn't get a project idea. Thus, although not generating a project idea doesn't reveal anything about managerial type *per se*, these managers are pooled in equilibrium with the set of managers who generated an idea and subsequently chose not to propose it.

3.2 Project Signals

Conditional on having a project idea, the manager can choose how long to spend evaluating the project (cycle time) at $t = 0$ prior to proposing it at $t = 1$. We define this choice of cycle time as choosing a value of $\eta \in [0, \frac{1}{2}]$.[7] The chosen value of η determines the precision of the informative signal of project quality the manager receives at $t = 1$.

The signal generating function, for a given cycle time choice η, will (noisily) reveal whether the project is good (G) or bad (B). The signal that the manager actually observes (Ψ) is given by

$$\Psi \in \{G, B\}. \tag{6}$$

[6]Observe that for $p \in [0,1]$, we have $\sigma^2 \leq \frac{1}{4}$. For tractability, we will put some restrictions on $f(p)$ later in the analysis.

[7]Technically, we are holding the time horizon fixed at one period. That is, when the manager chooses a longer cycle time (η), really he is just spending more money on testing this project idea, as opposed to delaying its launch. However, we interpret greater η being synonymous with spending more *time* evaluating a project.

We let $\Pr(\Psi = G \mid G) = \Pr(\Psi = B \mid B) = \theta(\eta) \in \left[\frac{1}{2}, 1\right]$, and $\Pr(\Psi = G \mid B) = \Pr(\Psi = B \mid G) = 1 - \theta(\eta)$. The properties of $\theta(\cdot)$ we would like are: $\theta'(\eta) > 0$, $\theta(\eta = 0) = \frac{1}{2}$ and $\theta(\eta = \frac{1}{2}) = 1$. To satisfy these three conditions, we assume the following function form

$$\theta(\eta) = \frac{1}{2} + \eta. \tag{7}$$

Consequently, we also have

$$1 - \theta(\eta) = \frac{1}{2} - \eta. \tag{8}$$

The direct cost to the firm of the manager's information acquisition is given by the function

$$C(\eta) = C\eta^2, \tag{9}$$

where $C > 0$. Thus, lengthening cycle time reduces the *total* expected value of the project.

The informative signal constitutes the report that the manager must present to the CEO when requesting funds. Thus, while the reported signal is observable and verifiable for $\Psi = G$, the investment of organizational resources that led to the generation of the signal is not. That is, the CEO does not observe either η or $C(\eta)$. Moreover, the CEO will observe Ψ if and only if the manager requests capital.

We interpret Ψ as the summary of the actual financial analysis of project cash flows conducted by the manager. At the time that investment capital is requested, the manager must present this financial analysis to the CEO to support his claim that the project is worth funding. Thus, while the manager can choose to not report how much time and money he spent investigating the project, he cannot misrepresent the result of his investigation.[8]

3.3 Preferences

All agents are assumed to be risk neutral. The CEO seeks to maximize the expected value of the firm. Managers, however, care both about firm value and their wages. We assume that the manager is paid a single wage at $t = 2$, which equals his reservation wage. Reservation wages depend on perceived ability. Since managerial ability varies over $p \in [0, 1]$, we normalize the most

[8] One might think that it should not be difficult to observe something as tangible as cycle time. However, whereas the average product-development cycle time for a company may be readily observed or inferred, it may be difficult to discern when exactly a product idea first came to the manager and how long the manager worked on it before making it known to others in the organization. Equally difficult to determine might be the organizational resources tied up in investigating the project, since these would include the costs of developing and testing prototypes, and conducting market research, as well as the time of various people providing help to generate information about the project.

talented (i.e., $p = 1$) manager's reservation wage to unity. Therefore, the wage (W) is paid on the basis of perceived ability. That is,

$$W = E(p \mid \{\Omega_2\}) \times 1, \tag{10}$$

where $\{\Omega_2\}$ represents the CEO's information set at time $t = 2$. The CEO's information set will include the manager's decision to propose a project or not at $t = 1$, and the project payoff at $t = 2$ if the project was funded.

The manager's utility function is assumed to be:

$$U = [A \times W] + [Z \times \text{Firm Value}], \tag{11}$$

where $A > 0$ and $Z > 0$. The manager will make both his information investment and capital request decisions to maximize his expected utility.

In the next section, we characterize the first-best equilibrium and compare this to the manager's privately optimal choice of η.

4 Equilibrium Analysis

4.1 First-Best Equilibrium

We establish the first-best level of project cycle time as follows. Since investing in the project without any additional information is a zero-NPV investment by assumption, the CEO will either choose a non-zero η or abandon the project entirely. If the CEO were to choose η in equilibrium, she would do so to balance the benefit of lowering the probability of investing in a bad project against the cost of extending cycle time (given by equation (9)).

Before solving for the first-best η, we must characterize the first-best investment policy for a given η, conditional on a realization of Ψ. Thus, we can calculate the expected NPV of the project conditional on observing either $\Psi = G$ or $\Psi = B$. The first, for a given η, is

$$E(NPV \mid \Psi = G) = [\Pr(G|\Psi = G) \times V_G] + [\Pr(B|\Psi = G) \times V_B] - I, \tag{12}$$

where

$$\begin{aligned} \Pr(G|\Psi = G) &= \frac{\Pr(\Psi = G|G)\Pr(G)}{\Pr(\Psi = G|G)\Pr(G) + \Pr(\Psi = G|B)\Pr(B)} \\ &= \frac{\left[\frac{1}{2} + \eta\right]\overline{p}}{\frac{1}{2} + \eta\,[2\overline{p} - 1]} \end{aligned} \tag{13}$$

and

$$\begin{aligned} \Pr(B|\Psi = G) &= \frac{\Pr(\Psi = G|B)\Pr(B)}{\Pr(\Psi = G|G)\Pr(G) + \Pr(\Psi = G|B)\Pr(B)} \\ &= \frac{\left[\frac{1}{2} - \eta\right][1 - \overline{p}]}{\frac{1}{2} + \eta\,[2\overline{p} - 1]}. \end{aligned} \tag{14}$$

It is easily verified that for any $\eta \in (0, \frac{1}{2}]$, $\overline{p} < \Pr(G|\Psi = G)$. Thus, $E(NPV \mid \Psi = G) > 0$ for any $\eta \in (0, \frac{1}{2}]$.

Similarly, for a given η,

$$E(NPV \mid \Psi = B) = [\Pr(G|\Psi = B) \times V_G] + [\Pr(B|\Psi = B) \times V_B] - I, \tag{15}$$

where

$$\begin{aligned} \Pr(G|\Psi = B) &= \frac{\Pr(\Psi = B|G)\Pr(G)}{\Pr(\Psi = B|G)\Pr(G) + \Pr(\Psi = B|B)\Pr(B)} \\ &= \frac{\left[\frac{1}{2} - \eta\right]\overline{p}}{\frac{1}{2} + \eta\,[1 - 2\overline{p}]} \end{aligned} \tag{16}$$

and

$$\begin{aligned} \Pr(B|\Psi = B) &= \frac{\Pr(\Psi = B|B)\Pr(B)}{\Pr(\Psi = B|G)\Pr(G) + \Pr(\Psi = B|B)\Pr(B)} \\ &= \frac{\left[\frac{1}{2} + \eta\right][1 - \overline{p}]}{\frac{1}{2} + \eta\,[1 - 2\overline{p}]}. \end{aligned} \tag{17}$$

It is also easily verified that for any $\eta \in (0, \frac{1}{2}]$, $\Pr(G|\Psi = B) < \overline{p}$. Thus, $E(NPV \mid \Psi = B) < 0$ for any $\eta \in (0, \frac{1}{2}]$.

The first-best investment policy, conditional on choosing η and observing Ψ, is to then invest only when $\Psi = G$. Thus, at $t = 0$, the CEO chooses η to

$$\max_{\eta} E(NPV) = [\Pr(\Psi = G) \times E(NPV|\Psi = G)] + [\Pr(\Psi = B) \times 0] - C\eta^2. \tag{18}$$

Taking the first-order condition of (18) with respect to η and setting it equal to zero yields

$$\eta_{FB} = \frac{1}{2C}\left[\overline{p}V_G - [1 - \overline{p}]V_B + I - 2\overline{p}I\right]. \tag{19}$$

The second-order condition is easily verified to be satisfied (i.e., negative), thereby insuring that (19) represents a global maximizing value of η_{FB}.

Upon substituting the zero NPV condition from (5) of $I = \overline{p}V_G + [1 - \overline{p}]V_B$ into (19), we can simplify it to obtain η_{FB}, which is stated in the theorem below.

Theorem 1

The first-best policy is to choose $\eta_{FB} = \frac{1}{C}\left[\overline{p}[1-\overline{p}][V_G - V_B]\right] > 0$, *and to invest in the project whenever* $\Psi = G$ *and reject it whenever* $\Psi = B$. *Moreover, a sufficient condition for* $\eta_{FB} < \frac{1}{2}$ *is* $2\overline{p}[1-\overline{p}][V_G - V_B] < C$.

The intuition is straightforward. The first-best investment in information about the project trades off the cost of this information, C, against the benefit of this information, which is an increase in the probability of choosing the good project rather than the bad. This benefit is proportional to $V_G - V_B$, the difference between the values of the good and bad projects. Thus, the first-best investment in information about the project is increasing in $V_G - V_B$ and decreasing in C.

4.2 Second-Best Equilibrium

We now turn to the case in which the manager privately chooses η. In a reputational equilibrium, the manager is concerned with both firm value and the CEO's perception of his ability. We begin the analysis with a definition of equilibrium. This is the equilibrium in a game in which the manager, privately informed about η and the signal of project quality he has observed, moves first by choosing to propose or not propose a project, and the CEO moves second by deciding whether to accept or reject a proposed project.

Definition: A reputational equilibrium consists of the following:

1. *For the manager*, conditional upon receiving a project idea:
   - a choice of cycle time η; and
   - a strategy that maps the outcome of the signal Ψ into the decision set: {propose the project, do not propose the project}.
2. *For the CEO*:
   - a set of beliefs about managerial ability conditional upon observing a project proposal and not observing a project proposal;
   - conditional upon seeing a project proposal, a strategy that determines whether or not the proposal is accepted; and

- conditional upon an accepted proposal, a set of beliefs about managerial ability that are further revised upon seeing the terminal project payoff.

The CEO's beliefs must be consistent with Bayes' rule along the equilibrium path, and the strategies of both the manager and the CEO must be sequentially rational.

We will focus only on pure-strategy equilibria.[9] Moreover, at this point, we will *conjecture* that in equilibrium, the CEO only approves projects for which $\Psi = G$ and that the manager proposes projects whenever $\Psi = G$, but does not propose if $\Psi = B$. We will verify this later. Since the manager cannot make a proposal if no project idea is received (occurring w.p. $1-q$), the CEO's beliefs will always be determined by Bayes' rule and the manager's choice of η will follow from expected utility maximization.

To solve for the manager's privately optimal choice of $\eta \in \left[0, \frac{1}{2}\right]$, we first characterize every possible reputational assessment that could occur along the equilibrium paths at dates $t = 1$ and $t = 2$. We then back up to $t = 0$ and evaluate the utility-maximizing choice of η given these assessments.

Reputation at t=1:

We begin with the reputational assessments revealed at $t = 1$. There are three possibilities. First, the manager had a project idea, chose η, observed $\Psi = G$ and thereby requested capital. Second, the manager had a project idea, chose η, observed $\Psi = B$ and thereby did not request capital. Third, the manager did not generate a project idea. We solve for the CEO's assessment of the manager's ability for each of these events.[10]

Now, for a manager who observed $\Psi = G$, the CEO assesses that

$$E(p|\Psi = G) = \int_0^1 [p \times \Pr(p \mid \Psi = G)]\, dp, \tag{20}$$

where for any $p' \in [0,1]$,

$$\begin{aligned} \Pr(p' \mid \Psi = G) &= \frac{[\,[\Pr(\Psi = G \mid G) \times \Pr(G \mid p')] + [\Pr(\Psi = G \mid B) \times \Pr(B \mid p')]]\, f(p')}{\Pr(\Psi = G)} \\ &= \frac{\left[\frac{1}{2} + \eta\,[2p' - 1]\right] f(p')}{\frac{1}{2} + \eta\,[2\overline{p} - 1]}. \end{aligned} \tag{21}$$

[9] Note that our definition of equilibrium does not specify any beliefs in response to out-of-equilibrium moves. This is because there are no out-of-equilibrium moves for the manager.

[10] Recall that in equilibrium, the CEO will not be able to distinguish between $\Psi = B$ and the manager not getting a project idea. However, the two individual assessments of managerial ability conditional on each of these two events must be characterized before deriving the CEO's equilibrium response.

Therefore, upon substituting (21) into (20) and evaluating, we have

$$E(p|\Psi = G) = \frac{1}{\frac{1}{2} + \eta\,[2\overline{p} - 1]} \left[\left[\frac{1}{2} - \eta\right]\overline{p} + 2\eta\left[\sigma^2 + \overline{p}^2\right]\right], \tag{22}$$

where we have used the fact that $\sigma^2 = E(p^2) - \overline{p}^2$.

Next, for a manager who observes $\Psi = B$, we similarly obtain that the CEO assesses that

$$E(p|\Psi = B) = \int_0^1 [p \times \Pr(p \mid \Psi = B)]\, dp, \tag{23}$$

where for any $p' \in [0, 1]$,

$$\begin{aligned}
\Pr(p' \mid \Psi = B) &= \frac{[\,[\Pr(\Psi = B \mid G) \times \Pr(G \mid p')] + [\Pr(\Psi = B \mid B) \times \Pr(B \mid p')]]\, f(p')}{\Pr(\Psi = B)} \\
&= \frac{\left[\frac{1}{2} + \eta\,[1 - 2p']\right] f(p')}{\frac{1}{2} + \eta\,[1 - 2\overline{p}]}.
\end{aligned} \tag{24}$$

Therefore, upon substituting (24) into (23) and evaluating, we have

$$E(p|\Psi = B) = \frac{1}{\frac{1}{2} + \eta\,[1 - 2\overline{p}]} \left[\left[\frac{1}{2} + \eta\right]\overline{p} - 2\eta\left[\sigma^2 + \overline{p}^2\right]\right]. \tag{25}$$

Lastly, for a manager who did not receive a project idea, we have

$$E(p|\text{no idea}) = \overline{p}, \tag{26}$$

since the probability of generating an idea is independent of managerial ability.

Observe that the above reputational assessments are derived as if each of three events at $t = 1$ were individually observable. But this is not the case. If the manager observes $\Psi = B$, he will simply claim that he did not have a project idea and pool with those managers who actually didn't generate a project idea. We define these two events as the joint "no request" event. Observe that the probability of a manager *not* generating an idea is $[1 - q]$, and the probability that the manager generated an idea but observed $\Psi = B$ is

$$q \times \Pr(\Psi = B) = q \times \left[\frac{1}{2} + \eta\,[1 - 2\overline{p}]\right].$$

Thus, with equations (22), (25) and (26), we can fully characterize the *two* possible reputational assessments of managers at $t = 1$. These are $E(p|\Psi = G)$ (given by 22) if capital is requested along with a $\Psi = G$ report, and

$$E(p|\text{no request}) = \frac{[1 - q]\,\overline{p} + q\left[\left[\frac{1}{2} + \eta\right]\overline{p} - 2\eta\,[\sigma^2 + \overline{p}^2]\right]}{1 - \frac{1}{2}q + q\eta\,[1 - 2\overline{p}]}, \tag{27}$$

if "no request" is observed.

It is easily seen that for any $q < 1$, $E(p \mid \Psi = B) < E(p|\text{no request})$, thereby allowing managers to *hide* when the investigation reveals $\Psi = B$. To summarize, at $t = 1$ we have the following reputational ordering

$$E(p|\Psi = B) < E(p|\text{no request}) < \overline{p} < E(p|\Psi = G). \tag{28}$$

Managers who choose "no request" in equilibrium have no further decisions to make or information revealed. The reputational assessment in (27) thus holds at $t = 2$ as well. This is not the case for a manager whose project is funded at $t = 1$. For him the project payoff provides another signal of his ability to the CEO, permitting the CEO to revise her assessment of the manager's ability.

Reputation at t=2:

We now solve for the reputational assessments at $t = 2$ for a manager whose (accepted) project pays off. Observe that only V_G or V_B can be realized, and that these payoffs perfectly reveal the project's type. Moreover, in equilibrium, all of these managers have observed $\Psi = G$ at $t = 1$ and therefore come into the second period with an assessment of ability given by (22). The two possible ability assessments at $t = 2$ are characterized below.

For a realization of V_G at $t = 2$, conditional upon observing $\Psi = G$ at $t = 1$, we have

$$E(p|V_G) = \int_0^1 [p \times \Pr(p \mid V_G, \Psi = G)]\, dp, \tag{29}$$

where for any $p' \in [0, 1]$,

$$\begin{aligned} \Pr(p' \mid V_G, \Psi = G) &= \frac{\Pr(G \mid p') \times \Pr(p' \mid \Psi = G)}{\int_0^1 [\Pr(G \mid p) \times \Pr(p \mid \Psi = G)]\, dp} \\ &= \frac{p' \left[\left[\frac{1}{2} + \eta\,[2p' - 1]\right] f(p')\right]}{\left[\left[\frac{1}{2} - \eta\right] \overline{p} + 2\eta\,[\sigma^2 + \overline{p}^2]\right]}. \end{aligned} \tag{30}$$

Therefore, upon substituting (30) into (29) and evaluating, we have

$$E(p|V_G) = \frac{\left[\left[\frac{1}{2} - \eta\right] [\sigma^2 + \overline{p}^2] + 2\eta\,[\overline{p}^3 + 3\overline{p}\sigma^2]\right]}{\left[\frac{1}{2} - \eta\right] \overline{p} + 2\eta\,[\sigma^2 + \overline{p}^2]}, \tag{31}$$

where we have assumed that the $\mathit{skewness}(p) = 0$; that is, $E(p^3) = \overline{p}^3 + 3\overline{p}\sigma^2$.

Similarly for a realization of V_B at $t = 2$, conditional upon observing $\Psi = G$ at $t = 1$, we have

$$E(p|V_B) = \int_0^1 [p \times \Pr(p \mid V_B, \Psi = G)]\, dp, \tag{32}$$

where for any $p' \in [0, 1]$,

$$\begin{aligned}\Pr(p' \mid V_B, \Psi = G) &= \frac{\Pr(B \mid p') \times \Pr(p' \mid \Psi = G)}{\int_0^1 \Pr(B \mid p) \Pr(p \mid \Psi = G) f(p) dp} \\ &= \frac{[1 - p'] \left[\left[\frac{1}{2} + \eta\,[2p' - 1]\right] f(p')\right]}{\left[\frac{1}{2} + \eta\,[2\overline{p} - 1]\right] - \left[\left[\frac{1}{2} - \eta\right] \overline{p} + 2\eta\,[\sigma^2 + \overline{p}^2]\right]}.\end{aligned} \tag{33}$$

Therefore, upon substituting (30) into (29) and evaluating, we have

$$E(p|V_B) = \frac{\left[\left[\frac{1}{2} - \eta\right] \overline{p} + \left[3\eta - \frac{1}{2}\right] [\sigma^2 + \overline{p}^2] - 2\eta\,[\overline{p}^3 + 3\overline{p}\sigma^2]\right]}{\left[\frac{1}{2} - \eta\right] \overline{p} + 3\eta\overline{p} - \eta - 2\eta\,[\sigma^2 + \overline{p}^2]}. \tag{34}$$

Equilibrium Decision at t=0:

We can now fully characterize the manager's decision at $t = 0$, *conditional* on having a project idea. Observe that if the manager doesn't generate a project idea, there is no decision to make. Thus, the manager with a project idea will choose η to maximize his expected utility (from (11)). This is given by

$$\begin{aligned}\max_{\eta} E(U) &= A \times \left[\begin{array}{c} \Pr(\Psi = B) \times E(p \mid \text{No Request}) \\ + \Pr(\Psi = G) \times \left[\begin{array}{c} [\Pr(G \mid \Psi = G) \times E(p \mid V_G)] \\ + [\Pr(B \mid \Psi = G) \times E(p \mid V_B)] \end{array}\right] \end{array}\right]. \\ &\quad + Z \times [E(\text{Firm Value})].\end{aligned}$$

For tractability, we now assume that $\overline{p} = \frac{1}{2}$. This implies that

$$\Pr(\Psi = G) = \Pr(\Psi = B) = \frac{1}{2},$$

$$E(p|V_G) = \frac{1}{\frac{1}{4} + 2\eta\sigma^2} \left[\frac{1}{8} + \frac{1}{2}\sigma^2 + 2\eta\sigma^2\right],$$

$$E(p|V_B) = \frac{1}{\frac{1}{4} - 2\eta\sigma^2} \left[\frac{1}{8} - \frac{1}{2}\sigma^2\right],$$

and

$$E(p|\text{No Request}) = \frac{\frac{1}{2} - \frac{1}{4}q - 2\eta q\sigma^2}{1 - \frac{1}{2}q}.$$

Collecting terms, we now can evaluate the manager's decision in equilibrium. At $t = 0$, after knowing if he has a project or not, the manager will choose η to maximize

$$\begin{aligned} \max_{\eta} E(U) &= A \times \left[\begin{array}{c} \left[\frac{\frac{1}{2}-\frac{1}{4}q-2\eta q\sigma^2}{2-q}\right] \\ +\left[\frac{\frac{1}{16}+\frac{1}{4}\sigma^2+\left[\frac{1}{8}+\frac{3}{2}\sigma^2\right]\eta+2\eta^2\sigma^2}{\frac{1}{2}+4\eta\sigma^2}\right] \\ +\left[\frac{\frac{1}{16}-\frac{1}{4}\sigma^2+\left[\frac{1}{2}\sigma^2-\frac{1}{8}\right]\eta}{\frac{1}{2}-4\eta\sigma^2}\right] \end{array} \right] \\ &\quad +Z \times \left[\frac{1}{2}\eta\left[V_G - V_B\right] - C\eta^2\right]. \end{aligned}$$

Evaluating the first-order condition with respect to η, we find that η is the solution to

$$\begin{aligned} 0 &= A\left(\frac{-2q\sigma^2}{2-q} + \frac{\frac{1}{16}+\frac{1}{2}\sigma^2-\sigma^4+2\eta\sigma^2+8\eta^2\sigma^4}{(\frac{1}{2}+4\eta\sigma^2)^2} + \frac{\frac{-1}{16}+\frac{1}{2}\sigma^2-\sigma^4}{(\frac{1}{2}-4\eta\sigma^2)^2}\right) \\ &\quad +Z\left(\frac{1}{2}[V_G - V_B] - 2C\eta\right). \end{aligned} \tag{35}$$

Equation (35) yields a fifth-order polynomial in η, thereby precluding an explicit solution for η. However, we can rearrange (35) as

$$\eta = f(\sigma^2, q, \eta, \alpha, \eta_{FB}), \tag{36}$$

where

$$\begin{aligned} f(\sigma^2, q, \eta, \alpha, \eta_{FB}) &\equiv \alpha\left(\begin{array}{c} \frac{-2q\sigma^2}{2-q} + \frac{\frac{1}{16}+\frac{1}{2}\sigma^2-\sigma^4+2\eta\sigma^2+8\eta^2\sigma^4}{(\frac{1}{2}+4\eta\sigma^2)^2} \\ +\frac{\frac{-1}{16}+\frac{1}{2}\sigma^2-\sigma^4}{(\frac{1}{2}-4\eta\sigma^2)^2} \end{array} \right) + \eta_{FB}, \\ \alpha &\equiv \frac{A}{2ZC}, \text{ and} \\ \eta_{FB} &\equiv \frac{V_G - V_B}{4C}. \end{aligned}$$

This formulation then allows us to identify the conditions for an interior solution for the manager's privately-optimal η, as well as conduct a comparative statics analysis of this η. The next two results provide the framework for both by first characterizing $f(\sigma^2, q, \eta, \alpha, \eta_{FB})$, and then by establishing a boundary condition on the exogenous parameters.

Lemma 1

$f(\sigma^2, q, \eta, \alpha, \eta_{FB})$ is (i) strictly decreasing in η, (ii) strictly increasing in σ^2 for a nonzero region[11] *of q and σ^2 values, iii) strictly decreasing in q, and (iv) strictly increasing in α for $\sigma^2 \in \left(0, \frac{1}{4}(\sqrt{2}-1)\right)$ and for all $\sigma^2 \in \left(0, \frac{1}{4}\right)$ if $q \leq \frac{2}{3}$.*

[11] In the proof, we provide a wide range of sufficient (but not necessary) conditions on q and σ^2 such that result holds. Possible distributions of p for which the restrictions on σ^2 would hold are also discussed in the proof.

Theorem 2

There exists an unique interior solution $\eta^* \in \left[0, \frac{1}{2}\right]$ if and only if

$$\alpha\sigma^2 \left(\frac{-2q}{2-q} + 4\frac{1}{(1+4\sigma^2)^2} \right) + \eta_{FB} < \frac{1}{2}.$$

Theorem 2 establishes the fact that the manager's privately-optimal cycle time choice η^* is unique. With these results in hand, we can now present the remainder of our results for feasible solutions of η^* that arise from all parameter values that satisfy Theorem 2.

Theorem 3

For any feasible solution η^*, we have $\eta^* > \eta_{FB}$.

The above theorem establishes that fact that a reputation-conscious ($\alpha > 0$) manager always chooses a cycle time that exceeds the first-best in equilibrium. The intuition was explained in the Introduction. The extent to which a manager's equilibrium choice of η^* exceeds the first-best η will depend on several things. These relationships are presented next.

Theorem 4

In a pure-strategy reputational sequential equilibrium, the manager proposes projects if and only if $\Psi = G$, and the CEO approves projects if and only if $\Psi = G$. The CEO's beliefs are given by equations (22), (26), (31), and (34). The manager's privately-optimal choice of η^* is the solution to (35), and has the following properties:

i. η^* is strictly decreasing in q;

ii. η^* is strictly increasing in α for $\sigma^2 \in \left(0, \frac{1}{4}(\sqrt{2}-1)\right)$ and for all $\sigma^2 \in \left(0, \frac{1}{4}\right)$ if $q \leq \frac{2}{3}$;

iii. η^* is strictly increasing in σ^2 for the nonzero regions of q and σ^2 given in Lemma 1.

The intuition underlying each of the results of Theorem 4 is as follows. First, q measures the probability of a manager generating a project idea at $t = 0$. Observe that it is the possibility that a project idea was not generated that allows a manager to hide when his analysis reveals that his project is likely to be bad (i.e., $\Psi = B$). Thus, as his ability to hide diminishes through increases in q, the manager's propensity to increase cycle time is reduced. Second, α measures the weight that the manager places on his career concerns (reputation) relative to the weight on firm value. Therefore, an increase in this ratio reflects the fact that the manager's concern about his reputation increases relative to his concern about firm value. He thus raises η^* accordingly. Lastly, an increase in the cross-sectional variance of perceived ability, σ^2, increases the perceived value to the manager of separating himself from the other managers. Thus, η^* rises to achieve this.

Our last two results build on the relationship between a manager's inclination to increase cycle time and the cross-sectional variance of managerial ability.

Theorem 5

Over the parameter ranges for which η^* is increasing in σ^2 and α, the variance of the firm's cash flows is strictly decreasing in both σ^2 and α.

This result says first that greater heterogeneity in the perceived abilities of managers within the firm leads to a *lower* variance of cash flows for the firm. At first blush, this seems surprising. The intuition is that as managerial heterogeneity increases, each manager responds by increasing cycle time (Theorem 4). This reduces the probabilities of both Type I and Type II errors, leading the firm to increase the proportion of good projects it invests in through time. The consequence is a lower variance of cash flows for the firm.[12]

The second part of the theorem is that the firm's cash flow variance goes down as the manager attaches greater weight to career concerns. This is very intuitive since a greater career concern causes an increase in cycle time.

5 Possible Organizational Solutions to the Cycle Time Distortion

In the first four subsections of this section we discuss how one might organizationally cope with the manager's desire to overinvest in gathering information about the project. In each case we also discuss the possible costs of the proposed resolution. This discussion of costs is *not* meant to suggest that the proposed resolutions should not be considered. Rather, since none is likely to completely eliminate the problem, a combination of these may have to be used in practice. In

[12]Since our model is single period, the cash flow variance in our analysis is the *ex ante* variance of the single cash flow from the project. If the firm is viewed as investing every period in a project, then we can interpret this also as the intertemporal variance of the firm's cash flows, which may be more useful empirically than the more technically-correct interpretation.

the last two subsections, we discuss the possible impact of the nature of the product market and industry structure, and the possible impact of the labor market structure.

5.1 Capital Rationing

As we discussed in Section 2, capital rationing has often been proposed as a way to address some of the investment distortions arising from managerial self-interest. Would it work here?

One way to think about how capital rationing would work is to imagine the CEO announcing that there is a fixed amount of capital to allocate during a particular time period, and then running a "horse race" among managers seeking funding. The idea is to encourage managers to get in the funding queue early to improve their chances of obtaining capital for the project, and thereby provide a counterbalance to their desire to lengthen cycle time excessively.

It is easy to see that this would be quite effective if it was personally important for managers to get their projects funded during a particular funding cycle, say due to an innate preference for capital, as in Harris and Raviv (1996). But in a setting more like the one developed in this paper, the manager's concern would primarily be with future perceptions of his ability rather than with getting project funding *per se.* Thus, the manager would simply prefer to wait until the next funding cycle rather than ask the CEO to fund a project that has been insufficiently investigated relative to the manager's private optimum.

In some cases, capital rationing may actually exacerbate the problem. Imagine a setting in which the manager does have a preference for getting the project funded within a given funding cycle. The manager recognizes, however, that it's a multiperiod game in which the CEO's decision to allocate capital to a particular manager depends not only on the observed signal Ψ, but also on the CEO's perception of the manager's ability. That is, managers are engaged in a "capital tournament" in which only a subset of managers proposing projects with $\Psi = G$ are funded, and these are the managers with the highest perceived abilities. Recognizing this, the manager may be tempted to lengthen cycle time even more since reducing the probability of having a bad project approved now has the additional benefit of increasing the chances of getting good projects approved in the future.

5.2 Redesigning the Capital Budgeting System

Since the manager is overspending organizational resources on investigating projects, one possibility is to redesign the capital budgeting system to track and monitor this expenditure. The manager could be given a "hard" (nonnegotiable) budget constraint for how much he can spend on investigating a project. This way capital budgeting becomes a multi-phase, multiple toll-gate process in which resources are incrementally committed to the project as more and more information about it is collected. Many companies, like Whirlpool and SmithKline Beecham, have adopted such capital budgeting processes that work the way venture capitalists do (see, for example Boquist, Milbourn and Thakor (1998) and Sharpe and Keelin (1998)).

Such an arrangement can attenuate the distortion we have focused on. However, one impediment to implementing it effectively is that the manager could be privately informed about one or more of the exogenous parameters that determine the first-best cycle time, η_{FB}. In that case, setting a hard budget constraint could introduce distortions that exceed those in the second-best solution we have described.

This suggests that cycle time distortions can vary widely across industries. In those industries where the product market structure and other characteristics are such that there is little opportunity for the manager to be privately-informed about the determinants of η_{FB}, cycle times will tend to be predictable and hard for managers to manipulate. An example is microchip design. Firms in such industries will *not* need elaborate multiple-toll-gate capital budgeting processes. On the other hand, industries with widely-varying R&D times and budgets, such as pharmaceuticals, will be faced with greater cycle time distortions and will need more elaborate capital budgeting systems. This is indeed what we see. Pharmaceutical companies like Merck and SmithKline Beecham use toll-gate capital budgeting systems, whereas chip designers commit huge amounts of capital once and set rigid completion dates.

5.3 Compensation-Based Resolutions

Reward for Reducing Cycle Time:

It is natural to wonder whether one can design the manager's compensation to overcome the problem. For example, one can reward managers explicitly for fast cycle times and speed to market. There are many companies that use variants of such reward systems, including 3M Corporation and Dana Corporation.

While such reward schemes should help, it is unlikely that they will eliminate the problem entirely. The problem is that it will be very difficult to avoid revising beliefs about managerial abilities based on whether the project proposed by the manager succeeded or not. The managers who get promoted are likely to be those who have had the largest number of successful projects. Thus, each manager will now seek to balance the rewards from shortening cycle time against the personal costs of proposing projects that fail. There will be instances in which the first-best will not be restored.

Reward for Failure:

Of course, one could also attempt to *reward* managers for failure rather than punishing them. This would make them less averse to failure and thus less inclined to overinvestigate projects. While this seems like a reasonable solution, what could frustrate it is moral hazard. If the manager has an effort choice decision that affects the probability of success of the project, then rewarding managers for failure could encourage them to shirk in providing effort.

Reward Based on Total Firm Value:

In our analysis, we have taken as exogenous the weights the manager puts on personal reputation and firm value. In reality, the firm could influence these weights in at least two ways. One is to increase the pecuniary compensation the manager receives that is based on total firm value, relative to other forms of compensation. The other is to de-emphasize merit-based promotions based on demonstrated individual performance, i.e., adopt a Japanese-style approach.

There are two difficulties, however, with this approach. First, to ignore individual performance in making ability assessments that are used to reward and promote people means discarding valuable information and tolerating an avoidable inefficiency in the way a typical organization sifts its talent pool to determine who rises through the ranks. Second, it encourages free-riding and worsens moral hazard in the supply of productive inputs.

5.4 Improve Screening and Training of Managers

We have shown that the manager lengthens cycle time as the cross-sectional variance of abilities across managers in the firm increases. This suggests that one way to tackle to problem would be to reduce this cross-sectional variance. This could be achieved through greater investment in *screening* applicants before they are chosen to be managers, and also by investing more in *training* them after they have become managers. Better screening would reduce the heterogeneity in the abilities of those hired, and subsequent training could upgrade their skills in evaluating projects, further reducing differences among managers. How much to spend on these activities will depend, of course, on the tradeoff between the costs of these activities and the benefits they produce by moving the second-best cycle time closer to first-best.

This issue is related to intrafirm tournaments to either motivate or sort out managers (e.g., Lazear and Rosen (1981), Nalebuff and Stiglitz (1983), and MacLeod and Malcolmson (1988)). Successive iterations of the tournament should weed out less able managers and reduce the perceived heterogeneity in managerial abilities, thereby eroding cycle time distortions.

5.5 The Impact of the Nature of the Product Market and Industry Structure

There are some industries (e.g., computer software) in which the nature of the product readily admits short product-development cycle times and the industry structure is so highly competitive that there is very rapid new product introduction. There are other industries (e.g., defense contracting for jet engines) where longer cycle times seem inevitable.

In industries such as computer software, where there is rapid product obsolescence due to innovation by competing firms, the excessive cycle time distortion we have analyzed is likely to be less of a problem. The reason is that the manager may be unable to get funding for introducing a product that a competitor has already introduced. Thus, if a manager takes too long to investigate a project, he runs the risk of being beaten to the punch by someone in a competing firm and thereby losing the project altogether.

5.6 The Impact of Labor Market Structure

Our analysis also suggests that differences in labor market structures across countries will lead to differences in cycle times. In a labor market like Japan's, for example, where there is little ability for a manager to move from firm to firm, the firm's internal capital budgeting and promotion/incentive systems can spread the managerial rewards from reputation well into the future. This can make the manager less concerned about his reputation and reduce the cycle time distortion. Thus, the greater labor market mobility in the U.S. than in Japan may contribute to the longer cycle times in the U.S. Of course, the cost of the Japanese labor market rigidity is that a firm cannot easily recruit "proven" talent from the outside; it can only recruit rookie managers with unknown skill.

6 Conclusion

We have shown in this paper that a reputation-conscious manager will invest excessive time and resources in investigating projects before deciding whether to propose them to his boss, the CEO. The reason is that the CEO revises her perceptions of the manager's ability based on whether the project he proposed succeeded or failed, and not on how he investigated them. Investigating a project more thoroughly increases the chances that a good project will not be overlooked and that a bad project will not be taken.

In addition to providing a possible explanation for cross-sectional variations in product-development cycle times, our analysis also generates the following empirical predictions.

1. The smaller the cross-sectional heterogeneity in perceived managerial abilities, the shorter will be cycle times. Thus, if there is lesser perceived heterogeneity among Japanese managers than among American managers, Japanese firms will have shorter cycle times.

2. Greater cross-sectional heterogeneity in perceived managerial abilities will lead to less risk in project selection and hence smaller variance in total firm cash flows.

3. Greater reliance on incentive-based compensation (that is not directly tied to firm value) and merit-based promotions will lead to longer cycle times and lower variance in total firm cash flows.

4. Firms in more competitive industries, and particularly those in which product innovation is an important basis of competition, will have shorter cycle times with less distortion away from first-best cycle times.

The types of moral hazard that are encountered in capital budgeting are varied and often very subtle. We have analyzed one such moral hazard and discussed its potentially wide-ranging implications. Future research could be directed at testing the empirical implications of our analysis and also further exploring the organizational implications of other types of moral hazard.

7 Appendix

7.1 Proof of Theorem 1

The result follows immediately from equations (13), (16), and (19). ■

7.2 Proof of Lemma 1

(i) Taking the derivative of $f(\sigma^2, q, \eta, \alpha, \eta_{FB})$ with respect to η, we see that

$$\begin{aligned}
\operatorname{sign}(\frac{\partial}{\partial \eta} f(\sigma^2, q, \eta, \alpha, \eta_{FB})) &= \operatorname{sign}(64\alpha\sigma^4\eta\left(4\sigma^2-1\right)^2 \frac{64\eta^2\sigma^4+3}{(1+8\eta\sigma^2)^3(-1+8\eta\sigma^2)^3}) \\
&\propto \operatorname{sign}(\frac{1}{-1+8\eta\sigma^2}) \leq 0
\end{aligned}$$

for all $\sigma^2 < \frac{1}{4}$ and $\eta \leq \frac{1}{2}$.

(ii) Letting $x \equiv \sigma^2$, we have

$$\begin{aligned}
\operatorname{sign}(\frac{\partial}{\partial \sigma^2} f(\sigma^2, q, \eta, \alpha, \eta_{FB})) &= \operatorname{sign}(\frac{q}{-2+q} - 2(4x-1)\frac{1024\eta^4x^3 - 192\eta^2x^2 + 48\eta^2x - 1}{(1+8\eta x)^3(-1+8\eta x)^3}) \\
&\geq -1 - 2(4x-1)\frac{1024\eta^4x^3 - 192\eta^2x^2 + 48\eta^2x - 1}{(1+8\eta x)^3(-1+8\eta x)^3}
\end{aligned}$$

We cannot unambiguously sign the partial derivative above. However, we can evaluate it numerically and establish several (individual) sufficient conditions for q and σ^2 such that

$$\frac{\partial}{\partial \sigma^2} f(\sigma^2, q, \eta, \alpha, \eta_{FB}) > 0.$$

In the table below, we provide these sufficient conditions.

η	q	σ^2 upper bound
0.5	$\frac{1}{2}$	0.11757
0.5	$\frac{2}{3}$	0.091164
0.5	$\frac{7}{8}$	0.061653
0.25	$\frac{1}{2}$	0.22648
0.25	$\frac{2}{3}$	0.20927
0.25	$\frac{7}{8}$	0.16582

To gain an understanding of the types of distributions for p for which the result applies, consider the following. As noted in Section 3, for $p \in [0,1]$, we always have $\sigma^2 \leq 0.25$. As another benchmark, if p was uniformly distributed over $[0,1]$, then $\sigma^2 = \frac{1}{12} = 0.083\overline{3}\cdots$. Thus, any distribution for which there is (even slightly) greater probability mass towards the mean of $\overline{p} = \frac{1}{2}$ than at either extreme of the distributional support, then $\sigma^2 < 0.083\overline{3}\cdots$. Observe that in the candidate regions of parameters provided in the table above, the only example that violates this σ^2 restriction is when q is extremely high and η is at its upper boundary. Since we know that $f(\sigma^2, q, \eta, \alpha, \eta_{FB})$ is strictly decreasing in η from part (i) of this lemma, any reduction in η away from the upper bound will increase the maximal value of σ^2. Therefore, we believe that most reasonable distributions of ability, including the uniform or triangular distribution, do in fact generate the result of this part of the Lemma.

(iii)

$$\text{sign}(\frac{\partial}{\partial q} f(\sigma^2, q, \alpha, \eta_{FB}; \eta)) = -4\frac{\sigma^2}{(-2+q)^2} < 0$$

(iv)

$$\begin{aligned}\text{sign}(\frac{\partial}{\partial \alpha} f(\sigma^2, q, \alpha, \eta_{FB}; \eta)) &= \text{sign}(\frac{-2q\sigma^2}{2-q} + \frac{\frac{1}{16} + \frac{1}{2}\sigma^2 - \sigma^4 + 2\eta\sigma^2 + 8\eta^2\sigma^4}{(\frac{1}{2} + 4\eta\sigma^2)^2} + \frac{\frac{-1}{16} + \frac{1}{2}\sigma^2 - \sigma^4}{(\frac{1}{2} - 4\eta\sigma^2)^2}) \\ &> \text{sign}(\frac{-2q\sigma^2}{2-q} + 4\frac{\sigma^2}{(1+4\sigma^2)^2}) > 0\end{aligned}$$

for $\sigma^2 < \frac{1}{4}(\sqrt{2}-1)$. It is also positive for any $\sigma^2 \in \left(0, \frac{1}{4}\right)$ if $q \leq \frac{2}{3}$. ■

7.3 Proof of Theorem 2

Define

$$g(\eta; .) = f(.; \eta) - \eta.$$

Then (36) has a solution if and only if $g(\eta; .)$ has a root $\eta^* \in [0, \frac{1}{2}]$. Since $f(.; \eta)$ is continuous and strictly decreasing in η, then $g(\eta; .)$ is continuous and strictly decreasing in η. It immediately follows that $g(\eta; .)$ has a *unique* root $\eta^* \in [0, \frac{1}{2}]$ if and only if $g(0; .) > 0$ and $g(\frac{1}{2}; .) < 0$, or

$$\begin{aligned}g(0; .) &= f(.; 0) = \frac{2\alpha\sigma^2}{2-q}\left(4 - 3q - \sigma^2(8-4q)\right) + \eta_{FB} > \eta_{FB} > 0 \\ g(\frac{1}{2}; .) &= f(.; \frac{1}{2}) - \frac{1}{2} = \alpha\sigma^2\left(\frac{-2q}{2-q} + 4\frac{1}{(1+4\sigma^2)^2}\right) + \eta_{FB} < \frac{1}{2}\end{aligned}$$

where we used that $\sigma^2 < \frac{1}{4}$ and $q \in [0, 1]$. Observe that $g(0; .) > \eta_{FB} > 0$, as shown in Theorem 1, and thus the only boundary condition that we must impose is that $g(\frac{1}{2}; .) < \frac{1}{2}$. ■

7.4 Proof of Theorem 3

Observe that the first-best solution η_{FB} corresponds to (36) with $\alpha = 0$. Therefore, since the solution η^* is strictly increasing in α, we have $\eta^* > \eta_{FB}$ for all $\alpha > 0$. ■

7.5 Proof of Theorem 4

As we showed in the proof of Theorem 3, $\eta^* > \eta_{FB}$. Thus, as long as $\eta_{FB} > 0$, the manager's privately-optimal choice is $\eta^* > 0$. As we showed in the analysis of first-best, for any $\eta > 0$, we have

$$\Pr(G|\Psi = B) < \overline{p} < \Pr(G|\Psi = G).$$

Therefore, since $\Pr(G) = \overline{p}$ represents a zero-NPV investment, the CEO will only invest in equilibrium for $\Psi = G$, and not for $\Psi = B$.

Similarly, given the observability of Ψ when the manager proposes his project and the fact that

$$E(p|\Psi = B) < E(p|\text{no idea}),$$

the manager will only propose a project if $\Psi = G$ and claim "no idea" otherwise.

We can now prove the latter half of the theorem. We prove all three properties of η^* in this theorem by means of contradiction.

(i) Consider the two solutions η' and η'' corresponding to $\eta' = f(\sigma^2, q', \alpha, \eta_{FB}; \eta')$ and $\eta'' = f(\sigma^2, q'', \alpha, \eta_{FB}; \eta'')$, with $q' > q''$. Assume that $\eta' > \eta''$, then given Lemma 1, we have

$$\eta' = f(\sigma^2, q', \alpha, \eta_{FB}; \eta') < f(\sigma^2, q'', \alpha, \eta_{FB}; \eta') < f(\sigma^2, q'', \alpha, \eta_{FB}; \eta'') = \eta''$$

which contradicts the assumption that $\eta' > \eta''$.

(ii) The following proof holds either over the region for which $\sigma^2 < \frac{1}{4}(\sqrt{2} - 1)$ or for *any* $\sigma^2 \in \left(0, \frac{1}{4}\right)$ if $q \leq \frac{2}{3}$. Now over these relevant regions, consider the two solutions η' and η'' corresponding to $\eta' = f(\sigma^2, q, \alpha', \eta_{FB}; \eta')$ and $\eta'' = f(\sigma^2, q, \alpha'', \eta_{FB}; \eta'')$, with $\alpha' > \alpha''$. Assume that $\eta' < \eta''$, then again given Lemma 1, we have

$$\eta' = f(\sigma^2, q, \alpha', \eta_{FB}; \eta') > f(\sigma^2, q, \alpha'', \eta_{FB}; \eta') > f(\sigma^2, q, \alpha'', \eta_{FB}; \eta'') = \eta''$$

which contradicts the assumption that $\eta' < \eta''$.

(iii) The following proof holds only over the regions of q and σ^2 presented in Lemma 1. Now over these regions, consider the two solutions η' and η'' corresponding to $\eta' = f((\sigma^2)', q, \alpha, \eta_{FB}; \eta')$ and $\eta'' = f((\sigma^2)'', q, \alpha, \eta_{FB}; \eta'')$, with $(\sigma^2)' > (\sigma^2)''$. Assume that $\eta' < \eta''$, then again given Lemma 1, we have

$$\eta' = f((\sigma^2)', q, \alpha, \eta_{FB}; \eta') > f((\sigma^2)'', q, \alpha, \eta_{FB}; \eta') > f((\sigma^2)'', q, \alpha, \eta_{FB}; \eta'') = \eta''$$

which contradicts the assumption that $\eta' < \eta''$.

The fact that this satisfies our definition of a reputational sequential equilibrium is easy to verify. The manager's and CEO's beliefs are clearly sequentially rational and the strategies of each satisfy the Nash equilibrium consistency requirement. Moreover, since the manager has no out-of-equilibrium move, the equilibrium is clearly sequential without having to verify the CEO's beliefs and best responses to possible out-of-equilibrium moves. ■

7.6 Proof of Theorem 5

We can express the variance of the firm's cash flows as

$$Var(V) = p'[V_G - E(V)]^2 + [1-p'][V_B - E(V)]^2, \tag{37}$$

where p' is the $\Pr(G)$ and $E(V) = p'V_G + [1-p']V_B$. If we calculate the variance of the firm's cash flows as of $t = 1$, then p' is given by $\Pr(G|\Psi = G)$ from equation (13). We can simplify (37) and obtain

$$Var(V) = p'[1-p'][V_G - V_B]^2. \tag{38}$$

It is obvious that (38) is maximized at $p' = \frac{1}{2}$, and is increasing in p' for all $p' \in [0, \frac{1}{2})$ and decreasing in p' for all $p' \in (\frac{1}{2}, 0]$.

Using the fact that (13) is strictly increasing in η and the prior $\overline{p} = \frac{1}{2}$, we can easily characterize the effects of σ^2 and α on $Var(V)$ by recalling their positive relationship with η^*. In Theorem 4, we showed that η^* was increasing in both σ^2 and α. Thus, $Var(V)$ is strictly decreasing in both σ^2 and α. ■

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