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Board Expertise and Executive Incentives

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Abstract. We investigate how board expertise affects chief executive officer (CEO) incentives and firm value. The CEO engages in a sequence of tasks: first acquiring information to evaluate a potential project, then reporting his or her assessment of the project to the board, and finally implementing the project if it is adopted. We demonstrate that the CEO receives higher compensation when the board agrees with the CEO on the assessment of the project. Board expertise leads to (weakly) better investment decisions and helps motivate the CEO's evaluation effort; however, it may induce underreporting and reduce the CEO's incentives to properly implement the project. Consequently, if motivating the CEO to evaluate projects is the major concern (e.g., innovative industries), board expertise exhibits an overall positive effect on firm value; however, if motivating the CEO to implement projects is the major concern (e.g., mature industries), board expertise can harm firm value.

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1. Introduction

It is commonly believed that board expertise enhances firm performance. The U.S. Securities and Exchange Commission (SEC) requires that, effective February 2010, all public companies "disclose for each director and any nominee for director the particular experience, qualifications, attributes or skills that qualified that person to serve as a director," presumably to encourage firms to enlist directors with more expertise.[1] Research on board expertise primarily focuses on its effect on firms' decision making but provides little insight into the effect of board expertise on executive incentives. In practice, management is responsible for searching for viable projects and their execution. Therefore, understanding how board expertise affects executive incentives is an important step toward understanding the effect of board expertise on firm performance.

To capture the interactions between the board and the chief executive officer (CEO), we construct a model in which a risk-averse CEO (purely for the purpose of exposition, we designate the CEO as a female) is hired by a risk-neutral board and is motivated to (1) evaluate a potential project, (2) truthfully report her assessment of the project to the board, and (3) implement the project if adopted. The board can use its expertise to further evaluate the project's profitability. On the basis of the available information (which includes both the CEO's reported information and the board's own assessment), the board makes the investment decision.[2] If the decision is to adopt the project, the board shifts its attention to motivating the CEO's implementation task. There is often a significant passage of time between project evaluation and implementation, and upon project adoption, the board may find it difficult to commit not to renegotiate the contract. We therefore allow for contract renegotiation before project implementation.[3]

We find that board expertise has a positive effect on motivating the CEO to evaluate the project. Because both the CEO and the board conduct analyses about the same underlying project, their assessments are inherently correlated. The more effort the CEO exerts to evaluate the project, the stronger is the positive correlation. Exploiting this, the board will optimally pay the CEO higher compensation if the two parties have similar assessments of the project simply because their agreement indicates high evaluation effort by the CEO. Furthermore, a board with more relevant expertise can better infer whether the CEO has carefully evaluated the project, thus providing a stronger incentive for the CEO to become informed. Note that rewarding consistent reports, in our setting, is not due to any collusion between the board and the CEO or to a powerful CEO extracting more rent (the standard managerial power view); rather, it is part of an optimal contract designed to motivate the CEO to exert more effort in evaluating the project.

In the event that the CEO's and the board's assessments diverge, the investment decision ultimately depends on the one that is more accurate. That is, the board may overrule the CEO's opinion if the board's expertise is high.[4] Anticipating that investment may still be undertaken even after her unfavorable report, the CEO has an incentive to *underreport* project quality. By doing so, she can guide down the board's perception of the project quality so as to extract a higher bonus for implementing the project.[5] The more difficult the project implementation task, the higher is the bonus required, and hence, the stronger is the underreporting incentive. In contrast, if board expertise is so low that an unfavorable CEO report definitely leads to no investment, the CEO has no incentive to underreport.[6] Thus, high board expertise can induce the underreporting incentive on the part of the CEO.

Board expertise may have another negative implication for CEO incentives. If board expertise is too low to influence the investment decision, higher board expertise will hurt the CEO's incentive to implement the project. In this case, the board's information cannot affect the project quality but only makes the board's perception of the project quality more volatile. This results in more volatile compensation paid to the CEO. To compensate the risk-averse CEO, the board will end up paying more to the CEO.

To summarize, board expertise leads to (weakly) better investment decisions and helps motivate the CEO to exert evaluation effort; however, it can also induce underreporting and disincentivize the CEO from implementing the project. Therefore, the relative severity of the effort problems determines the overall effect of board expertise on firm value. If motivating the CEO to implement the project is the first-order concern, board expertise may harm firm value; otherwise, board expertise exhibits a monotonic positive effect on firm value. For different industries or at different stages in the life cycle of firms, CEOs can add more value in different ways: for young firms or companies operating in innovative industries, much of the value created by CEOs occurs at the project screening stage; for mature firms or companies operating in less innovative industries, CEOs tend to create more value at the project implementation stage. We therefore predict that board expertise will improve firm value for young firms or companies operating in innovative industries. For mature companies or companies operating in less innovative industries, board expertise may harm firm value.

1.1. Related Literature

Our paper adds to the emerging literature studying the effect of board expertise on firm value. Several empirical studies have examined this issue and found an overall positive association between board expertise and firm value/performance, but in some more-specific settings, board expertise has been found to be associated with worse firm performance.[7] Theoretical analyses of this issue remain scarce so far. Levit (2012) demonstrates that board expertise may decrease firm value because it reduces the CEO's information-acquisition effort. This is in similar spirit to Aghion and Tirole (1997), who show that in an incomplete contract setting in which the principal (board) and the agent (CEO) have different preferences regarding investments, a board possessing information reduces the chances that the CEO has effective control over investment, hence reducing the CEO's incentive to acquire information. Our paper also shows that board expertise may decrease firm value, but through a different mechanism. In fact, in our complete contracting setting, board expertise improves the CEO's incentive to acquire information, but it may hurt the CEO's incentive to implement the project and induce underreporting.

Our paper also adds to the debate on the managerial power view versus the optimal contracting view regarding CEO compensation (Bebchuk and Fried 2004, Edmans and Gabaix 2016, Ferri and Goex 2017).[8] Though often challenged, the managerial power view has been taken seriously by both scholars and policymakers and has led to major regulatory changes. Recent studies (e.g., Drymiotes 2007, Laux 2008, Kumar and Sivaramakrishnan 2008, Laux and Mittendorf 2011) try to reconcile these two views by arguing that even though a dependent board may facilitate rent extraction by managers, it could be an optimal choice for the shareholders owing to other benefits.[9] Our paper adopts a different approach to challenge the managerial power view. We show that the empirical findings often interpreted as supporting the managerial power view (e.g., a positive association between CEO–board agreement and CEO compensation) can be consistent with the optimal contracting view. Another example is Baldenius et al. (2019), who, rooted in the optimal contracting framework, show that board friendliness and CEO equity grants are positively associated in equilibrium.

In terms of model setup, our paper is closely related to the sequential task models studied by Arya et al. (2006) and Laux (2006). Arya et al. (2006) study a situation in which a team comes up with project ideas, with individuals subsequently implementing various components of the project. Laux (2006) studies a setting in which an agent must be motivated to work on two tasks: evaluating a potential project and, if the project is adopted, implementing it. Our paper introduces additional information held by the board and considers contract renegotiation at the interim stage. Finally, the evaluation task studied in our paper is similar to those of Lambert (1986) and Balakrishnan (1991), who examine information acquisition before investment decisions.

2. Model Setup

We consider the interaction between a board of directors and a CEO, where the CEO must be motivated to (1) evaluate a potential project, (2) truthfully report her assessment of the project to the board, and (3) implement the project if adopted. The board designs the CEO's compensation contract up front and actively influences the firm's course of action in the following sense: (1) the board uses its expertise to further evaluate the project, and (2) it makes the investment decision. We assume that the board has limited commitment power, and as a result, it renegotiates the compensation contract with the CEO before project implementation.

The CEO's (first-stage) evaluation effort a_1 and (second-stage) implementation effort a_2 are binary: $a_1 \in \{0, 1\}$ and $a_2 \in \{0, 1\}$. If the effort level is zero, the cost is normalized to zero; if the effort level is 1, the cost is $k_1 > 0$ and $k_2 > 0$, respectively. If the project is adopted, it returns a gross cash flow x depending on the realized project quality $\theta \in \{0, 1\}$, the CEO's implementation effort a_2, and the size of the project X:

$$x = \theta \cdot a_2 \cdot X.$$

That is, the project succeeds only if the project is of good quality $\theta = 1$ and the CEO has exerted effort to implement it. The size of the project X is exogenous and commonly known. If the project is rejected, the firm's gross cash flow is 0, and the CEO receives a wage as specified in the contract, ending the game.

The project quality θ is either good ($\theta = 1$) or bad ($\theta = 0$), with equal probability. The CEO expends effort a_1 to evaluate the project. If the CEO exerts evaluation effort (i.e., $a_1 = 1$), she receives an informative signal $s \in \{G, B\}$ with accuracy $0.5 + i$ about the project quality, where $i \in [\underline{i}, 0.5)$ for $\underline{i} > 0$. That is, $\Pr[s = G|\theta = 1] = \Pr[s = B|\theta = 0] = 0.5 + i$. If the CEO does not exert evaluation effort, the signal s is pure noise. After the CEO privately receives the signal, she submits a (costless) report $\hat{s}$ about s to the board.

On the basis of the CEO's report, the board uses its expertise to conduct further analyses and generates an additional signal $m \in \{H, L\}$ about the project quality. Board expertise is parameterized by $j \in [\underline{j}, 0.5)$, where $\underline{j} > 0$. The informativeness of the board's signal m depends on board expertise j, whether the CEO has truthfully reported her signal, and the CEO's evaluation effort:

$$\begin{aligned}\Pr[m = H|\theta = 1, s, \hat{s}] &= \Pr[m = L|\theta = 0, s, \hat{s}]\\ &= 0.5 + j \cdot \mathbb{1}_{\hat{s}=s} \cdot a_1,\end{aligned}$$

where $\mathbb{1}_{\hat{s}=s}$ is an indicator function that takes the value of 1 if $\hat{s} = s$. Only if the CEO has taken evaluation effort to collect relevant information *and* truthfully disclosed those findings in her report is the board's additional signal m informative.[10] This information structure aims to capture an important feature of the board's project evaluation: the board usually needs the CEO's input to generate additional insights because the board is less familiar with the firm's daily operations than the CEO.[11] For example, the CEO usually obtains product-specific information, and the board needs a full understanding of a product's nature before it can provide pertinent information about the market potential. A similar assumption is made in Adams and Ferreira (2007): the quality of board advice is higher when the CEO truthfully reveals her private information to the board. In addition, directors holding more relevant expertise (higher j) are able to provide a more accurate assessment. To focus on the effect of board expertise on CEO incentives, we abstract away the board's strategic reporting problem and instead assume that the board is always truthful or, equivalently, that the board's signal is public and contractible.

The board makes the investment decision on the basis of the CEO's report and its own assessment. The project, if pursued, requires an upfront cost $I > 0$. To ensure a nontrivial investment problem, we normalize $I = X/2$.[12] This implies that, ignoring the implementation cost k_2, the ex ante net present value (NPV) of the project is zero. Hence, an assessment of the project is necessary to determine whether the project has a positive or negative NPV.

The board aims to maximize firm value, which is the investment profit less compensation cost:

$$V = (x - I)d - w, \tag{1}$$

where $d \in \{0, 1\}$ represents the investment decision and w represents the CEO's wage. The CEO has negative exponential utility $-e^{-r(\cdot)}$, where r represents the CEO's risk aversion:

$$U_{\text{CEO}} = -e^{-r(w - a_1 k_1 - a_2 k_2)}.$$

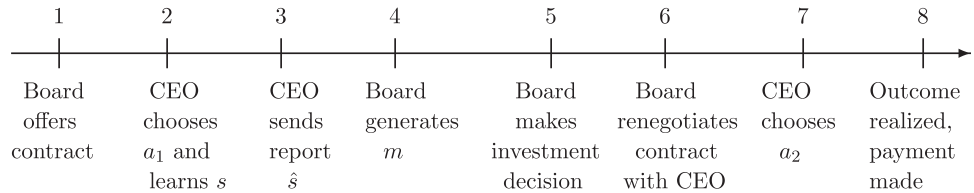
The CEO's reservation utility is $-e^0 = -1$. The sequence of events is shown in Figure 1.

We assume that the size of the project X is large enough and the effort costs k_1 and k_2 are small enough that the board always wants to induce the CEO to exert evaluation effort, truthfully report her assessment, and choose high implementation effort if the project is adopted.

3. Analysis

We solve the game by backward induction. First, we examine the contract renegotiation at date 6. Then we

Figure 1. Timeline



study the board's investment decision at date 5. Finally, we describe the board's optimization problem at date 1.

3.1. Contract Renegotiation at Date 6

After the investment is made, the board's objective shifts to ensuring that the invested project is implemented efficiently. At this date point in time (date 6), the board can offer a revised contract to the CEO. The CEO's compensation contract can be written as $(W_{\hat{s}m}, \overline{W}_{\hat{s}m})$, as a function of the CEO's report $\hat{s}$, the board's signal m, and the final project outcome x. If the final project outcome is zero, that is, $x = 0$ (owing to either project failure or no investment), the CEO receives $W_{\hat{s}m}$ for any $(\hat{s}, m)$. If the outcome is a success $(x = X)$, the CEO receives $\overline{W}_{\hat{s}m}$.[13] The corresponding utility terms are $(U_{\hat{s}m}, \overline{U}_{\hat{s}m})$.

Without loss of generality, we restrict our attention to renegotiation-proof contracts. A contract is renegotiation-proof if the board has no incentive to alter it at date 6, given the board's belief about the CEO's actions taken so far. For any information event $(\hat{s}, m)$ that induces investment, an initial contract $(W_{\hat{s}m}, \overline{W}_{\hat{s}m})$ is renegotiation-proof if it minimizes the expected compensation cost at date 6 subject to the implementation effort constraint $(IC_{\hat{s}m} - a_2)$, which ensures that the CEO exerts implementation effort

$$e^{rk_2}\left(p(\hat{s}, m)\overline{U}_{\hat{s}m} + \left[1 - p(\hat{s}, m)\right]U_{\hat{s}m}\right) \geq U_{\hat{s}m}. \quad (IC_{\hat{s}m} - a_2)$$

Here $p(\hat{s}, m) \equiv \Pr[\theta = 1 | a_1 = 1, s, \hat{s} = s, m]$ represents the board's posterior belief of the state being 1 based on its information set $(\hat{s}, m)$ and its belief about the CEO's actions.[14]

The interim optimization problem is equivalent to a single-period moral hazard problem. The implementation effort constraint $(IC_{\hat{s}m} - a_2)$ must be binding. Therefore, we have the following lemma.

Lemma 1. *A renegotiation-proof contract must have that*

$$Q_{\hat{s}m} \equiv \overline{W}_{\hat{s}m} - W_{\hat{s}m} = -\frac{1}{r}\ln\left(1 - \frac{1 - e^{-rk_2}}{p(\hat{s}, m)}\right). \quad (2)$$

For an initial contract to be renegotiation-proof, the bonus for success $Q_{\hat{s}m}$ must be set just high enough to motivate the CEO (on the equilibrium path) to take the implementation effort. Any extra bonus would be renegotiated away to shield the CEO from unnecessary compensation risk. In addition, the higher the perceived project quality $p(\hat{s}, m)$, the lower is the required bonus $Q_{\hat{s}m}$ to motivate the implementation effort.

3.2. The Optimal Investment Decision at Date 5

At date 5, the board makes the investment decision on the basis of its information set $(\hat{s}, m)$. The objective is to maximize the expected firm value (at date 5), denoted by $V_{t=5}(d \mid \hat{s}, m)$. By (1), it is the expected investment profit of the project net of the expected wage

$$V_{t=5}(d \mid \hat{s}, m) = d \cdot \left[p(\hat{s}, m)X - I\right] - \underbrace{\left[W_{\hat{s}m} + d \cdot p(\hat{s}, m) \cdot Q_{\hat{s}m}\right]}_{\text{expected wage}}.$$

The expected wage is composed of a base salary $W_{\hat{s}m}$ and an expected bonus (to motivate the CEO's implementation effort). The board pays out the bonus $Q_{\hat{s}m}$ only if the project is adopted $(d = 1)$ and succeeds (with anticipated probability $p(\hat{s}, m)$).

Denote by $d^*_{\hat{s}m}$ the optimal investment decision at date 5. It is given by

$$d^*_{\hat{s}m} \in \underset{d \in \{0,1\}}{\operatorname{argmax}} \; d \cdot \left[p(\hat{s}, m)(X - Q_{\hat{s}m}) - I\right] - W_{\hat{s}m}. \quad (3)$$

The optimal investment decision is to invest if and only if $p(\hat{s}, m)(X - Q_{\hat{s}m}) - I \geq 0$ and is summarized in the following proposition.

Proposition 1. *There exist $\delta_1 > 0$ and $\delta_2 > 0$ such that*

- *If $j \leq i - \delta_1$, then $d^*_{\hat{G}m} = 1$ and $d^*_{\hat{B}m} = 0$ for $m \in \{H, L\}$. That is, the optimal investment decision is solely determined by the CEO's report $\hat{s} \in \{\hat{G}, \hat{B}\}$.*
- *If $i - \delta_1 < j < i + \delta_2$, then $d^*_{\hat{G}H} = 1$ and $d^*_{\hat{s}m} = 0$ for all other $(\hat{s}, m)$ combinations. That is, the investment is undertaken if and only if both $\hat{s}$ and m are favorable.*
- *If $j \geq i + \delta_2$, then $d^*_{\hat{s}H} = 1$ and $d^*_{\hat{s}L} = 0$ for $\hat{s} \in \{\hat{G}, \hat{B}\}$. That is, the optimal investment decision is solely determined by the board's signal m.*

The optimal investment decision in general is determined by the party with higher accuracy. The only exception is when the CEO and the board have comparable accuracy $(j \in (i - \delta_1, i + \delta_2))$ yet contradictory signals. In this case, the posterior project quality is "close to" the prior, which is the indifference point of investment before considering implementation cost. Factoring in the implementation cost, the expected investment profit is too small to cover this compensation cost, making it optimal to forgo the project.

3.3. The Board's Optimization Problem at Date 1

At date 1, the board designs the CEO's compensation contract to maximize firm value, denoted by $FV \equiv V_{t=1}$, subject to the constraints that ensure that the CEO evaluates the project, reports truthfully,[15] and implements the project if invested. Renegotiation-proofness, that is, the binding implementation effort constraint $(IC_{\hat{s}m} - a_2)$ ensures that the CEO does not deviate at the implementation stage. It remains to ensure that the CEO exerts evaluation effort and reports her information truthfully.

We first compute the board's objective function. As shown in Appendix A, the expected firm value can be separated into two parts:

$$FV \equiv EV_{a_2} - CC_{a_1+\mathrm{TT}}. \tag{4}$$

Here EV_{a_2} represents the firm's expected cash flow net of the bonus paid to motivate implementation effort

$$EV_{a_2} \equiv \sum_{s\in\{G,B\},m\in\{H,L\}} \Pr[s,m \mid a_1 = 1, \hat{s} = s] \cdot d^*_{\hat{s}m} \cdot \left[p(\hat{s},m)(X - Q_{\hat{s}m}) - I\right],$$

and $CC_{a_1+\mathrm{TT}}$ represents the expected compensation cost to motivate the CEO's evaluation effort and truth telling

$$CC_{a_1+\mathrm{TT}} \equiv \sum_{s\in\{G,B\},m\in\{H,L\}} \Pr[s,m \mid a_1 = 1, \hat{s} = s] \cdot W_{\hat{s}m}.$$

This separation implies that, as a result of renegotiation, the incentive problem of motivating the CEO's implementation effort can be fully separated from that of motivating the CEO's evaluation effort and truth telling. Therefore, the board's optimization problem at date 1 amounts to choosing $\{W_{\hat{s}m}\}$ to minimize $CC_{a_1+\mathrm{TT}}$.

The board's optimization program at date 1 can be laid out as follows:

$$\mathcal{P}: \min_{\{W_{\hat{s}m}\in R\}} CC_{a_1+\mathrm{TT}} = (0.25+ij)\left(W_{\hat{G}H} + W_{\hat{B}L}\right) + (0.25-ij)\left(W_{\hat{B}H} + W_{\hat{G}L}\right)$$

subject to

$$(0.5+2ij)U_{\hat{G}H} + (0.5-2ij)U_{\hat{G}L} \geq 0.5U_{\hat{B}H}\left(1 + d^*_{\hat{B}H}\cdot \max\left\{0, \frac{0.5+i}{p\left(\hat{B},H\right)} - 1\right\}\left(1-e^{rk_2}\right)\right) + 0.5U_{\hat{B}L}, \tag{TT_G}$$

$$(0.5-2ij)U_{\hat{B}H} + (0.5+2ij)U_{\hat{B}L} \geq 0.5U_{\hat{G}H} + 0.5U_{\hat{G}L}, \tag{TT_B}$$

$$EU \geq \max\{0.5U_{\hat{G}H} + 0.5U_{\hat{G}L}, 0.5U_{\hat{B}H} + 0.5U_{\hat{B}L}\}, \tag{$IC - a_1$}$$

$$EU \geq -e^{r\cdot 0} = -1, \tag{IR}$$

where $EU = e^{rk_1}[(0.25+ij)(U_{\hat{G}H} + U_{\hat{B}L}) + (0.25-ij)\cdot(U_{\hat{B}H} + U_{\hat{G}L})]$.

The solution to this optimization program is denoted by $W^*_{\hat{s}m}$. The reporting constraint (TT_s) ensures that the CEO reports her signal s truthfully. The incentive compatible constraint $(IC - a_1)$ ensures that the CEO exerts evaluation effort at date 1. The participation constraint (IR) ensures that the CEO is willing to participate in the contract. The detailed constraints analysis is relegated to Appendix A.

4. The Optimal Contract

In this section, we characterize the optimal contract. To better illustrate the economic forces, we break down the analysis into two steps. We first examine a simplified version of the model in which the CEO's reporting is nonstrategic. Then we return to the full model in which the CEO reports her information to the board strategically.

4.1. A Relaxed Program: Nonstrategic CEO Reporting

Assume that the CEO's signal is publicly observable and contractible. In this case, the board only needs to motivate the CEO to exert evaluation and implementation efforts.

Proposition 2. *In the relaxed program where the CEO's reporting is nonstrategic, the optimal renegotiation-proof contract is as follows:*

- *The CEO will receive a higher wage if her report is consistent with the board's signal*

$$W^*_{\hat{G}H} = W^*_{\hat{B}L} = -\frac{1}{r}\ln\left(1 - \frac{1-e^{-rk_1}}{4ij}\right) > W^*_{\hat{B}H} = W^*_{\hat{G}L} = -\frac{1}{r}\ln\left(1 + \frac{1-e^{-rk_1}}{4ij}\right);$$

- *On top of the base wage $W^*_{\hat{s}m}$, the CEO will receive a bonus $Q^*_{\hat{s}m}$ if the final outcome of the project is a success. The bonus depends on the perceived project quality $p(\hat{s},m)$:*

$$Q^*_{\hat{s}m} = \overline{W}^*_{\hat{s}m} - W^*_{\hat{s}m} = -\frac{1}{r}\ln\left(1 - \frac{1-e^{-rk_2}}{p(\hat{s},m)}\right), \quad \textit{for } \hat{s}\in\left\{\hat{G},\hat{B}\right\} \textit{ and } m\in\{H,L\}.$$

Both the CEO and the board are evaluating the same project; therefore, the two parties' signals are inherently positively correlated. If the CEO carefully evaluates the project, both her and the board's signals are more informative. Therefore, conformity of the two parties' signals indicates higher evaluation effort by the CEO and thereby should lead to greater compensation to the CEO.[16] Such a compensation arrangement is a part of an optimal contract, even though it may be interpreted by proponents of the managerial power view as evidence that more powerful CEOs get paid more because boards agreeing with CEOs are often seen as weak ones that meekly rubber-stamp powerful CEOs' proposals.

4.2. The Full Model: Strategic CEO Reporting

We now return to the full model where the CEO's reporting is strategic. In this more realistic setting, the CEO may have an incentive to underreport her signal.[17] Recall that to motivate the CEO to implement the project, the board will pay the CEO a bonus for project success. By Lemma 1, the less favorable the board's belief about the project quality, the higher is the bonus the CEO will receive. This may incentivize the CEO to underreport her signal so as to guide down the board's perception about the project quality and receive a higher bonus for implementing the project. Note that this underreporting incentive does not always exist: if the CEO's favorable report is necessary for the investment to occur, then the CEO has no incentive to underreport because an unfavorable report leads to no investment, and no investment implies a zero possibility of the CEO reaping any bonus. Whether the CEO's favorable report is necessary for the investment depends on the level of board expertise (Proposition 1). Therefore, board expertise plays an important role in inducing the CEO's underreporting incentive. We therefore consider the following two cases.

4.2.1. Low Board Expertise. If board expertise is low (i.e., $j < i + \delta_2$), then by Proposition 1, the CEO's favorable report is necessary for the investment to be undertaken. Hence, $d^*_{\hat{B}H} = 0$ in the (TT_G) constraint of program $\mathcal{P}$. The CEO who observes G then has no incentive to report $\hat{s} = \hat{B}$ simply because reporting $\hat{B}$ leads to no investment, and no investment implies that the CEO has no chance to reap any bonus. Therefore, we have the following proposition.

Proposition 3. *If board expertise is low, specifically, $j < i + \delta_2$, then the CEO's reporting constraints (TT_G) and (TT_B) are both slack. The optimal contract is the same as that characterized in Proposition 2.*

As argued earlier, low board expertise ($j < i + \delta_2$) eliminates the CEO's underreporting incentive. Then the CEO's truthful reporting comes as a free by-product of the contract designed to motivate her evaluation effort. To see this, recall that to motivate the CEO's evaluation effort, the CEO will receive a higher wage if her report is consistent with the board's signal. This arrangement will incentivize the CEO to tell the truth because, by doing so, the CEO can maximize the probability of her report being consistent with the board's.

4.2.2. High Board Expertise. If board expertise is high enough to fully determine the investment decision (i.e., $j \geq i + \delta_2$), then, by Proposition 1, the investment may still be undertaken even if the CEO has issued an unfavorable report. Specifically, in the case in which the board's own signal is high, the board will go ahead with the investment despite the bad report issued by the CEO; that is, $d^*_{\hat{B}H} = 1$ in the (TT_G) constraint of program $\mathcal{P}$. Anticipating this, a CEO who observes G has an incentive to deflate her report to $\hat{B}$ to get a higher bonus for project implementation. The following proposition examines this scenario.

Proposition 4. *If board expertise is high, specifically, $j \geq i + \delta_2$, then there exists*

$$Z \equiv \frac{1 - e^{-rk_1}}{1 + \frac{1 - e^{-rk_1}}{4ij}} - 0.5(e^{rk_2} - 1) \cdot \max\left\{0, \frac{0.5 + i}{p\left(\hat{B}, H\right)} - 1\right\}$$

such that

- *If $Z \geq 0$, the CEO's reporting constraints (TT_G) and (TT_B) are slack, and the optimal contract is the same as that characterized in Proposition 2.*
- *If $Z < 0$, the CEO's reporting constraint upon observing signal G, (TT_G), is binding.*

If board expertise is high, that is, $j \geq i + \delta_2$, the CEO with signal G has countervailing reporting incentives: (1) a truthful report maximizes the probability of issuing a consistent report with the board, whereas (2) deflating the report increases the bonus at the project implementation stage. The term Z captures the relative importance of the two countervailing incentives:

$$Z \propto \underbrace{\left(1 - e^{-rk_1}\right)}_{\text{Truth-Telling Incentive}} \underbrace{- 0.5e^{rk_2}\left(\overline{U}_{\hat{B}H} - U_{\hat{B}H}\right)\max\left\{0, \left(0.5 + i - p(\hat{B}, H)\right)\right\}}_{\text{Underreporting incentive}}$$

If the truth-telling incentive dominates (i.e., $Z \geq 0$), the CEO's reporting constraint (TT_G) will be slack. If the underreporting incentive dominates (i.e., $Z < 0$), constraint (TT_G) will be binding.

The following corollary sheds light on the economic circumstances under which (TT_G) is likely to be slack.

Corollary 1. *$dZ/dk_1 > 0$ and $dZ/dk_2 \leq 0$.*

The CEO's reporting constraint (TT_G) is more likely to be slack if (1) the CEO's first-stage evaluation effort cost k_1 is larger or (2) the CEO's second-stage implementation effort cost k_2 is smaller. Intuitively, with higher k_1, evaluation effort is more difficult to motivate, demanding a larger pay premium for consistent reports. This provides a stronger truth-telling incentive; that is, it relaxes the constraint (TT_G). In contrast, the CEO's underreporting incentive is weaker for smaller implementation effort cost k_2 because smaller k_2 leads to a lower bonus for project success, which reduces the CEO's benefit from underreporting.

5. The Effect of Board Expertise

In this section, we examine the effect of board expertise on CEO incentives and firm value. Recall that by (4), $FV = EV_{a_2} - CC_{a_1+\mathrm{TT}}$. Our first step is to examine the effect of board expertise on EV_{a_2}, the firm's expected cash flow net of the bonus paid to motivate implementation effort.

Lemma 2. *EV_{a_2} is continuous and nonmonotonic in board expertise j: it first decreases in j for $j \le i - \delta_1$, and then it increases in j for $j > i - \delta_1$.*

We proceed in two steps to illustrate the effect of board expertise j on EV_{a_2}: (1) how does board expertise affect the investment decision, and (2) how does board expertise affect the CEO's incentive to implement the project. If $j \le i - \delta_1$, by Proposition 1, board expertise is too low to influence the investment decision. Therefore, board information does not affect the average (invested) project quality but only makes the perceived project quality more volatile. This results in more volatile compensation to the CEO. To compensate the risk-averse CEO, the board will have to pay her more.[18] That is, for $j \le i - \delta_1$, board expertise lowers EV_{a_2}. In contrast, if board expertise is high enough to influence the investment decision (i.e., $j > i - \delta_1$), the board with higher expertise helps the firm make better investment decisions and hence improves EV_{a_2} (see Figure 2 for illustration). For this numerical example, $k_2 = 30, i = 0.3, r = 0.02, X = 800$.

Now we examine the effect of board expertise on $CC_{a_1+\mathrm{TT}}$, which is the ex ante compensation cost of motivating project evaluation and truthful reporting by the CEO. As the following result shows, the severity of the first-stage evaluation effort problem relative to the second-stage implementation effort problem plays an important role.

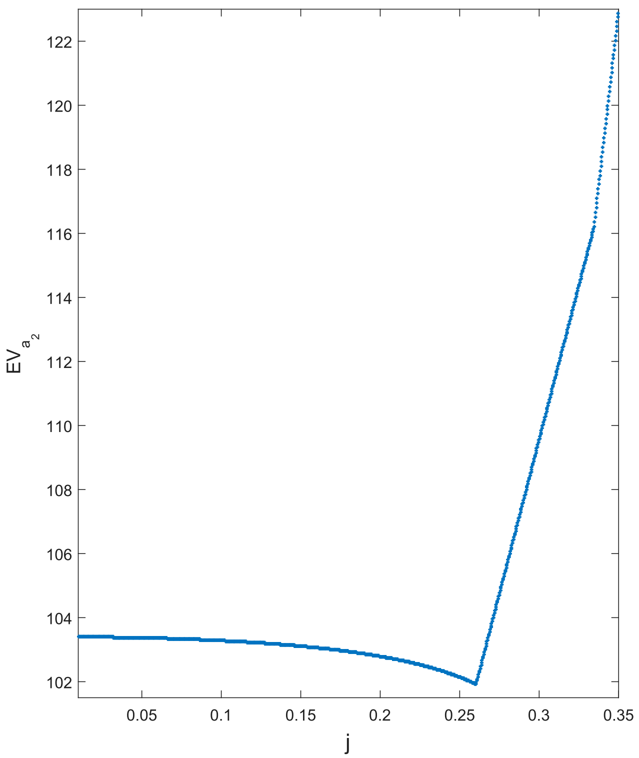
Lemma 3. *For any given implementation effort cost k_2, there exists a cutoff $f_1(k_2)$ such that*

a. *If the evaluation effort cost is high, that is, $k_1 > f_1(k_2)$, then the reporting constraints (TT_G) and (TT_B) are always slack, and CC_{a_1+TT} is continuously decreasing in j.*

b. *If the evaluation effort cost is low, that is, $k_1 < f_1(k_2)$, then constraint (TT_G) is binding at $j = i + \delta_2$. Then CC_{a_1+TT} has a discrete jump up at $j = i + \delta_2$.*

A board with higher expertise can better infer whether the CEO has carefully evaluated the project, thus providing a stronger incentive for the CEO to

Figure 2. (Color online) EV_{a_2} as a Function of Board Expertise j

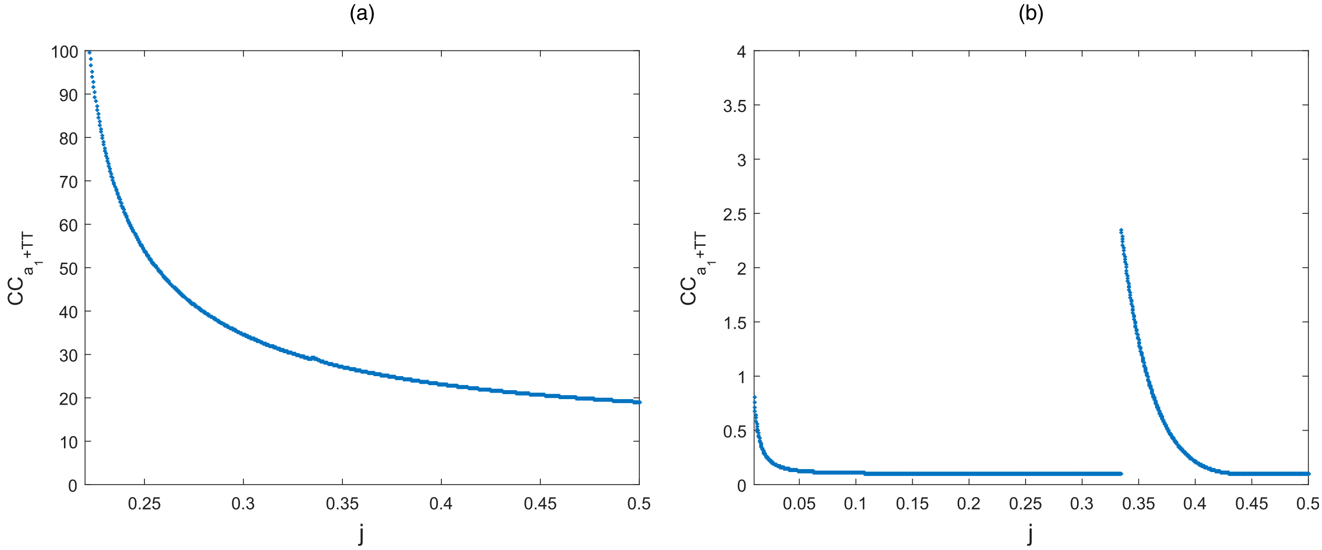


become informed. Therefore, the compensation cost of motivating CEO evaluation effort decreases in board expertise j. Now the question is whether motivating the CEO's truthful reporting requires additional cost (i.e., whether the reporting constraints are binding). This will depend on (1) whether the CEO's underreporting incentive is induced, which is determined by the level of board expertise, and (2) in case the underreporting incentive is induced, the relative severity of the two effort problems (i.e., k_1 relative to k_2).

To elaborate, the pay premium on board–CEO agreement, which aims to motivate the CEO's evaluation effort, also generates an incentive for the CEO to tell the truth. If $j < i + \delta_2$, by Proposition 3, the CEO has no underreporting incentive, and therefore the CEO's truthful reporting can be motivated at no additional cost. However, once board expertise is high enough, that is, $j \ge i + \delta_2$, the CEO starts to have an incentive to deflate her report to reap a larger bonus at the implementation stage. In this case, with both truth-telling and underreporting incentives in place, one has to examine which one dominates. By Corollary 1, the truth-telling incentive is stronger for larger k_1, and the underreporting incentive is stronger for larger k_2.

Fixing k_2, if k_1 is large, then the CEO's truth-telling incentive dominates her underreporting incentive. As a result, the CEO's truthful reporting can be motivated at no additional cost. Therefore, the compensation cost $CC_{a_1+\mathrm{TT}}$ is simply the compensation cost of

Figure 3. (Color online) $CC_{a_1+\mathrm{TT}}$ as a Function of Board Expertise j



For $k_1 = 15$ For $k_1 = 0.1$

motivating evaluation effort, which decreases in board expertise j (see Figure 3(a)). In contrast, if k_1 is small, the CEO's truth-telling incentive no longer dominates her underreporting incentive, so the CEO's truthful reporting has to be motivated at an additional cost. This additional cost explains the discrete jump of $CC_{a_1+\mathrm{TT}}$ at $j = i + \delta_2$ (see Figure 3(b)).[19] For this numerical example, $k_2 = 30, i = 0.3, r = 0.02, X = 800$.

To summarize, other than the intuitive result that higher board expertise leads to (weakly) better investment decisions, board expertise also has nontrivial effects on CEO incentives: (1) it improves the CEO's incentive to exert evaluation effort, but (2) it may hurt the CEO's incentive to implement the project, and (3) it could induce the CEO's underreporting incentive. The overall effect of board expertise on firm value needs to weigh all the effects together and will depend on the relative severity of the two effort problems.

Proposition 5. *Given the implementation effort cost k_2,*

a. *If the evaluation effort cost is high, specifically, $k_1 > \max\{f_1(k_2), f_2(k_2)\}$, then FV is continuously and monotonically increasing in board expertise j.*

b. *If the evaluation effort cost is low, specifically, $k_1 < \min\{f_1(k_2), f_3(k_2)\}$, then FV is nonmonotonic in board expertise j: it is first decreasing in j when $j \le i - \delta_1$ and then increasing in j, but with a discrete drop at $j = i + \delta_2$.*

Both $f_2(k_2)$ and $f_3(k_2)$ are defined in Appendix B.

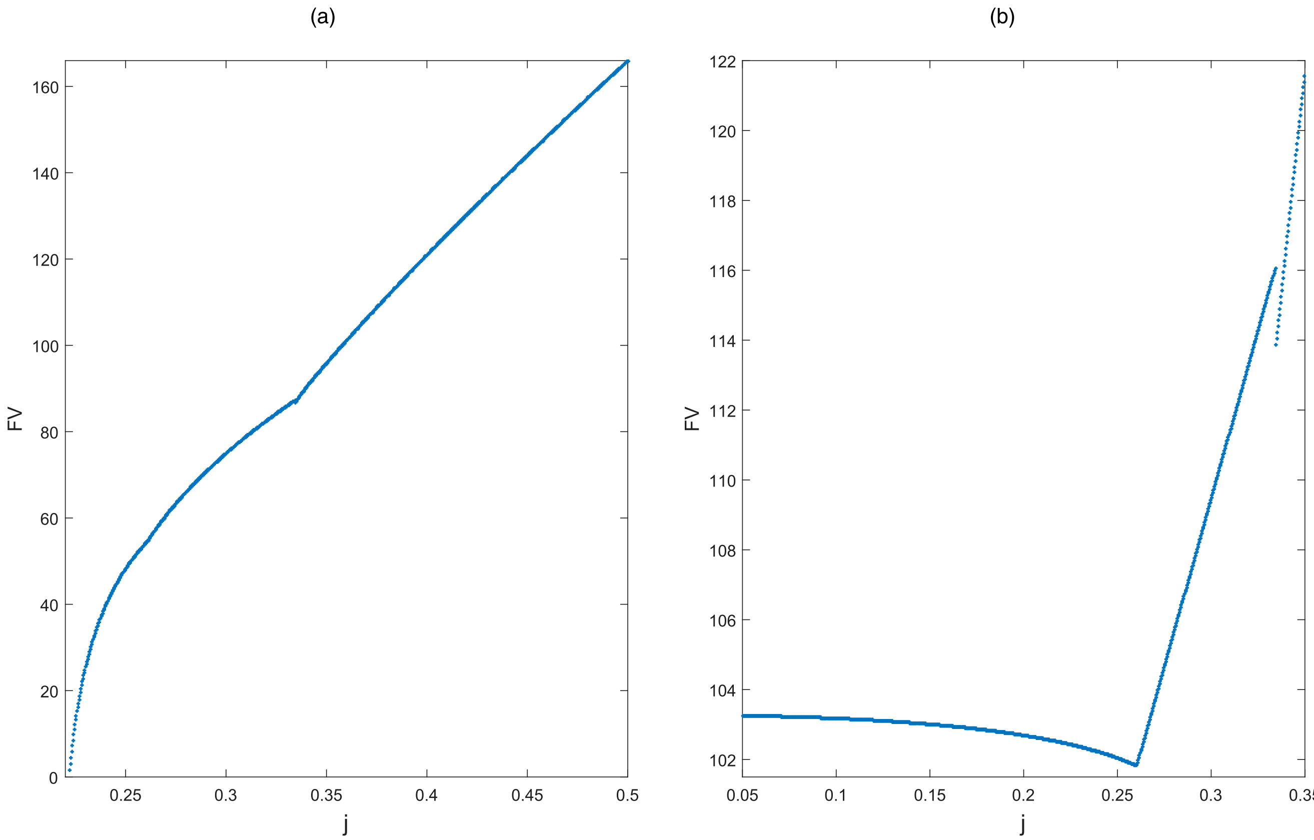
If board expertise is too low to influence the investment decisions (i.e., $j \le i - \delta_1$), the impact of board expertise on firm value is through its impact on CEO incentives. For k_1 small (i.e., the evaluation effort problem is less severe), the positive effect of board expertise on the CEO's evaluation incentive is dominated by its negative effect on implementation incentive; therefore, the overall effect on firm value is negative. Otherwise, board expertise increases firm value.

If $j > i - \delta_1$, higher board expertise leads to better investment decisions, which is of first-order importance. Therefore, the general effect of board expertise on firm value is positive. At the same time, if $k_1 < f_1(k_2)$, the CEO's truthful reporting has to be motivated at an additional cost, once the underreporting incentive is induced at $j = i + \delta_2$ (Lemma 3). This additional cost causes a discrete jump of $CC_{a_1+\mathrm{TT}}$ and thus a discrete drop of firm value at $j = i + \delta_2$.

Therefore, for a large enough k_1, board expertise improves firm value monotonically. However, for a small k_1, there are at least two scenarios where greater board expertise locally decreases firm value: (1) j is too small to influence investment decisions, and (2) j is just high enough to induce the CEO's underreporting incentive (see Figure 4). For this numerical example, $k_2 = 30, i = 0.3, r = 0.02, X = 800$.

On the basis of Proposition 5, we predict that for firms that frequently encounter projects that require relatively costly first-stage investigation, board expertise monotonically increases firm value, whereas for firms that frequently encounter projects that require relatively low-cost first-stage investigation, board expertise may locally decrease firm value. Empirically, one may construct an event study to examine, around the time that firms announce new projects, how different types of projects affect the association between board expertise and firm value.

Figure 4. (Color online) Ex Ante Firm Value FV as a Function of Board Expertise j



For $k_1 = 15$ For $k_1 = 0.1$

6. Conclusion

Over the years, the public and regulators have recognized that directors' backgrounds and expertise are important in affecting corporate strategies and CEO incentives. By modeling the interactions between the board and the CEO in a project investment setting, we show that high board expertise leads to (weakly) better investment decisions and helps motivate the CEO to exert evaluation effort. However, it may inadvertently create an incentive for the CEO to underreport her assessment and may weaken the CEO's incentive in project implementation. Weighing all these effects together, if motivating the CEO to evaluate the project is the first-order concern (e.g., for more innovative industries such as computer software and pharmaceutical companies), board expertise has a monotonic positive effect on firm performance; however, if motivating the CEO to implement the project is the first-order concern (e.g., for less innovative industries such as retailers and restaurant companies), board expertise may hurt firm performance owing to the negative effects on the CEO's reporting and implementation incentives.

Our paper also contributes to the debate on managerial power versus optimal contracting view in terms of CEO compensation. To better separate from the managerial power view, we have taken the idealized stance that the board is independent of the CEO and designs the CEO contract in the best interests of the shareholders. Recent evidence shows that, likely owing to regulatory and other external pressures,[20] board independence has increased significantly.[21] Therefore, in the current environment, our assumption of an independent board designing a CEO compensation contract is not too far from reality.

To our knowledge, there are only a few empirical papers (Wang et al. 2015, Nanda and Onal 2016, Korczak et al. 2018) relating the design of CEO incentive contracts to the industry expertise of directors. Their findings do not directly speak to our mechanism. One possible reason is that although the separation of the CEO's evaluation, reporting, and implementation tasks is appealing conceptually, it is empirically challenging to separately measure the CEO's compensation for these different tasks. One way to indirectly test our theory is to partition firms on the relative severity of the CEO's evaluation effort problem relative to the implementation effort problem. We hope future empirical studies with finer empirical designs can test our empirical predictions.

Another interesting feature for boards of directors is that there are committees in charge of different functions: executive compensation, project review, and so forth. How different dimensions of board expertise match with different committees and affect firm performance (Klein 1998) would be an interesting venue to explore.

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Appendix A. Detailed Formulation of Program $\mathcal{P}$
We first compute the board's objective function. Along the equilibrium path, event (s, m) occurs with probability $\Pr[s, m \mid a_1 = 1, \hat{s} = s]$. Then the expected firm value at date 1 is

$$FV = \mathbb{E}\big[V_{t=5}(d^*_{\hat{s}m} \mid \hat{s}, m)\big] \overset{(3)}{=} \sum_{s\in\{G,B\}, m\in\{H,L\}} \Pr[s, m \mid a_1 = 1, \hat{s} = s] \cdot \big\{d^*_{\hat{s}m} \cdot \big[p(\hat{s}, m)(X - Q_{\hat{s}m}) - I\big] - W_{\hat{s}m}\big\}.$$

Recall that Lemma 1 shows that the bonus for project success $Q_{\hat{s}m}$ (which motivates the CEO's implementation effort) is independent of $W_{\hat{s}m}$. Therefore the expected firm value can be separated into two parts:

$$FV \equiv EV_{a_2} - CC_{a_{1+\mathrm{TT}}},$$

where EV_{a_2} and $CC_{a_{1+\mathrm{TT}}}$ are defined in the main text. Given the separation, the board's optimization problem at date 1 amounts to choosing $W_{\hat{s}m}$ to minimize $CC_{a_{1+\mathrm{TT}}}$.

We next formulate the constraints. For that purpose, we define $D(a_1, s, \hat{s}, m)$ as the CEO's date 4 interim payoff if she has taken effort a_1, observed signal s, issued report $\hat{s}$, and the board's signal is m.

The reporting constraint (TT_s) ensures that the CEO reports truthfully at date 3 after she exerts evaluation effort and observes signal s:

$$\sum_{m\in\{H,L\}} \Pr[m|a_1 = 1, s, \hat{s} = s] \cdot D(a_1 = 1, s, \hat{s} = s, m) \geq \sum_{m\in\{H,L\}} 0.5 \cdot D(a_1 = 1, s, \hat{s} \neq s, m). \qquad (TT_s)$$

Note that the CEO reports before the board's signal is generated. This is why we need to take expectation over the board's signal m. The right-hand side represents the CEO's off-equilibrium payoff when she misreports $\hat{s} \neq s$, in which case the board observes H or L with equal probability 0.5 because its signal is pure noise under our information structure.

The CEO's equilibrium expected payoff can be computed as

$$EU = e^{rk_1}\left[\sum_{s\in\{G,B\}, m\in\{H,L\}} \Pr[s, m|a_1 = 1, \hat{s} = s] \cdot D(a_1 = 1, s, \hat{s} = s, m)\right].$$

The incentive-compatible constraint $(IC - a_1)$ ensures that the CEO chooses to exert evaluation effort at date 1. If the CEO fails to evaluate the project (i.e., $a_1 = 0$), then her signal is completely uninformative, and thus, she may simply report $\hat{G}$ or $\hat{B}$. The right-hand side presents the CEO's off-equilibrium payoff when she fails to evaluate the project ($a_1 = 0$) and simply reports (1) $\hat{G}$ or (2) $\hat{B}$. Note that if the CEO fails to evaluate the project, the board's signal is also uninformative: H and L occur with equal probability 0.5.

$$EU \geq \max\left\{\sum_{m\in\{H,L\}} 0.5 \cdot D\Big(a_1 = 0, s, \hat{s} = \hat{G}, m\Big), \sum_{m\in\{H,L\}} 0.5 \cdot D\Big(a_1 = 0, s, \hat{s} = \hat{B}, m\Big)\right\}. \qquad (IC - a_1)$$

The participation constraint (IR) ensures that the CEO is willing to participate in the contract. The right-hand side presents the CEO's reservation utility:

$$EU \geq -1. \qquad (IR)$$

Next, we compute the CEO's date 4 interim payoff $D(a_1, s, \hat{s}, m)$:

$$D(a_1, s, \hat{s}, m) = \begin{cases} U_{\hat{s}m} & \text{if } d^*_{\hat{s}m} = 0, \\ \max\{U_{\hat{s}m}, e^{rk_2}(\Pr[\theta = 1 \mid a_1, s, \hat{s}, m]\overline{U}_{\hat{s}m} + \Pr[\theta = 0 \mid a_1, s, \hat{s}, m]U_{\hat{s}m})\} & \text{if } d^*_{\hat{s}m} = 1. \end{cases} \qquad (A.1)$$

If no investment is undertaken ($d^*_{\hat{s}m} = 0$), the game ends, and the CEO simply receives $U_{\hat{s}m}$. If the investment is undertaken ($d^*_{\hat{s}m} = 1$), the CEO can choose whether to exert implementation effort at date 7. In case no implementation effort is exerted, the project for sure is a failure, and the CEO receives $U_{\hat{s}m}$. If the CEO chooses to exert implementation effort, then with probability $\Pr[\theta = 1 \mid a_1, s, \hat{s}, m]$, the project will succeed, and the CEO will receive $\overline{U}_{\hat{s}m}$. The project will fail with probability $\Pr[\theta = 0 \mid a_1, s, \hat{s}, m]$.

The following lemma simplifies $D(a_1, s, \hat{s}, m)$, which we plug in to the constraints (TT_s), $(IC - a_1)$, and (IR) to get the program $\mathcal{P}$ in the main text.

Lemma A.1. *The CEO's date 4 interim payoff $D(a_1, s, \hat{s}, m)$ can be simplified to $U_{\hat{s}m}$ except when the CEO deflates the report. In this case,*

$$D(a_1 = 1, s = G, \hat{s} = \hat{B}, m = H) = U_{\hat{B}H}\left(1 + d^*_{\hat{B}H} \cdot \max\left\{0, \frac{0.5 + i}{p(\hat{B}, H)} - 1\right\}\left(1 - e^{rk_2}\right)\right).$$

Proof. Recall that renegotiation-proofness implies that the implementation effort constraint ($IC_{\hat{s}m} - a_2$) is binding. That is,

$$e^{rk_2}\left(p(\hat{s}, m)\overline{U}_{\hat{s}m} + [1 - p(\hat{s}, m)]U_{\hat{s}m}\right) = U_{\hat{s}m}. \tag{A.2}$$

In the following, we compute $D(a_1, s, \hat{s}, m)$ for each case.

Case 1 (On the Equilibrium Path, That Is, $a_1 = 1$ and $\hat{s} = s$). Recall that $p(\hat{s}, m)$ is evaluated on the equilibrium path, that is, $p(\hat{s}, m) = \Pr[\theta = 1 \mid a_1 = 1, s, \hat{s} = s, m]$. Therefore, (A.2) is equivalent to

$$e^{rk_2}(\Pr[\theta = 1 \mid a_1 = 1, s, \hat{s} = s, m]\overline{U}_{\hat{s}m} + \Pr[\theta = 0 \mid a_1 = 1, s, \hat{s} = s, m]U_{\hat{s}m}) = U_{\hat{s}m}.$$

Then, by (A.1), $D(a_1 = 1, s, \hat{s} = s, m) = U_{\hat{s}m}$.

Case 2 (Off-Equilibrium Path Where the CEO Chooses $a_1 = 0$). If the CEO chooses $a_1 = 0$, then under the information structure, both the CEO's and the board's signals are uninformative; therefore, the project quality is just the prior. That is,

$$\Pr[\theta = 1 \mid a_1 = 0, s, \hat{s}, m] = 0.5.$$

Note that by (A.1), if $d^*_{\hat{s}m} = 0$, $D(a_1 = 0, s, \hat{s}, m) = U_{\hat{s}m}$. If $d^*_{\hat{s}m} = 1$, then, by Proposition 1, the perceived project quality $p(\hat{s}, m)$ must be greater than the prior; that is, $p(\hat{s}, m) > 0.5$. Therefore,

$$\begin{aligned}
&e^{rk_2}(\Pr[\theta = 1 \mid a_1 = 0, s, \hat{s}, m]\overline{U}_{\hat{s}m} + \Pr[\theta = 0 \mid a_1 = 0, s, \hat{s}, m]U_{\hat{s}m}) \\
&= e^{rk_2}(0.5\overline{U}_{\hat{s}m} + 0.5U_{\hat{s}m}) \\
&< e^{rk_2}(p(\hat{s}, m)\overline{U}_{\hat{s}m} + [1 - p(\hat{s}, m)]U_{\hat{s}m}) \\
&= U_{\hat{s}m}.
\end{aligned}$$

The inequality arises from $p(\hat{s}, m) > 0.5$ and $\overline{U}_{\hat{s}m} > U_{\hat{s}m}$. The last equality is from Equation (A.2). Consequently, if $d^*_{\hat{s}m} = 1$, $D(a_1 = 0, s, \hat{s}, m) = U_{\hat{s}m}$.

Case 3 (Off-Equilibrium Path Where the CEO Chooses $a_1 = 1$ but Inflates the Report (i.e., $s = B$ but $\hat{s} = \hat{G}$)). In this case, the board's signal is uninformative; hence the true project quality is

$$\Pr[\theta = 1 | a_1 = 1, s = B, \hat{s} = \hat{G}, m] = \Pr[\theta = 1 \mid a_1 = 1, s = B] = 0.5 - i,$$

which is smaller than the perceived project quality $p(\hat{s}, m)$ that induces $d^*_{\hat{s}m} = 1$. A similar argument as in Case 2 shows that $D(a_1 = 1, s = B, \hat{s} = \hat{G}, m) = U_{\hat{G}m}$.

Case 4 (Off-Equilibrium Path Where the CEO Chooses $a_1 = 1$ but Deflates the Report (i.e., $s = G$ but $\hat{s} = \hat{B}$)). Depending on the board's signal m, there are two cases:

a. For $m = L$, by Proposition 1, $d^*_{\hat{B}L} = 0$. That is, the investment is foregone if both the CEO's report and the board's signal are unfavorable. In this case, by (A.1), $D(a_1 = 1, s = G, \hat{s} = \hat{B}, m = L) = U_{\hat{B}L}$.

b. For $m = H$, by Proposition 1, $d^*_{\hat{B}H}$ may equal 0 or 1 depending on the level of board expertise j. In the case that $d^*_{\hat{B}H} = 1$, because the CEO deflates her report, the board's signal will be uninformative, and the true project quality is

$$\Pr[\theta = 1 | a_1 = 1, s = G, \hat{s} = \hat{B}, m = H] = \Pr[\theta = 1 \mid a_1 = 1, s = G] = 0.5 + i.$$

Therefore, by (A.1),

$$\begin{aligned}
&D\left(a_1 = 1, s = G, \hat{s} = \hat{B}, m = H\right) \\
&= \max\left\{U_{\hat{B}H}, e^{rk_2}\left[(0.5 + i)\overline{U}_{\hat{B}H} + (0.5 - i)U_{\hat{B}H}\right]\right\} \\
&= \max\left\{U_{\hat{B}H}, e^{rk_2}\left[(0.5 + i)\left(\overline{U}_{\hat{B}H} - U_{\hat{B}H}\right) + U_{\hat{B}H}\right]\right\} \\
&= \max\left\{U_{\hat{B}H}, e^{rk_2}\left[\frac{(0.5 + i)\left(e^{-rk_2} - 1\right)}{p\left(\hat{B}, H\right)} + 1\right]U_{\hat{B}H}\right\}.
\end{aligned}$$

The last equality arises from $\overline{U}_{\hat{B}H} - U_{\hat{B}H} = \frac{(e^{-rk_2} - 1)}{p(\hat{B}, H)}U_{\hat{B}H}$, which is derived from the binding implementation effort constraint (A.2). Therefore,

$$\begin{aligned}
&D\left(a_1 = 1, s = G, \hat{s} = \hat{B}, m = H\right) \\
&= \begin{cases} U_{\hat{B}H} & \text{if } d^*_{\hat{B}H} = 0 \\ \max\left\{U_{\hat{B}H}, e^{rk_2}\left[\frac{(0.5 + i)\left(e^{-rk_2} - 1\right)}{p\left(\hat{B}, H\right)} + 1\right]U_{\hat{B}H}\right\} & \text{if } d^*_{\hat{B}H} = 1 \end{cases} \\
&= U_{\hat{B}H}\left(1 + d^*_{\hat{B}H} \cdot \max\left\{0, e^{rk_2}\left[\frac{(0.5 + i)\left(e^{-rk_2} - 1\right)}{p\left(\hat{B}, H\right)} + 1\right] - 1\right\}\right) \\
&= U_{\hat{B}H}\left(1 + d^*_{\hat{B}H} \cdot \max\left\{0, \frac{0.5 + i}{p\left(\hat{B}, H\right)} - 1\right\}\left(1 - e^{rk_2}\right)\right). \quad \square
\end{aligned}$$

Appendix B. Proofs of the Main Results

B.1. Proof of Proposition 1

The proof of Proposition 1 follows two steps. In Step 1, we derive the optimal investment decision based on the perceived project quality $p(\hat{s}, m)$. In Step 2, we link the perceived project quality with the level of board expertise.

Step 1. Define p^c as the cutoff project quality that just makes $p(\hat{s}, m)(X - Q_{\hat{s}m}) - I = 0$. Recall that by Equation (2), $Q_{\hat{s}m} = -\frac{1}{r}\ln(1 - \frac{1 - e^{-rk_2}}{p(\hat{s}, m)})$. Therefore, p^c is determined by

$$p^c\left(X + \frac{1}{r}\ln\left(1 - \frac{1 - e^{-rk_2}}{p^c}\right)\right) - I = 0. \tag{B.1}$$

Then the optimal investment decision is

$$d^*_{\hat{s}m} = 1 \quad \text{if and only if} \quad p(\hat{s}, m) \geq p^c.$$

Proof. The board's optimization program at date 5 is

$$d^*_{\hat{s}m} \in \underset{d \in \{0,1\}}{\operatorname{argmax}} \; d \cdot [p(\hat{s}, m)(X - Q_{\hat{s}m}) - I] - W_{\hat{s}m}.$$

The solution is

$$d^*_{\hat{s}m} = 1 \quad \text{if and only if} \quad p(\hat{s}, m)(X - Q_{\hat{s}m}) - I \geq 0.$$

Note that p^c is the cutoff project quality that just makes $p(\hat{s}, m)(X - Q_{\hat{s}m}) - I = 0$. Therefore, to show that the optimal investment decision is to invest if and only if $p(\hat{s}, m) \geq p^c$, all we need to show is that $\frac{d\,[p(\hat{s},m)(X-Q_{\hat{s}m})-I]}{d\,p(\hat{s},m)} > 0$. Given

$$\frac{d\,[p(\hat{s}, m)(X - Q_{\hat{s}m}) - I]}{d\,p(\hat{s}, m)} = X - \frac{d\,p(\hat{s}, m)Q_{\hat{s}m}}{d\,p(\hat{s}, m)},$$

a sufficient condition for $\frac{d\,[p(\hat{s},m)(X-Q_{\hat{s}m})-I]}{d\,p(\hat{s},m)} > 0$ is to show that $\frac{d\,p(\hat{s},m)Q_{\hat{s}m}}{d\,p(\hat{s},m)} < 0$, which implies that the firm pays less in expected bonus when the project is more likely to succeed. Plugging in $Q_{\hat{s}m}$,

$$p(\hat{s}, m)Q_{\hat{s}m} = p(\hat{s}, m)\left[-\frac{1}{r}\ln\left(1 - \frac{1 - e^{-rk_2}}{p(\hat{s}, m)}\right)\right].$$

Tedious algebra shows that

$$\frac{d\,p(\hat{s}, m)Q_{\hat{s}m}}{d\,p(\hat{s}, m)} = -\frac{1}{r}\left[\ln\left(1 - \frac{1 - e^{-rk_2}}{p(\hat{s}, m)}\right) + \frac{\frac{1-e^{-rk_2}}{p(\hat{s},m)}}{1 - \frac{1-e^{-rk_2}}{p(\hat{s},m)}}\right],$$

$$\frac{d^2\,[p(\hat{s}, m)Q_{\hat{s}m}]}{d\,p(\hat{s}, m)d\,k_2} = -\frac{1}{\left(1 - \frac{1-e^{-rk_2}}{p(\hat{s},m)}\right)^2}\frac{(1 - e^{-rk_2})}{p(\hat{s}, m)}\frac{e^{-rk_2}}{p(\hat{s}, m)} < 0.$$

The last inequality comes from $0 < e^{-rk_2} < 1$ for any $k_2 > 0$. Hence, for any $k_2 > 0$,

$$\frac{d\,p(\hat{s}, m)Q_{\hat{s}m}}{d\,p(\hat{s}, m)} < \left.\frac{d\,p(\hat{s}, m)Q_{\hat{s}m}}{d\,p(\hat{s}, m)}\right|_{k_2=0} = 0. \quad \square$$

Step 2. We link the perceived project quality $p(\hat{s}, m)$ with the level of board expertise j and the CEO's report $\hat{s}$ and the board's signal m. If $j < i$, the ranking of $p(\hat{s}, m)$ is

$$p\left(\hat{G}, H\right) > p\left(\hat{G}, L\right) > \underbrace{0.5}_{\text{the prior}} > p\left(\hat{B}, H\right) > p\left(\hat{B}, L\right). \tag{B.2}$$

Next, we compare p^c with $p(\hat{s}, m)$. Recall that $I = 0.5X$, and therefore, by (B.1), p^c is determined by

$$p^c\left(X + \frac{1}{r}\ln\left(1 - \frac{1 - e^{-rk_2}}{p^c}\right)\right) - 0.5X = 0$$

$$\Leftrightarrow (p^c - 0.5)X + p^c\underbrace{\frac{1}{r}\ln\left(1 - \frac{1 - e^{-rk_2}}{p^c}\right)}_{-} = 0$$

$$\Rightarrow p^c > 0.5.$$

This implies that after considering the implementation cost, the investment threshold is higher than 0.5, the prior. Clearly, $p^c(X, k_2)$ is a function of X and k_2.

Now let us look back to the ranking of $p(\hat{s}, m)$ in (B.2). Clearly, $p^c > p(\hat{B}, H) > p(\hat{B}, L)$; hence $d^*_{\hat{B}H} = d^*_{\hat{B}L} = 0$. We now need to compare $p(\hat{G}, L)$ with p^c. Define δ_1 such that $p(\hat{G}, L)\,|_{j=i-\delta_1} = p^c$. Because $p(\hat{G}, L)$ is decreasing in j, then for $j \leq i - \delta_1$, $p(\hat{G}, L) \geq p^c$ and consequently $d^*_{\hat{G}L} = 1$. For $j > i - \delta_1$, $p(\hat{G}, L) < p^c$, and therefore $d^*_{\hat{G}L} = 0$.

The case of $j > i$ is symmetric and hence the detailed reasoning is omitted. In that case, the key is the comparison of $p(\hat{B}, H)$ with p^c. Therefore, we define δ_2 such that $p(\hat{B}, H)\,|_{j=i+\delta_2} = p^c$.

Plugging in the terms, $\delta_1(X, k_2, i)$ and $\delta_2(X, k_2, i)$ are determined, respectively, by

$$p\left(\hat{G}, L\right)|_{j=i-\delta_1} = \frac{1}{1 + \frac{(0.5-i)(0.5+i-\delta_1)}{(0.5+i)(0.5-i+\delta_1)}} = p^c(X, k_2), \tag{B.3}$$

$$p\left(\hat{B}, H\right)|_{j=i+\delta_2} = \frac{1}{1 + \frac{(0.5+i)(0.5-i-\delta_2)}{(0.5-i)(0.5+i+\delta_2)}} = p^c(X, k_2). \quad \square \tag{B.4}$$

Proof of Proposition 2. Without (TT_s) constraints, the new optimization program $\mathcal{P}^N$ is (recall that $W_{\hat{s}m} = \Phi(U_{\hat{s}m}) = -\frac{1}{r}\ln(-U_{\hat{s}m})$)

$$\min_{\{U_{\hat{s}m} \in R\}} CC_{a_1+\mathrm{TT}} = (0.25 + ij)[\Phi(U_{\hat{G}H}) + \Phi(U_{\hat{B}L})] + (0.25 - ij)[\Phi(U_{\hat{B}H}) + \Phi(U_{\hat{G}L})]$$

subject to

$$EU \geq 0.5U_{\hat{G}H} + 0.5U_{\hat{G}L}, \tag{$IC - a_1 - 1$}$$

$$EU \geq 0.5U_{\hat{B}H} + 0.5U_{\hat{B}L}, \tag{$IC - a_1 - 2$}$$

$$EU \geq -e^{r \cdot 0} = -1, \tag{IR}$$

where $EU = e^{rk_1}[(0.25 + ij)(U_{\hat{G}H} + U_{\hat{B}L}) + (0.25 - ij)(U_{\hat{B}H} + U_{\hat{G}L})]$.

Step 1. We show that the solution to program $\mathcal{P}^N$ is the same as that to the following program $\mathcal{P}'$:

$$\min_{\{U_{\hat{s}m} \in R\}} \quad CC_{a_1+\mathrm{TT}} = (0.25 + ij)[\Phi(U_{\hat{G}H}) + \Phi(U_{\hat{B}L})] + (0.25 - ij)[\Phi(U_{\hat{B}H}) + \Phi(U_{\hat{G}L})]$$

subject to

$$EU \geq 0.25(U_{\hat{B}H} + U_{\hat{B}L} + U_{\hat{G}L} + U_{\hat{G}H}), \tag{$IC' - a_1$}$$

$$EU \geq -e^{r \cdot 0} = -1. \tag{IR}$$

Proof. Note that the constraint $(IC' - a_1)$ derives from $(IC - a_1 - 1) + (IC - a_1 - 2)$. Clearly, the constraints in program $\mathcal{P}'$ are more relax than the constraints in the original program $\mathcal{P}^N$.

Next we show that for program $\mathcal{P}'$, the optimal solutions entail that $U_{\hat{G}H} = U_{\hat{B}L}$ and $U_{\hat{B}H} = U_{\hat{G}L}$. Let μ and λ denote the Lagrangian multipliers for constraints $(IC' - a_1)$ and (IR), respectively. The first-order conditions are

$$\Phi'(U_{\hat{G}H}) = \lambda e^{rk_1} + \mu\left[e^{rk_1} - \frac{0.25}{0.25 + ij}\right],$$

$$\Phi'(U_{\hat{B}L}) = \lambda e^{rk_1} + \mu\left[e^{rk_1} - \frac{0.25}{0.25 + ij}\right].$$

Given that $\Phi'(U) = -\frac{1}{rU}$ is monotonic in U, $\Phi'(U_{\hat{G}H}) = \Phi'(U_{\hat{B}L})$ implies that $U_{\hat{G}H} = U_{\hat{B}L}$. In the same way, we find $U_{\hat{B}H} = U_{\hat{G}L}$.

Given $U_{\hat{G}H} = U_{\hat{B}L}$ and $U_{\hat{B}H} = U_{\hat{G}L}$, the constraint ($IC' - a_1$) is exactly the same as ($IC - a_1 - 1$) and ($IC - a_1 - 2$). Therefore, the solution to the relaxed program $\mathcal{P}'$ will also satisfy the constraints in the original program $\mathcal{P}^N$ and will be the solution to the original program $\mathcal{P}^N$. ◻

Step 2. We solve for program $\mathcal{P}'$. Plugging in $U_{\hat{G}H} = U_{\hat{B}L}$ and $U_{\hat{B}H} = U_{\hat{G}L}$ to program $\mathcal{P}'$, and taking the first-order conditions, we get

$$\Phi'(U_{\hat{G}H}) = \mu\left[e^{rk_1} - \frac{0.5}{0.5+2ij}\right] + \lambda e^{rk_1},$$

$$\Phi'(U_{\hat{G}L}) = \mu\left[e^{rk_1} - \frac{0.5}{0.5-2ij}\right] + \lambda e^{rk_1}.$$

We argue that $\mu > 0$. Suppose not; instead, suppose that $\mu = 0$; then it follows that $U_{\hat{G}H} = U_{\hat{G}L}$, which will violate constraint ($IC' - a_1$).

Note that $\mu > 0$ implies that constraint ($IC' - a_1$) is binding. It is easy to show that for this type of moral hazard problem, constraint (IR) is always binding. With both constraints binding, we can solve for the choice variables:

$$U^*_{\hat{G}H} = U^*_{\hat{B}L} = -1 + \frac{1-e^{-rk_1}}{4ij},$$

$$U^*_{\hat{B}H} = U^*_{\hat{G}L} = -1 - \frac{1-e^{-rk_1}}{4ij}. \quad ◻$$

Proof of Proposition 3. If $j < i + \delta_2$, then by Proposition 1, $d^*_{\hat{B}H} = 0$. The reporting constraints are ((TT^0_G) represents the (TT_G) constraint for $d^*_{\hat{B}H} = 0$)

$$(0.5+2ij)U_{\hat{G}H} + (0.5-2ij)U_{\hat{G}L} \ge 0.5U_{\hat{B}H} + 0.5U_{\hat{B}L}, \qquad (TT^0_G)$$

$$(0.5-2ij)U_{\hat{B}H} + (0.5+2ij)U_{\hat{B}L} \ge 0.5U_{\hat{G}H} + 0.5U_{\hat{G}L}. \qquad (TT_B)$$

It is easy to verify that with $U^*_{\hat{G}H} = U^*_{\hat{B}L} > U^*_{\hat{B}H} = U^*_{\hat{G}L}$ as characterized in Proposition 2, both constraints (TT^0_G) and (TT_B) are slack. Therefore, the optimal solution in this case is the same as that characterized in Proposition 2. ◻

Proof of Proposition 4. If $j \ge i + \delta_2$, then by Proposition 1, $d^*_{\hat{B}H} = 1$. The (TT_B) constraint is the same, but (TT_G) becomes

$$(0.5+2ij)U_{\hat{G}H} + (0.5-2ij)U_{\hat{G}L} \ge 0.5U_{\hat{B}H}\left(1 + \max\left\{0, \frac{0.5+i}{p(\hat{B},H)} - 1\right\}\left(1 - e^{rk_2}\right)\right) + 0.5U_{\hat{B}L}. \qquad (TT^1_G)$$

Substituting the solution in Proposition 2 into the current (TT_s) constraint, it is easy to verify that constraint (TT_B) is slack. Constraint (TT^1_G) is reduced to

$$1 - e^{-rk_1} \ge 0.5\max\left\{0, \frac{0.5+i}{p(\hat{B},H)} - 1\right\}\left(e^{rk_2} - 1\right)\left(1 + \frac{1-e^{-rk_1}}{4ij}\right). \qquad (B.5)$$

Define

$$Z \equiv \frac{1-e^{-rk_1}}{1+\frac{1-e^{-rk_1}}{4ij}} - 0.5\left(e^{rk_2}-1\right)\cdot\max\left\{0, \frac{0.5+i}{p(\hat{B},H)} - 1\right\}.$$

If $Z \ge 0$, then the (TT^1_G) constraint is also slack. Therefore, the optimal solution of program $\mathcal{P}$ in this case is the same as that characterized in Proposition 2.

In contrast, if $Z < 0$, then the (TT^1_G) constraint in this program must be binding. We prove by contradiction. Suppose that the (TT^1_G) constraint is instead slack, then the optimal solution is the same as that characterized in Proposition 2, and the (TT^1_G) constraint can be reduced to (B.5). If $Z < 0$, the (TT^1_G) constraint is violated, which implies a contradiction. ◻

Proof of Lemma 2. Recall that

$$EV_{a_2} \equiv \sum_{s\in\{G,B\},m\in\{H,L\}} \Pr[s,m \mid a_1 = 1, \hat{s} = s]\cdot d^*_{\hat{s}m} \cdot \left[p(\hat{s},m)(X - Q_{\hat{s}m}) - I\right].$$

Because $d^*_{\hat{s}m}$ is chosen optimally to maximize $d\cdot[p(\hat{s},m)\cdot(X - Q_{\hat{s}m}) - I]$, which is continuous in j, it is clear that the value function $d^*_{\hat{s}m}\cdot[p(\hat{s},m)(X - Q_{\hat{s}m}) - I]$ is also continuous in j, and so is EV_{a_2}.

We can separate EV_{a_2} into two parts:

$$EV_{a_2} \equiv \underbrace{\sum_{s\in\{G,B\},m\in\{H,L\}} \Pr[s,m \mid a_1 = 1, \hat{s} = s]\cdot d^*_{\hat{s}m}\cdot\left[p(\hat{s},m)X - I\right]}_{\text{expected cash flow}} - CC_{a_2},$$

where

$$CC_{a_2} \equiv \sum_{s\in\{G,B\},m\in\{H,L\}} \Pr[s,m \mid a_1 = 1, \hat{s} = s]\cdot d^*_{\hat{s}m}\cdot p(\hat{s},m)\cdot Q_{\hat{s}m}.$$

Thus, CC_{a_2} represents the ex ante compensation cost of motivating the CEO's implementation effort. Because the optimal investment decision $d^*_{\hat{s}m}$ varies for different j regions (Proposition 1), below we examine how EV_{a_2} changes with j for three regions of j:

1. If $j \le i - \delta_1$, the optimal investment policy is $d^*_{\hat{G}m} = 1$ and $d^*_{\hat{B}m} = 0$ for $m \in \{H, L\}$. Then

$$EV_{a_2}(j \le i - \delta_1) = 0.5[(0.5+i)X - I] - CC_{a_2}(j \le i - \delta_1), \quad (B.6)$$

where

$$\begin{aligned} CC_{a_2}(j \le i - \delta_1) &= 0.5(0.5+i)(0.5+j)\underbrace{\left[-\frac{1}{r}\ln\left(1 - \frac{1-e^{-rk_2}}{p(\hat{G},H)}\right)\right]}_{Q_{\hat{G}H}} \\ &\quad + 0.5(0.5+i)(0.5-j)\underbrace{\left[-\frac{1}{r}\ln\left(1 - \frac{1-e^{-rk_2}}{p(\hat{G},L)}\right)\right]}_{Q_{\hat{G}L}} \\ &= -\frac{1}{r}0.5(0.5+i) \\ &\quad \cdot \underbrace{\left\{(0.5+j)\ln\left(1 - \frac{1-e^{-rk_2}}{p(\hat{G},H)}\right) + (0.5-j)\ln\left(1 - \frac{1-e^{-rk_2}}{p(\hat{G},L)}\right)\right\}}_{\equiv\Omega}. \end{aligned} \quad (B.7)$$

The term inside the braces, Ω, is the expected utility of a risk-averse individual with utility function $\ln(\cdot)$ who is facing the following lottery:

$$\begin{cases} 1-\dfrac{1-e^{-rk_2}}{p(\hat{G},H)} & \text{with probability } 0.5+j, \\ 1-\dfrac{1-e^{-rk_2}}{p(\hat{G},L)} & \text{with probability } 0.5-j. \end{cases}$$

The mean of the lottery is $1-\frac{1-e^{-rk_2}}{0.5+i}$, which is independent of j. At the same time, as j increases, $p(\hat{G},H)$ increases and $p(\hat{G},L)$ decreases. As a result, the larger value $1-\frac{1-e^{-rk_2}}{p(\hat{G},H)}$ becomes even larger and the smaller value $1-\frac{1-e^{-rk_2}}{p(\hat{G},L)}$ becomes even smaller. That is, as j increases, the lottery becomes a mean-preserving spread of the original lottery. Therefore, Ω is decreasing in j, which leads to $\frac{dCC_{a_2}(j\le i-\delta_1)}{dj}>0.$[22] Hence,

$$\frac{dEV_{a_2}(j\le i-\delta_1)}{dj}=-\frac{dCC_{a_2}(j\le i-\delta_1)}{dj}<0.$$

2. If $i-\delta_1<j<i+\delta_2$, the optimal investment policy is $d^*_{\hat{G}H}=1$. Then

$$EV_{a_2}(i-\delta_1<j<i+\delta_2)=(0.25+ij)\left[p\left(\hat{G},H\right)\left(X-Q_{\hat{G}H}\right)-I\right].$$

Therefore,

$$\begin{aligned}\frac{dEV_{a_2}(i-\delta_1<j<i+\delta_2)}{dj} &= i\underbrace{\left[p\left(\hat{G},H\right)\left(X-Q_{\hat{G}H}\right)-I\right]}_{+,\text{ by } d^*_{\hat{G}H}=1} \\ &\quad+(0.25+ij)\underbrace{\frac{d\left[p\left(\hat{G},H\right)\left(X-Q_{\hat{G}H}\right)\right]}{d\,p\left(\hat{G},H\right)}}_{+,\text{by proof of Proposition 1}}\underbrace{\frac{dp\left(\hat{G},H\right)}{dj}}_{+} \\ &>0.\end{aligned}$$

3. If $j\ge i+\delta_2$, the optimal investment policy is $d^*_{\hat{s}H}=1$ and $d^*_{\hat{s}L}=0$. Then

$$\begin{aligned}EV_{a_2}(j\ge i+\delta_2) &= (0.25+ij)\left[p\left(\hat{G},H\right)\left(X-Q_{\hat{G}H}\right)-I\right] \\ &\quad+(0.25-ij)\left[p\left(\hat{B},H\right)\left(X-Q_{\hat{B}H}\right)-I\right].\end{aligned}$$

Therefore,

$$\begin{aligned}\frac{dEV_{a_2}(j\ge i+\delta_2)}{dj} &= i\underbrace{\left[p\left(\hat{G},H\right)\left(X-Q_{\hat{G}H}\right)-p\left(\hat{B},H\right)\left(X-Q_{\hat{B}H}\right)\right]}_{+} \\ &\quad+(0.25+ij)\underbrace{\frac{d\left[p\left(\hat{G},H\right)\left(X-Q_{\hat{G}H}\right)\right]}{d\,p\left(\hat{G},H\right)}}_{+}\underbrace{\frac{dp\left(\hat{G},H\right)}{dj}}_{+} \\ &\quad+(0.25-ij)\underbrace{\frac{d\left[p\left(\hat{B},H\right)\left(X-Q_{\hat{B}H}\right)\right]}{d\,p\left(\hat{B},H\right)}}_{+}\underbrace{\frac{dp\left(\hat{B},H\right)}{dj}}_{+} \\ &>0.\end{aligned}$$

The terms in the brackets are all positive because $p(\hat{s},m)(X-Q_{\hat{s}m})$ is increasing in $p(\hat{s},m)$, which is proven in Step 1 of the proof of Proposition 1. □

Proof of Lemma 3. Recall that by Propositions 3 and 4, the reporting constraint (TT_G) takes different forms at the two sides of $j=i+\delta_2$. If $j<i+\delta_2$, (TT_G) takes the form of (TT_G^0), which is always slack (Proposition 3). If $j\ge i+\delta_2$, constraint (TT_G) becomes (TT_G^1), which is slack if and only if $Z\ge 0$ (Proposition 4). Therefore, to check as to whether the value function CC_{a_1+TT} is continuous at $j=i+\delta_2$, the key is to examine whether constraint (TT_G^1) is binding at $j=i+\delta_2$ (i.e., whether Z is positive at $j=i+\delta_2$).

By the proof of Proposition 1, δ_2 is a function of X and k_2 but is independent of k_1. Define $\zeta(k_1,k_2)$ as the value of Z at $j=i+\delta_2(k_2)$:

$$\begin{aligned}\zeta(k_1,k_2) &\equiv Z\left(k_1,k_2,j=i+\delta_2(k_2)\right) \\ &= \frac{1-e^{-rk_1}}{1+\frac{1-e^{-rk_1}}{4i(i+\delta_2(k_2))}}-0.5\left(e^{rk_2}-1\right)\cdot\max\left\{0,\frac{0.5+i}{p^c(k_2)}-1\right\},\end{aligned}$$

where we apply that definition of δ_2, which is $p(\hat{B},H)|_{j=i+\delta_2}=p^c$.[23]

To evaluate when $\zeta(\cdot)$ is positive, we define $f_1(k_2)$ as the cutoff k_1 value that makes $\zeta(\cdot)=0$:

$$\zeta(k_1=f_1(k_2),k_2)=0. \tag{B.8}$$

In addition, note that

$$\frac{\partial\,\zeta(\cdot)}{\partial\,k_1}=\frac{\partial\,Z(\cdot)}{\partial\,k_1}>0.$$

Therefore, for $k_1\ge f_1(k_2)$, $\zeta(k_1,k_2)\ge 0$, and for $k_1<f_1(k_2)$, $\zeta(k_1,k_2)<0$.

1. For $k_1\ge f_1(k_2)$, $\zeta(k_1,k_2)\ge 0$; that is, Z is (weakly) positive at $j=i+\delta_2$. It is easy to verify that Z is increasing in j (see the online appendix); therefore, Z will be positive for all $j>i+\delta_2$. This implies that constraint (TT_G^1) will be slack for all $j\ge i+\delta_2$. Recall that constraint (TT_G^0) is always slack for $j<i+\delta_2$. Hence, for all level of j, the optimal solution is the same as that characterized in Proposition 2. Plugging in the optimal solution, we get

$$\begin{aligned}CC_{a_1+\mathrm{TT}} &= \sum_{s\in\{G,B\},m\in\{H,L\}}\Pr[s,m\mid a_1=1,\hat{s}=s]\cdot W^*_{\hat{s}m} \\ &= -\frac{1}{r}\left\{(0.5+2ij)\ln\left(1-\frac{1-e^{-rk_1}}{4ij}\right)\right. \\ &\qquad\left.+(0.5-2ij)\ln\left(1+\frac{1-e^{-rk_1}}{4ij}\right)\right\}.\end{aligned} \tag{B.9}$$

Applying the same mean-preserving spread argument as in the proof of CC_{a_2}, we could show that as j increases, the lottery becomes a mean-preserving contraction of the original lottery. Hence, $CC_{a_1+\mathrm{TT}}$ is decreasing in j.[24]

2. For $k_1<f_1(k_2)$, $\zeta(k_1,k_2)<0$; that is, Z is negative at $j=i+\delta_2$. This implies that (TT_G^1) is binding at $j=i+\delta_2$. Note that (TT_G) takes different forms at the two sides of $j=i+\delta_2$. Therefore, (TT_G) does not go from no-binding to just binding at $j=i+\delta_2$. Instead, starting from $j=i+\delta_2$, (TT_G) takes the

new form (TT_G^1), which is *strictly* binding at $j = i + \delta_2$. The shadow cost of the binding (TT_G^1) constraint depends on k_1: the smaller the k_1, that is, the further away from $f_1(k_2)$, the larger is the shadow cost. This shadow cost explains the discrete jump of CC_{a_1+TT} at $j = i + \delta_2$. □

Technical Lemma

For the proof of Proposition 5, we will need the technical lemma that characterizes the properties of CC_{a_1+TT} and CC_{a_2}.

Lemma B.1.

1. *If the reporting constraints* (TT_G) *and* (TT_B) *are slack, then*

$$\frac{d\ CC_{a_1+TT}}{d\ j} < 0, \quad \frac{d^2\ CC_{a_1+TT}}{dj\ dk_1} < 0, \quad \text{and} \quad \frac{d^2\ CC_{a_1+TT}}{d\ j^2} > 0.$$

2. *If* $j \le i - \delta_1$, *then*

$$\frac{d\ CC_{a_2}}{d\ j} > 0 \quad \text{and} \quad \frac{d^2\ CC_{a_2}}{d\ j^2} > 0.$$

The proof of Lemma B.1 is relegated to the online appendix. □

Proof of Proposition 5. The proof of Proposition 5 follows two steps. Step 1 examines how firm value FV changes with j for $j \le i - \delta_1$. Step 2 studies how FV changes with j for $j > i - \delta_1$.

Step 1. We show that for $j \le i - \delta_1$, FV is continuous in j and

$$\frac{dFV}{dj}\begin{cases} > 0 & \text{if } k_1 > f_2(k_2) \\ < 0 & \text{if } k_1 < f_3(k_2). \end{cases}$$

Proof. If $j \le i - \delta_1$, by (B.6),

$$FV = EV_{a_2} - CC_{a_1+TT} = 0.5[(0.5 + i)X - I] - CC_{a_2} - CC_{a_1+TT}.$$

In this region, both EV_{a_2} and CC_{a_1+TT} are continuous in j. Hence, FV is continuous in j. Furthermore,[25]

$$\frac{dFV}{dj}(k_1,k_2,i,j) = -\underbrace{\frac{dCC_{a_2}}{dj}(k_2,i,j)}_{+,\text{ by Lemma B.1}} - \underbrace{\frac{dCC_{a_1+TT}}{dj}(k_1,i,j)}_{-,\text{ by Lemma B.1}}.$$

That is, for $j \le i - \delta_1$, board expertise j does not affect investment decision, so the impact of j on FV is through its impact on CC_{a_2} and CC_{a_1+TT}, which have opposite directions.

Define $f_2(k_2)$ and $f_3(k_2)$, respectively, as the cutoff k_1 values such that $\frac{dFV}{dj} = 0$ at $j = i$ and $j = \underline{j}$; that is,

$$\frac{dFV}{dj}\left(k_1 = f_2(k_2), k_2, i, j = i\right) = 0, \tag{B.10}$$

$$\frac{dFV}{dj}\left(k_1 = f_3(k_2), k_2, i, j = \underline{j}\right) = 0. \tag{B.11}$$

Note that by the technical Lemma B.1, we can show that

$$\frac{d^2FV}{dj^2} = -\frac{d^2CC_{a_2}}{dj^2} - \frac{d^2CC_{a_1+TT}}{dj^2} < 0, \tag{B.12}$$

$$\frac{d^2FV}{djdk_1} = -\frac{d^2CC_{a_1+TT}}{djdk_1} > 0. \tag{B.13}$$

Therefore, if $k_1 > f_2(k_2)$, for $j \le i - \delta_1$,

$$\frac{dFV}{dj}(k_1,k_2,i,j) > \frac{dFV}{dj}(k_1,k_2,i,j = i) > \frac{dFV}{dj}\left(k_1 = f_2(k_2),k_2,i,j = i\right) = 0.$$

The first inequality arises from $j \le i - \delta_1 < i$ and $\frac{d^2FV}{dj^2} < 0$; the second inequality is due to $k_1 > f_2(k_2)$ and $\frac{d^2FV}{djdk_1} > 0$; the last equality is due to the definition of $f_2(k_2)$ in (B.10).

Similarly, if $k_1 < f_3(k_2)$, then for all $j \ge \underline{j}$,

$$\frac{dFV}{dj}(k_1,k_2,i,j) \le \frac{dFV}{dj}\left(k_1,k_2,i,j = \underline{j}\right) < \frac{dFV}{dj}\left(k_1 = f_3(k_2),k_2,i,j = \underline{j}\right) = 0.$$

The first inequality arises from $j \ge \underline{j}$ and $\frac{d^2FV}{dj^2} < 0$; the second inequality is due to $k_1 < f_3(k_2)$ and $\frac{d^2FV}{djdk_1} > 0$; the last equality is due to the definition of $f_3(k_2)$ in (B.11). □

Step 2. For $j > i - \delta_1$,

$$\begin{cases} FV \text{ is continuously increasing in } j, & \text{if } k_1 \ge f_1(k_2) \\ FV \text{ has a discrete drop at } j = i + \delta_2, & \text{if } k_1 < f_1(k_2). \end{cases}$$

Proof. Recall that $FV = EV_{a_2} - CC_{a_1+TT}$. For $j > i - \delta_1$, Lemma 2 shows that EV_{a_2} is continuously increasing in j. On the CC_{a_1+TT} side, by Lemma 3, for $k_1 \ge f_1(k_2)$, CC_{a_1+TT} is continuously decreasing in j. Combining both effects together, if $k_1 \ge f_1(k_2)$, FV is continuously increasing in j.

In contrast, Lemma 3 shows that for $k_1 < f_1(k_2)$, there is a discrete jump of CC_{a_1+TT} at $j = i + \delta_2$. Given that EV_{a_2} is continuous, $FV = EV_{a_2} - CC_{a_1+TT}$ will have a discrete drop at $j = i + \delta_2$. □

Finally, note that both EV_{a_2} and CC_{a_1+TT} are continuous at $j = i - \delta_1$. Combining Step 1 and Step 2 together,

a. For $k_1 > \max\{f_1(k_2), f_2(k_2)\}$, FV is continuous and increasing in j.

b. For $k_1 < \min\{f_1(k_2), f_3(k_2)\}$, $\frac{dFV}{dj} < 0$ for $j \le i - \delta_1$, and FV has a discrete drop at $j = i + \delta_2$. □

Endnotes

[1] Proxy Disclosure Enhancements, SEC Rel. No. 33-9089 (December 16, 2009), 74 Fed. Reg. 68334, available at http://www.sec.gov/rules/final/2009/33-9089.pdf.

[2] In their sample, Schwartz-Ziv and Weisbach (2013) show that in 61% of cases, the boards receive formal opportunities to make decisions.

[3] In practice, boards usually assess CEOs' compensation arrangements at least annually to ensure that the current incentive plan provides optimal motivation. Contract renegotiation is commonly used in the literature to model the periodic adjustment in CEO contracts (Laux 2008, Tian 2014).

[4] Schwartz-Ziv and Weisbach (2013) show that in 2.5% of the cases, boards partially or completely vote against the CEO. According to the PricewaterhouseCoopers (PWC) 2017 Annual Corporate Directors Survey, 60% of directors say their board strongly challenges management assumptions on strategy.

[5] This underreporting incentive is in the similar spirit to the misreporting incentive in the capital budgeting literature (Antle and Eppen 1985, Baiman et al. 2013) but is associated with the effort problems.

[6] In our complete contracting setting, the CEO is not an empire builder and therefore has no incentive to overreport project quality.

[7] For example, Masulis et al. (2012), Dass et al. (2014), Faleye et al. (2018), and Kang et al. (2018) find that directors with industry expertise are positively associated with various firm performance measures. However, Guner et al. (2008) find firms with bankers on boards (as a form of expertise) are associated with worse acquisition outcomes. Minton et al. (2014) show that financial expertise is weakly associated with better performance before the 2007–2008 financial crisis but that it is strongly associated with lower performance dur-ing the crisis. Almandoz and Tilcsik (2016) find that in the presence of significant decision uncertainty, a higher proportion of experts on a board is associated with a higher likelihood of organizational failure.

[8] Related to the managerial power view, Friedman (2014) examines the effects of a CEO's power to press a chief financial officer to bias earnings. Baldenius et al. (2014) study how CEO power affects board composition.

[9] For example, Drymiotes (2007) and Kumar and Sivaramakrishnan (2008) show that greater board dependence may lead to greater board monitoring incentives. Laux (2008) demonstrates that board dependence can serve as a commitment device and curb excessive CEO turnover. Goex (2016) examines the economic consequences of say on pay when the firm's governance structure is endogenous.

[10] Our main results will be qualitatively unchanged for an alternative information structure in which the accuracy of the board's signal is solely determined by board expertise j. The benefit of our baseline information structure is to guarantee that it is always optimal to induce evaluation effort and truth telling (the two key incentive concerns that we observe in practice). The analysis of the alternative information structure is available upon request.

[11] According to the PWC 2017 Annual Corporate Directors Survey, 93% of directors say that their management teams are at least somewhat effective (55% say "very effective" and 38% say "somewhat effective") in providing the appropriate materials for directors to evaluate proposed strategies.

[12] For general priors $\Pr(\theta = 1) = q$, the normalized condition would be $I = qX$.

[13] One might think that the CEO's compensation should also depend on whether the investment is undertaken. However, because the investment decision will be fully determined by the CEO's report $\hat{s}$ and the board's signal m, the investment decision itself does not provide any additional information on top of the $(\hat{s}, m)$ combination and will be redundant in the CEO's compensation contract.

[14] Because we focus on pure strategy equilibria, there is no information asymmetry *on the equilibrium path*. Therefore, for each information event $(\hat{s}, m)$, the board just proposes *one* revised contract based on its equilibrium belief.

[15] Recall that the board's information is pure noise if the CEO misreports. Hence, the board always prefers to induce the CEO's truthful report, for a large enough X.

[16] That is, the board's project evaluation role helps provide incentives to motivate the CEO's evaluation effort. Related, Drymiotes and Sivaramakrishnan (2012) also show that the board's consulting role may have a positive externality on the CEO's performance evaluation. The result that consistent reports receive a reward is also shown in more general managerial compensation schemes (Şabac and Tian 2015).

[17] Note that the CEO never has an incentive to overreport her signal. In our complete contracting setting, the CEO does not earn any rent from the investment and therefore has no incentive to overstate the project quality (to induce more investment).

[18] This result echoes the literature demonstrating the superiority of a coarser information system when the principal has no commitment power (Cremer 1995, Arya. et al 1997, 2000).

[19] To provide intuition for the discontinuity, note that our optimization program has a subtle but important difference from a typical optimization program. In our program, there is a regime change: the reporting constraint takes different forms in the left and right limit of $j = i + \delta_2$. For $j < i + \delta_2$, the CEO has no underreporting incentive (because $d^*_{\hat{B}H} = 0$), and hence the reporting constraint is (TT^0_G); for $j \geq i + \delta_2$, in contrast, the CEO's underreporting incentive is induced (because $d^*_{\hat{B}H} = 1$), and the reporting constraint is (TT^1_G). Technically, these are two different constraints. Hence, the reporting constraint does not go from nonbinding to just binding at $j = i + \delta_2$. Instead, starting from $j = i + \delta_2$, the reporting constraint takes a new form, and this new (TT^1_G) constraint is *strictly* binding at $j = i + \delta_2$ for $k_1 < f_1(k_2)$. The shadow cost of the binding (TT^1_G) constraint depends on k_1: the further away k_1 is from $f_1(k_2)$, the larger is the shadow cost. Only in the knife-edge case where $k_1 = f_1(k_2)$ is the new (TT^1_G) constraint just binding at $j = i + \delta_2$, and the shadow cost continuously converges to zero.

[20] The New York Stock Exchange (NYSE) and Nasdaq require that all companies have a majority of independent directors after 2005. The NYSE further requires that the nominating, auditing, and compensation committees of companies listed on the NYSE consist entirely of independent directors. Similar stringent independence requirements on compensation committees are also included in Section 952 of the Dodd–Frank Act of 2010.

[21] For example, according to data from the proxy advisory firm Institutional Shareholder Services, 36% of Stand and Poor's 500 Index companies had no other employee directors besides their CEOs in 1999. The percentage of such companies has increased steadily since then, reaching an astonishing 75% in 2015 (Faleye 2016).

[22] $CC_{a_2}(j \leq i - \delta_1)$ increasing in j is also shown in Lemma B.1. For the purpose of providing better intuition, we rely on the mean-preserving spread here to prove the result.

[23] We suppress the argument X in the $\delta_2(\cdot)$ and $p^c(\cdot)$ functions.

[24] Again, the same result is also shown in Lemma B.1 using a different approach. For the purpose of providing better intuition, we rely on the mean-preserving spread argument.

[25] We spell out all the omitted arguments here. Later, to avoid clutter, we suppress the arguments when there is no scope for confusion. Note that CC_{a_2} depends on k_2 but not k_1. The opposite holds for $CC_{a_1+\mathrm{TT}}$.

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