Board Expertise and Executive Incentives [1]

Xiaojing Meng, NYU Stern

Jie Joyce Tian, University of Waterloo

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Abstract

We investigate how board expertise affects executive incentives and firm value in a project investment setting. To increase the probability of project success, the CEO engages in a sequence of tasks: first acquiring information to evaluate a potential project, then reporting his assessment of the project to the board, and finally implementing the project if invested. We show that the CEO will get a higher compensation if the board and the CEO agrees. Such a compensation arrangement is purely an outcome of optimal contracting, even though the managerial power view may interpret it as evidence that more powerful CEOs get more pay. In addition, board expertise in evaluating the project helps motivate the CEO to acquire information, but may hurt the CEO's incentives to properly implement the project. Consequently, higher board expertise can improve or hurt firm value. We also show that when board expertise is high enough, the CEO has incentives to *underreport* his assessment of the project to the board.

1 Introduction

There has been a long debate on executive compensation in both academia and the public arena. One side is the "optimal contracting" view, which argues that executives' contracts are chosen optimally by the board to maximize shareholder value. The other side is the "managerial power" view (Bebchuk, Fried, and Walker [2002], Bebchuk and Fried [2004]), which claims that the traditional agency models are inconsistent with current compensation practice: because boards of directors at public companies are beholden to the firms' top executives, executives' contracts are effectively chosen by executives themselves to maximize their own rents. Though challenged by some leading researchers (e.g., Murphy [2003], Holmstrom and Kaplan [2003], Holmstrom [2005], Core, Guay and Thomas [2005], among others),[1] the managerial power perspective has been taken very seriously by both scholars and policymakers, and led to major regulatory changes. For example, the SEC mandated increased disclosure of compensation in 2006, and say-on-pay legislation was passed as part of the Dodd-Frank Act in 2010.

One central piece of evidence supporting the managerial power view is that managers with more power over boards will get more pay. In this paper, we study the interaction between the board and the CEO in a principal-agent model and show that the same prediction can also be generated through optimal contracting. To best separate from the managerial power hypothesis, in our model, the board is as-

[1]For example, Murphy [2003] argues that the escalation in executive pay during the 1990s coincided with increasingly independent boards; this evidence is inconsistent with the managerial power hypothesis. Holmstrom [2005] argues that the managerial power hypothesis cannot explain why did the problems with executive pay arise in the 1990s but not earlier, thereby failing the timing test. Moreover, it seems that executive pay patterns in closely held companies like family firms do not significantly deviate from those in widely held companies, hence the managerial power hypothesis also fails the comparative institutional test. Core, Guay and Thomas [2005] argue that "in many settings where managerial power exists, observed contracts anticipate and try to minimize its costs and therefore may in fact be optimal. The optimal contract and managerial power perspectives are not competing explanations of executive pay."

sumed to maximize shareholder value. That is, the contracting between the board and the CEO is completely “arm's-length”, using the terminology in Bebchuk and Fried [2004].

Specifically, we model a project investment setting in which the CEO engages in a sequence of tasks in order to increase the probability of a project success: first acquiring information to evaluate a potential project, then reporting his assessment of the project to the board to seek approval, and finally implementing the project (if invested). The board is not involved with the day-to-day operations of the firm, but can use its (industry, financial or legal) expertise to further evaluate the project's profitability. Based on the available information (which includes both the CEO's report and the board's own incremental assessment), the board makes the investment decision. Then the board's attention shifts to motivating the CEO's implementation task.[2]

We show that the board's expertise in evaluating the project helps motivate the CEO to evaluate the project. As both the CEO and the board conduct analysis about the same project, their assessments are inherently positively correlated, and the more carefully the CEO evaluates the project, the stronger is the correlation. Exploiting this, the board will optimally pay the CEO a higher compensation if the two parties have similar assessment about the project, simply because such agreement is indicative of high evaluation effort by the CEO. Such a compensation arrangement is purely an outcome of optimal contracting, even though the managerial power view may interpret it as evidence that more powerful CEOs get more pay, because board agreeing with CEO is often interpreted as weak boards rubber-stamping powerful CEOs' proposals.

This result also provides a positive perspective on the observed high frequency of board agreement with the CEO (Schwartz-Ziv and Weisbach [2013]). Instead of implying boards rubber-stamping the CEOs' proposal most of the time, the high

[2] In practice, boards usually assess CEOs' compensation arrangement at least annually to ensure the current incentive plan provides optimal motivation.

frequency of board agreement with the CEO could indicate that the board members possess highly relevant expertise and the CEO carefully evaluates the project.

In the event that the CEO and the board's assessments disagree, the investment decision ultimately depends on the one with a (significantly) higher precision.[3] Therefore, the board will overrule the CEO's opinion if its relevant expertise is very high. Anticipating that his unfavorable report may still lead to investment, the CEO has incentives to *underreport* the project quality. By doing so he can guide down the board's perceived project quality and extract a higher bonus for implementing the project. On the other hand, if the board expertise is not that high such that a unfavorable CEO report definitely leads to no investment, the CEO has no incentives to underreport his information.

How does board expertise affect the CEO's effort incentives? Recall that the CEO needs to provide two types of effort: evaluating and implementing the project. For the evaluation incentives, board with more relevant expertise is better capable of inferring whether the CEO has carefully evaluated the project, thus providing stronger incentives for the CEO to evaluate the project. For the CEO's implementation incentives, it will depend on whether the board expertise is high enough to influence the investment decision. If board expertise is too low to influence the investment decision, higher board expertise will on average hurt the CEO's incentives to implement the project. The reason is that, in this case the board's information does not affect the average (invested) project quality, but only makes the board's perceived project quality and thereby the CEO's compensation more volatile. Higher board expertise increases such compensation volatility, and therefore hurts the risk-averse CEO's incentives to implement the project.[4] If, on the other hand, board expertise is

[3]If the two parties' precision is similar yet the assessments are contradictory, the project will be abandoned.

[4]An important assumption here is that the board has limited commitment power and will use its signal in CEO contracting in a sequentially rational manner. Just as in Arya, Glover, and Sivaramakrishnan[1997] and Arya. et. al [2000], which show a coarser information system can serve as a substitute for commitment, we show that lower board expertise can help reduce the

high enough to fully determine the investment decision, higher board expertise will improve the CEO's incentives to implement the project, because higher board expertise guides the investment towards more profitable projects for which the marginal benefit of the CEO's implementation effort is high.

Finally, we find board expertise may not always increase firm value. Specifically, if board expertise is not high enough to influence the investment decisions, the impact of board expertise on firm value is mainly through its impact on the CEO's incentives. Even if board expertise increases the CEO's incentives to *evaluate* the project, it hurts the CEO's incentives to *implement* the project (for low board expertise). Therefore, we predict for firms in mature industries that require relatively easier first-stage investigation but costly second-stage implementation, board expertise will decrease firm value.

Related Literature Our paper adds to the debate of managerial power versus optimal contracting view regarding CEO compensation. One side is the optimal contracting view. For example, Bushman and Indjejikian [1993], Indjejikian [1999], Dutta and Reichelstein [2005], among others, study the performance evaluation and compensation design from an agency perspective. The other side is the managerial power view (e.g.,Bebchuk and Fried [2004]), which argues that the board are captured by the managers to extract rent from shareholders. Many papers (Drymiotes [2007], Kumar and Sivaramakrishnan [2008], Laux [2008], and Laux and Mittendorf [2011]) challenge the managerial power view by arguing that even though dependent board may facilitate rent extracting by the managers, it could benefit the shareholders through other channels. 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. Our paper adopts a different approach to challenge the managerial power view. We show that some of the empirical findings often interpreted as managerial power are also consistent with

compensation cost.

the optimal contracting view. For example, our model predicts that the CEO will get a higher compensation if the board and the CEO agrees. Such a compensation arrangement is purely an outcome of optimal contracting, even though it may be interpreted by the managerial power view as evidence that more powerful CEOs get more pay.

Our paper also adds to the fast-growing literature studying the effect of board expertise on firm value. Many empirical studies (e.g., Masulis et al. [2012], Faleye, Hoitash, and Hoitash [2014], Wang, Xie and Zhu [2015], and Guner, Malmendier and Tate [2008]) have examined this issue and provided mixed evidence. However the theoretical analysis so far is scarce. Levit [2012] demonstrates that board expertise may reduce firm value because board expertise reduces the CEO's information acquisition effort. This is in similar spirit as Aghion and Tirole [1997] which shows that the precision of the board will hurt the CEO's incentives to collect information. In their incomplete contract setting, the board and the CEO have different preferences regarding investment. When the board has the "formal" authority over investment, board possessing information will reduce the chances that the CEO exercises the "real" authority (or "effective" control), hence reducing the CEO's incentives to acquire information. Our paper also shows that board expertise may decrease firm value, but through a completely different mechanism. In fact, we show that board expertise *increases* the CEO's information acquisition effort, because board holding more relevant expertise is more capable of inferring the CEO's evaluation effort, thus providing stronger incentives for the CEO to become informed.

In terms of model setup, our paper is closely related to the sequential task models studied in Arya, Glover and Radhakrishnan [2006] and Laux [2006]. Arya, Glover and Radhakrishnan [2006] study a situation where a team is used to come 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 (about the project) held by the principal and considers contract renegotiation at the interim stage. In addition, the evaluation task studied in our paper is similar to Lambert [1986] and Balakrishnan [1991] which examine information acquisition activities before investment decisions.

There is also a large body of work examining the board's monitoring and/or advising roles, e.g., Adams and Ferreira [2007], Baldenius, Melumad and Meng [2014], Drymiotes and Sivaramakrishnan [2012], Harris and Raviv [2008], Kumar and Sivaramakrishnan [2008], Raheja [2005], Song and Thakor [2006], Tian [2014] etc. Our paper shows an additional role played by the board's advising activities: its information serves an incentive role in motivating the CEO to acquire information. This result is related to Drymiotes and Sivaramakrishnan [2012]'s finding that the board's consulting role may have a positive externality on the CEO's performance evaluation by improving the informativeness of the short-term performance report about the CEO's productive effort.

The rest of the paper proceeds as follows. Section 2 lays out the model. Section 3 describes the board's optimization problem. Section 4 characterizes the CEO's optimal contract. Section 5 examines the effects of board expertise. Section 6 considers alternative information structure and shows the robustness of the results. Section 7 concludes.

2 Model Setup

We consider the interaction between a board of directors and a CEO, where the CEO is to be motivated to: (1) evaluate a potential project, (2) truthfully report his assessment of the project to the board,and (3) if the project is adopted, implement the project. The board of directors designs the CEO's compensation contract upfront and actively influences the firm's course of actions in the following sense: (a) the board uses its expertise to further evaluate the project; (b) it makes the investment decision;[5] (c) it renegotiates the compensation contract with the CEO.

[5] In this complete contract setting, it does not matter who, the CEO or the board, has the formal authority to make the investment decision. The reason is that even if the CEO has the authority

The CEO's (first-stage) evaluation effort a_1 and (second-stage) implementation effort a_2 are binary: $a_1 \in \{0, 1\}$ and $a_2 \in \{0, 1\}$. The cost of $a_t = 0$ is normalized to zero, and the cost of $a_t = 1$ is $k_t > 0$, where $t = 1, 2$. If the project is adopted, the project returns a cash flow x depending on the realized project quality $\theta \in \{0, 1\}$, the CEO's implementation effort a_2 and the exogenous size of the project X:

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

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

The project quality θ is either bad ($\theta = 0$) or good ($\theta = 1$), with ex-ante probability of $\theta = 1$ being 1/2. The CEO can expend effort a_1 to gather information about the project. If the CEO exerts evaluation effort, he receives an informative signal $s \in \{G, B\}$ with precision $0.5 + i$ about the project quality, where $i \in (0, 0.5)$. If the CEO does not exert evaluation effort, the signal s is pure noise.

$$Pr[s = G|\theta = 1] = Pr[s = B|\theta = 0] = 0.5 + i \cdot a_1.$$

After the CEO privately receives the signal, he submits a report $\hat{s}$ about s to the board.

Based on 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. The informativeness of the board's signal m depends on the board's expertise $i_B \in (0, 0.5)$, whether the CEO has truthfully reported his signal, and the CEO's evaluation effort:

$$Pr[m = H|\theta = 1, s, \hat{s}] = Pr[m = L|\theta = 0, s, \hat{s}] = 0.5 + i_B \cdot \mathbb{1}_{\hat{s}=s} \cdot a_1, \quad (Info - Main)$$

where $\mathbb{1}_{\hat{s}=s}$ is an indicator function that takes the value of 1 if $\hat{s} = s$. This information structure aims to capture an important feature of the board's project evaluation: the quality of the board's project evaluation depends on the quality of the CEO's

to make the investment decision, it is the board who designs the contract to induce the decision it wants.

report, as the board is less familiar with the firm's operation than the CEO (Adams and Ferreira [2007]). Only if the CEO has taken evaluation effort to collect relevant information *and* truthfully disclosed those findings in his report, the board's additional signal m is informative. In addition, directors holding more relevant expertise (higher i_B) are able to provide more precise project evaluation.

It is worth mentioning that our main results are robust to the information structure. For example, if the quality of the board's signal m is entirely independent of the CEO's report, i.e.,

$$Pr[m = H|\theta = 1, s, \hat{s}] = Pr[m = L|\theta = 0, s, \hat{s}] = 0.5 + i_B, \qquad (Info - Alt)$$

similar results will hold. The reason is: given that both the CEO and the board are discovering information about the same project, the two parties' signals are inherently correlated. The CEO's evaluation effort increases the precision of his own signal, which in turn increases the correlation between the two parties' signals. This feature holds for the alternative information structure. As we show below, it is this increased correlation that is used to incentivize the CEO to take the evaluation effort.

The board then makes the investment decision based on the CEO's report and its own assessment. The project, if invested, requires an up-front cost $I > 0$. We assume that, ignoring the implementation cost k_2, the investment threshold (i.e., the posterior probability of $\theta = 1$ which leads to investment) is 0.5, or equivalently, $0.5X - I = 0$. Taking into consideration that the project has to be implemented at some cost to produce any cash flow, the final investment threshold will be strictly higher than 0.5.

The board aims to maximize the investment profit less compensation cost:

$$V = (x - I)d - w, \qquad (1)$$

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

$$U_{CEO} = -e^{-r(w-a_1k_1-a_2k_2)} = e^{r(a_1k_1+a_2k_2)}(-e^{-rw}).$$

The CEO's reservation utility is $-e^0 = -1$.

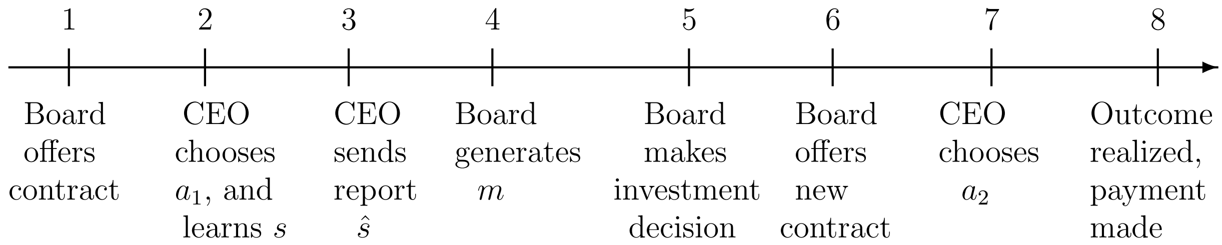

Figure 1: Timeline

The sequence of events is described in Figure 1. We assume that the size of the project X is large enough so that the board always wants to induce the CEO to exert both efforts.

3 Analysis

We solve the game by backward induction. First, we examine the contract renegotiation at Date 6. Then we 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 moment (Date 6), the board can offer a revised contract to the CEO which keeps the CEO no worse off but is beneficial for the board. Note that renegotiation happens only when the investment is undertaken.

The CEO's compensation contract can be written as $(W_{\hat{s}m}, \overline{W}_{\hat{s}m})$, depending on the CEO's report $\hat{s}$, the board's signal m, and the final project outcome x.[6] If the final project outcome is zero, i.e. $x = 0$ (either due to project failure or no investment),

[6] Note that the investment decision is fully determined by the CEO's report $\hat{s}$ and the board's signal m. That is, the investment decision itself does not provide additional information value and hence is omitted in the CEO's compensation contract.

the CEO receives $W_{\hat{s}m}$ for any $(\hat{s}, m)$. If the outcome is a success $(x = X)$, the CEO receives $\overline{W}_{\hat{s}m}$.[7] The corresponding utility terms are $(U_{\hat{s}m}, \overline{U}_{\hat{s}m})$. In the following analysis, we work on the utility space.

Instead of describing the actual renegotiation, we restrict attention to contracts that are renegotiation-proof. A contract $(W_{\hat{s}m}, \overline{W}_{\hat{s}m})$ is renegotiation-proof if the principal will choose not to alter it at the renegotiation stage. For any information event $(\hat{s}, m)$ that induces investment, it minimizes the board's expected compensation cost (at Date 6) subject to the implementation effort constraint $(IC_{\hat{s}m} - a_2)$ and the interim IR constraint $(IR_{\hat{s}m})$:

$$\begin{aligned} e^{rk_2}\left[Pr[\theta = 1 \mid \hat{s}, m]\overline{U}_{\hat{s}m} + (1 - Pr[\theta = 1 \mid \hat{s}, m])\, U_{\hat{s}m}\right] \quad &\geq \quad U_{\hat{s}m} \qquad\qquad (IC_{\hat{s}m} - a_2) \\ e^{rk_2}\left[Pr[\theta = 1 \mid \hat{s}, m]\overline{U}_{\hat{s}m} + (1 - Pr[\theta = 1 \mid \hat{s}, m])\, U_{\hat{s}m}\right] \quad &\geq \quad EU^I(\hat{s}, m) \qquad (IR_{\hat{s}m}) \end{aligned}$$

where $EU^I(\hat{s}, m)$ is the CEO's expected interim utility according to the initial contract. The board proposes the revised contract with the belief that the CEO has exerted evaluation effort and truthfully reported his information.[8] That is, $\Pr[\theta = 1|\hat{s}, m] \equiv \Pr[\theta = 1|s, m, a_1 = 1, \hat{s} = s]$. The implementation effort constraint $(IC_{\hat{s}m} - a_2)$ ensures the CEO exerts implementation effort, and the interim IR constraint $(IR_{\hat{s}m})$ ensures the CEO is no worse off than under the initial compensation contract.[9]

Now the interim optimization problem is equivalent to a single-period moral hazard problem. Both the implementation effort constraint $(IC_{\hat{s}m} - a_2)$ and the interim IR constraint $(IR_{\hat{s}m})$ have to be binding. That implies

$$\overline{U}_{\hat{s}m} = \left(1 - \frac{1 - e^{-rk_2}}{\Pr[\theta = 1|\hat{s}, m]}\right) U_{\hat{s}m}. \tag{2}$$

[7]Note that $\overline{W}_{\hat{s}m}$ is relevant only if the investment is undertaken upon $(\hat{s}, m)$.

[8]Due to limited commitment, the Revelation Principle does not apply in our model (Arya, Glover and Sunder [1998]). The reason we focus on truth-telling equilibrium here is that such equilibrium is the one the board wants to induce when investment scale X is sufficiently large.

[9]Note that the board proposes the revised contract only based on the on-equilibrium belief. To avoid being revealed as the deviating type, the CEO (even off-equilibrium path) will always accept the revised contract.

Converting to the wage space, we get

$$\overline{W}_{\hat{s}m} - W_{\hat{s}m} = -\frac{1}{r} Ln \left(1 - \frac{1 - e^{-rk_2}}{\Pr[\theta = 1|\hat{s}, m]} \right) \equiv Q_{\hat{s}m}. \tag{3}$$

Where $Q_{\hat{s}m}$ denotes the bonus for success. $Q_{\hat{s}m}$ is set just high enough to motivate the CEO (on the equilibrium path) to take the implementation effort. Note that the higher the anticipated project quality $\Pr[\theta = 1|\hat{s}, m]$, the lower the required bonus $Q_{\hat{s}m}$.

For later use, let's calculate the anticipated project quality $\Pr[\theta = 1|\hat{s}, m]$:

$$\begin{aligned}
\Pr[\theta = 1|\hat{s} = G, m = H] = \Pr[\theta = 1|s = G, m = H, a_1 = 1, \hat{s} = s] &= \frac{1}{1 + \frac{(0.5-i)(0.5-i_B)}{(0.5+i)(0.5+i_B)}}, \\
\Pr[\theta = 1|\hat{s} = B, m = H] = \Pr[\theta = 1|s = B, m = H, a_1 = 1, \hat{s} = s] &= \frac{1}{1 + \frac{(0.5+i)(0.5-i_B)}{(0.5-i)(0.5+i_B)}}, \\
\Pr[\theta = 1|\hat{s} = G, m = L] = \Pr[\theta = 1|s = G, m = L, a_1 = 1, \hat{s} = s] &= \frac{1}{1 + \frac{(0.5-i)(0.5+i_B)}{(0.5+i)(0.5-i_B)}}, \\
\Pr[\theta = 1|\hat{s} = B, m = L] = \Pr[\theta = 1|s = B, m = L, a_1 = 1, \hat{s} = s] &= \frac{1}{1 + \frac{(0.5+i)(0.5+i_B)}{(0.5-i)(0.5-i_B)}}.
\end{aligned} \tag{4}$$

3.2 The Ex-Post Optimal Investment Decision at Date 5

At Date 5, the board makes the investment decision based on its information set $(\hat{s}, m)$. The objective is to maximize the expected firm value (at Date 5), which, by (1), is the expected NPV of the project net of the expected wage. Denoted by $EW_{\hat{s}m}$ the expected wage the board anticipates to pay the CEO when the signal/report combination is $(\hat{s}, m)$:

$$EW_{\hat{s}m} = W_{\hat{s}m} + d \cdot Pr[\theta = 1|\hat{s}, m] \underbrace{\left(\overline{W}_{\hat{s}m} - W_{\hat{s}m}\right)}_{Q_{\hat{s}m}} \tag{5}$$

The expected wage includes a base salary $W_{\hat{s}m}$ and an expected bonus. Only when the project is invested ($d = 1$) and succeeds (with anticipated probability $Pr[\theta = 1|\hat{s}, m]$), the board pays out the bonus $Q_{\hat{s}m}$.

Denote by $d^*_{\hat{s}m}$ the optimal investment decision at Date 5. Then, by (1) and (5),

$$\begin{aligned} d^*_{\hat{s}m} \in \underset{d\in\{0,1\}}{\operatorname{argmax}} \quad & d \cdot (Pr[\theta = 1|\hat{s}, m]X - I) - EW_{\hat{s}m} \\ = \quad & d \cdot [Pr[\theta = 1|\hat{s}, m] (X - Q_{\hat{s}m}) - I] - W_{\hat{s}m} \end{aligned} \tag{6}$$

The optimal investment decision $d^*_{\hat{s}m}$ is summarized by the following Proposition.

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

- *If $i_B < i - \delta_1$, then $d^*_{Gm} = 1$ and $d^*_{Bm} = 0$ for $m \in \{H, L\}$. That is, the optimal investment decision is fully determined by the CEO's report $\hat{s} \in \{G, B\}$.*
- *If $i - \delta_1 \leq i_B \leq i + \delta_2$, then $d^*_{GH} = 1$ 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 $i_B > i + \delta_2$, then $d^*_{\hat{s}H} = 1$ and $d^*_{\hat{s}L} = 0$ for $\hat{s} \in \{G, B\}$. That is, the optimal investment decision is fully determined by the board's signal m.*

If the CEO's report and the board's signal are consistent with each other, then the optimal investment decision is straightforward: to invest if both parties think favorably about the project and to forgo investment if both parties consider the project to be bad. If the two parties' signals are contradictory, the optimal investment decision in general goes with the signal with significantly higher precision. If the precision of the two contradictory signals is very similar ($i_B \in [i - \delta_1, i + \delta_2]$), the optimal investment decision is to forgo investment. The reason is that, if the CEO and the board have similar precision yet have contradicting signals, the posterior project quality is "close to" the prior, 0.5, which is the indifference point of investment before considering implementation cost. Considering that the implementation effort has to be motivated in order to generate cash flow, the expected NPV of the project is too small to cover such compensation cost, rendering the project to be optimally forgone.

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, subject to the constraints that ensure the CEO not to deviate from the equilibrium actions — evaluating the project, truthfully reporting, and implementing the project when invested. Renegotiation-proofness, i.e., the binding implementation effort constraint ($IC_{\hat{s}m} - a_2$), ensures that the CEO (on the equilibrium path) does not deviate at the implementation stage. It remains to ensure that the CEO exerts evaluation effort and reports his information truthfully.

Firm value is the expected NPV of the project net of the expected compensation cost (at Date 1), and can be computed as follows:[10]

$$FV \equiv \left[\sum_{\hat{s}=s\in\{G,B\}, m\in\{H,L\}} Pr[s,m] \cdot d^*_{\hat{s}m} \cdot \{Pr[\theta=1|s,m]X - I\} \right] - CC.$$

With probability $Pr[s,m]$, the event (s,m) occurs. In this case, the project will succeed (generating cash flow X) with probability $Pr[\theta = 1 \mid s,m]$ if the investment is undertaken (i.e., $d^*_{\hat{s}m} = 1$). If the investment is forgone, the cash flow is zero. CC represents the *ex-ante* (total) expected compensation cost:

$$\begin{aligned} CC &= \sum_{\hat{s}=s\in\{G,B\}, m\in\{H,L\}} Pr[s,m] \cdot EW_{\hat{s}m} \\ &= \underbrace{\sum_{\hat{s}=s\in\{G,B\}, m\in\{H,L\}} Pr[s,m] \cdot W_{\hat{s}m}}_{CC_{a_1}} + \underbrace{\sum_{\hat{s}=s\in\{G,B\}, m\in\{H,L\}} Pr[s,m] \cdot d^*_{\hat{s}m} \cdot Pr[\theta=1|s,m] \cdot Q_{\hat{s}m}}_{CC_{a_2}} \end{aligned}$$

Specifically, we denote CC_{a_1} as the expected compensation cost to motivate first-stage evaluation effort, and CC_{a_2} as the expected compensation cost to motivate second-stage implementation effort. By the binding implementation effort constraint (3), the bonus for project success $Q_{\hat{s}m}$ is independent of $W_{\hat{s}m}$. That is, as a result of the renegotiation-proofness, the CEO's two effort problems can be separated. Neither the

[10]With a slight abuse of notation, we use $Pr[s,m] = Pr[s,m,a_1 = 1, \hat{s} = s]$ to represent the probability of (s,m) on the equilibrium path. Similarly, we use $Pr[\theta = 1|s,m]$ to represent the posterior probability of $\theta = 1$ on the equilibrium path, which equals $Pr[\theta = 1|s,m,a_1 = 1, \hat{s} = s]$.

expected NPV nor the compensation cost to motivate second-stage implementation effort (CC_{a_2}) are affected by $W_{\hat{s}m}$. Therefore, the board's optimization problem at Date 1 amounts to choosing $W_{\hat{s}m}$ to minimize CC_{a_1}.

To formulate the constraints that ensure the CEO exerts evaluation effort and reports his information truthfully, it is useful to write out the CEO's Date-4 interim payoff if he has taken effort a_1, observed signal s, issued report $\hat{s}$ and the board's signal is m, defined as $D(a_1, s, \hat{s}, m)$. Since the CEO has the option to choose whether to take implementation effort at Date-7 if the investment is undertaken at Date-5, the CEO's Date-4 payoff $D(a_1, s, \hat{s}, m)$ may include an option value associated with project implementation, denoted by $O(a_1, s, \hat{s}, m)$.

$$D(a_1, s, \hat{s}, m) \;\; = \;\; U_{\hat{s}m} + d^*_{\hat{s}m} \cdot O(a_1, s, \hat{s}, m). \tag{7}$$

If no investment is undertaken ($d^*_{\hat{s}m} = 0$), the CEO does not have the option to choose implementation effort, hence the CEO simply receives $U_{\hat{s}m}$. If the investment is undertaken ($d^*_{\hat{s}m} = 1$), the CEO has the option to choose whether to exert implementation effort, and the option value is

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

To understand how the option value is computed, note that in case the CEO chooses not to exert implementation effort, the project for sure is a failure and he receives $U_{\hat{s}m}$. That is, the option value associated with project implementation is zero. If the CEO chooses to exert implementation effort, then with probability $\Pr[\theta = 1 \mid s, m, a_1, \hat{s}]$ ($\Pr[\theta = 0 \mid s, m, a_1, \hat{s}]$), the project will succeed (fail), and the CEO receives $\overline{U}_{\hat{s}m}$ ($U_{\hat{s}m}$). The CEO's option value in this case is

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

Now we are ready to state the constraints. The truthtelling constraint (TT_s) ensures that the CEO reports truthfully after he exerts evaluation effort and observes signal s :

$$\sum_{m\in\{H,L\}} Pr[m|s,a_1=1,\hat{s}=s]\cdot D(a_1=1,s,\hat{s}=s,m)$$
$$\geq \sum_{m\in\{H,L\}} \underbrace{Pr[m|s,a_1=1,\hat{s}\neq s]}_{=\frac{1}{2}}\cdot D(a_1=1,s,\hat{s}\neq s,m) \qquad (TT_s)$$

To understand the truthtelling constraint, note that the CEO reports before the board's signal is generated. That's why we need to take expectation over the board's signal m. The right hand side represents the CEO's off-equilibrium payoff when he misreports $\hat{s}\neq s$, in which case the board observes H or L with equal probability $\frac{1}{2}$ since her signal is pure noise.

The incentive compatible constraint $(IC-a_1)$ ensures that the CEO chooses to exert evaluation effort. If the CEO chooses not to evaluate the project, then he may simply report G or B. In that case, the board's signal is uninformative. That is, the board will observe $m=H,L$ each with probability $\frac{1}{2}$. Given that the CEO also observes $s=G,B$ each with probability $\frac{1}{2}$, the probability of event (s,m) occurring is $\frac{1}{4}$. The right hand side again presents the CEO's off-equilibrium payoff when he fails to evaluate the project $(a_1=0)$ and simply reports (i) G or (ii) B.

$$e^{rk_1}\left[\sum_{\hat{s}=s\in\{G,B\},m\in\{H,L\}} Pr[s,m,\hat{s}=s|a_1=1]\cdot D(a_1=1,s,\hat{s}=s,m)\right]$$
$$\geq \max\left\{\sum_{s\in\{G,B\},m\in\{H,L\}} \underbrace{Pr[s,m|a_1=0,\hat{s}=G]}_{=\frac{1}{4}}\cdot D(a_1=0,s,\hat{s}=G,m),\right.$$
$$\left.\sum_{s\in\{G,B\},m\in\{H,L\}} \underbrace{Pr[s,m|a_1=0,\hat{s}=B]}_{=\frac{1}{4}}\cdot D(a_1=0,s,\hat{s}=B,m)\right\} \quad (IC-a_1)$$

To simplify the above constraint, note that:

Lemma 1 *The CEO's Date-4 interim payoff $D(a_1,s,\hat{s},m)=U_{\hat{s}m}$ if one of the following scenarios occurs:*

(i) Both the CEO's report and the board's signal are unfavorable, i.e., $\hat{s}=B$ and $m=L$;

(ii) On equilibrium path, i.e., $a_1 = 1$ and $\hat{s} = s$;

(iii) Off-equilibrium path where the CEO chooses $a_1 = 0$;

(iv) Off-equilibrium path where the CEO inflates the report, i.e., $s = B$ but $\hat{s} = G$.

According to (7), the CEO's Date-4 interim payoff $D(a_1, s, \hat{s}, m)$ deviates from $U_{\hat{s}m}$ only when the CEO faces a non-zero option value associated with project implementation. In scenario (i), both the CEO's report and the board's signal are unfavorable, which leads to no investment according to Proposition 1. In this case, the CEO simply has no option to choose implementation effort at Date-7. In scenario (ii), on the equilibrium path the CEO is indifferent between shirking and exerting implementation effort, therefore the option value associated with project implementation is zero. To see this, recall that the board proposes the revised contract based on the on-equilibrium project quality and is set to make the CEO indifferent between shirking and exerting implementation effort.

In scenario (iii) and (iv), after either type of deviation, even if the investment is induced, the CEO chooses to shirk on implementation at Date-7 and hence the option value associated with project implementation is zero. To understand this, recall that the bonus for success ($Q_{\hat{s}m}$) is set to make the CEO indifferent between shirking and exerting implementation effort, based on the board's perceived project quality $\Pr[\theta = 1 \mid \hat{s}, m]$. The higher the perceived project quality, the lower the bonus offered. If (iii) the CEO fails to evaluate the project (the true project quality is just the prior, 0.5); or (iv) he evaluates the project, observes signal B, but misreports G (the true project quality in this case is $0.5 - i$), the CEO's private information suggests that the true project quality is worse than the board's perceived project quality (which is always higher than 0.5 in case the investment is induced). He will then choose to shirk on implementation because the expected bonus is not sufficient to cover his implementation cost.[11]

[11]Technically speaking, these two types of deviation will lead to later deviation at the implementation stage.

Lemma 1 suggests that the only scenario where the CEO's Date-4 payoff $D(a_1, s, \hat{s}, m)$ may include a positive option value is when the CEO has deviated at the reporting stage by misreporting $\hat{s} = B$ while the true signal is $s = G$. In this case, the CEO could mislead the board to believe that the project quality is worse than the actual one, and therefore gets a higher bonus for implementing the project. Hence the board's optimization program at Date 1 is:

$$\mathcal{P}: \min_{\{U_{\hat{s}m} \in R\}} \qquad CC_{a_1}$$

subject to

$$(0.5 + 2i_B i)U_{GH} + (0.5 - 2i_B i)U_{GL} \geq 0.5D(a_1 = 1, s = G, \hat{s} = B, H) + 0.5U_{BL} \tag{TT_G}$$

$$(0.5 - 2i_B i)U_{BH} + (0.5 + 2i_B i)U_{BL} \geq 0.5U_{GH} + 0.5U_{GL} \tag{TT_B}$$

$$EU \geq \max\{0.5U_{GH} + 0.5U_{GL}, 0.5U_{BH} + 0.5U_{BL}\} \tag{$IC - a_1$}$$

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

where

$$EU \equiv e^{rk_1} \left[\sum_{\hat{s}=s \in \{G,B\}, m \in \{H,L\}} Pr[s, m, \hat{s} = s | a_1 = 1] U_{\hat{s}m} \right], \text{and}$$
$$D(a_1 = 1, s = G, \hat{s} = B, H) = U_{BH} + d^*_{BH} \cdot O(a_1 = 1, s = G, \hat{s} = B, H).$$

The solution to the optimization problem is denoted by $U^*_{\hat{s}m}$, which, converting to the wage space, is $W^*_{\hat{s}m}$. As argued above, the only scenario where the CEO's payoff $D(a_1, s, \hat{s}, m)$ may be different from $U_{\hat{s}m}$ occurs at the off-equilibrium path when the CEO misreports his signal G (the right hand side of constraint (TT_G)).

4 The Optimal CEO Contract

In this section, we characterize the CEO's optimal renegotiation-proof contract. As the board's optimization program $\mathcal{P}$ suggests, the CEO's off-equilibrium payoff when he deflates his report (the right hand side of constraint (TT_G)) is affected by the investment decision d^*_{BH}, which is in turn affected by the level of board expertise. Therefore, we consider the following two cases.

4.1 Low Board Expertise

If board expertise is low, i.e., $i_B \leq i + \delta_2$, then by Proposition 1, the investment is forgone if the CEO report $\hat{s} = B$. The following proposition demonstrates how the board's project evaluation role helps provide the CEO's evaluation effort incentive.

Proposition 2 *If the board's expertise is not too high, specifically, $i_B \leq i + \delta_2$, then the optimal contract is:*

$$W^*_{GH} = W^*_{BL} = -\frac{1}{r}Ln\left(1 - \frac{1 - e^{-rk_1}}{4i_B i}\right) > W^*_{BH} = W^*_{GL} = -\frac{1}{r}Ln\left(1 + \frac{1 - e^{-rk_1}}{4i_B i}\right),$$

$$\overline{W}^*_{\hat{s}m} = W^*_{\hat{s}m} - \frac{1}{r}Ln\left(1 - \frac{1 - e^{-rk_2}}{\Pr[\theta = 1|\hat{s}, m]}\right), \quad \textit{for } \hat{s} \in \{G, B\} \textit{ and } m \in \{H, L\},$$

where $\Pr[\theta = 1|\hat{s}, m]$ *takes the values given by (4).*

The two reporting constraints (TT_G) and (TT_B) are slack.

Note that both the CEO and the board are evaluating the same project, therefore the two parties' signals are naturally positively correlated. If the CEO carefully evaluates the project, both his and the board's signals are more informative. That is, as demonstrated in Figure 2, both the correlation between s and θ, and the correlation between m and θ are increased by a_1. Consequently, the correlation between s and m will also be increased by a_1. Therefore, conformity of the board's and the CEO's signals (recall that the CEO truthfully reveals his information in equilibrium) is indicative of higher evaluation effort by the CEO and should lead to a higher compensation to the CEO. As illustrated in Figure 2, the alternative information structure will also work: even if the board's project evaluation is independent of the CEO's input (i.e., the correlation between m and θ is independent of a_1), the correlation between signals s and m still becomes stronger if the CEO has carefully evaluated the project, because such effort increases the precision of the CEO's own signal.

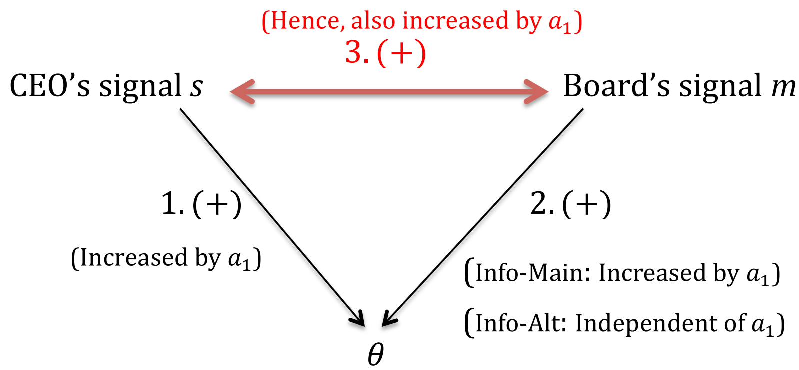

Figure 2: Correlation between the two parties' signals

Furthermore, in order to motivate the CEO to exert implementation effort, the board needs to pay out a bonus for project success $Q_{\hat{s}m} \equiv \overline{W}^*_{\hat{s}m} - W^*_{\hat{s}m}$ to the CEO. Note that the CEO's two tasks — evaluation effort and implementation effort — are incentivized separately: implementation effort is motivated by referencing the project outcome and evaluation effort is motivated by referencing the conformity of board signal and CEO's report. This separation is due to the board's renegotiation with the CEO after the first task is sunk.

In addition, because the CEO receives a higher wage if his report is consistent with the board's signal, he has incentives to truthfully report. By doing so he maximizes the probability of his report being consistent with the board. That is, motivating evaluation effort provides natural incentives for the CEO to disclose his findings truthfully. On the other hand, the CEO who observes G may have incentives to deflate his report to B because by doing so he can mislead the board to believe that the project quality is not so good and thus will get a higher bonus for implementing the project.[12] Such deflating reporting incentive exists only if the investment is anticipated to be undertaken: if the project is not invested, then there is no need for the CEO to implement it. For low board expertise, $i_B \leq i + \delta_2$, by Proposition 1, the CEO's favorable report is necessary to induce investment. This eliminates the CEO's

[12]Technically, such deflating reporting incentive arises from the CEO's option value associated with project implementation.

incentives to deflate his report because an unfavorable CEO report always leads to no investment. Therefore, for $i_B \leq i + \delta_2$, the CEO only has natural incentives to truthfully disclose his findings, and hence the CEO's truthful reporting constraints are slack.

4.2 High Board Expertise

If the board expertise is sufficiently high so that an unfavorable CEO report may still lead to investment, i.e., $d^*_{BH} = 1$, then the CEO has incentives to deflate his report to B. The following proposition examines the optimal contract in this scenario:

Proposition 3 *If the board's expertise is high, specifically, $i_B > i + \delta_2$, then there exists*

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

such that

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

If the board's expertise is high, $i_B > i + \delta_2$, by Proposition 1, investment is undertaken upon (B, H). Then the CEO with signal G has countervailing reporting incentives: (a) the CEO has natural incentives to truthfully report because by doing so he maximizes the probability of issuing a consistent report with the board; (b) the CEO has incentives to deflate his report to B in order to receive a larger bonus at the project implementation stage. If the truthful reporting force dominates, i.e., $Z \geq 0$, the CEO's truthful reporting constraint (TT_G) will be slack. If the misreporting force dominates, i.e., $Z < 0$, Constraint (TT_G) will have to be binding.

The following corollary examines under what circumstances the CEO's truthful reporting constraint (TT_G) is more likely to be slack.

Corollary 1 $\frac{\partial Z}{\partial k_1} \geq 0$ *and* $\frac{\partial Z}{\partial k_2} \leq 0$.

The CEO's truthful reporting constraint (TT_G) is more likely to be slack if (i) the CEO's first-stage evaluation effort cost k_1 is larger; or (ii) the CEO's second-stage evaluation effort cost k_2 is smaller. Intuitively, with higher evaluation cost k_1, evaluation effort is more difficult to motivate, demanding a larger payment difference between consistent and inconsistent reports. That provides stronger truthful reporting incentive and relaxes the constraint (TT_G). On the other hand, the CEO's misreporting incentive is weaker for smaller implementation effort cost k_2 because smaller k_2 leads to lower bonus for project success, which reduces the CEO's benefit from misreporting.

Our result demonstrates a potential downside of high board expertise. If board expertise is high enough to determine the investment decision, it creates incentives for the CEO to deflate his report of the project quality.

5 The Effect of Board Expertise

In this section, we examine the effect of board expertise on CEO incentives and firm value. While it is clear that the CEO's incentive to evaluate the project is always enhanced by facing a board that is more capable to assess the project,[13] the impact of board expertise on the CEO's implementation incentive is mixed.

Lemma 2 *The effect of board expertise on the CEO's implementation effort incentives depends on whether the board's information can influence the investment decision. Specifically,*

(i) If $i_B < i - \delta_1$, i.e., the investment decision depends solely on the CEO's report, board expertise ***negatively*** *affects the CEO's implementation incentives:* $\frac{\partial CC_{a_2}}{\partial i_B} > 0$;

[13] The board with higher expertise provides information more strongly correlated with the CEO's report if the CEO has carefully evaluates the project. That is, it is easier for the board to infer whether the evaluation effort has been taken.

*(ii) If $i_B > i+\delta_2$, i.e., the investment decision depends solely on the board's information, board expertise **positively** affects the CEO's implementation incentives: $\frac{\partial CC_{a_2}}{\partial i_B} < 0$.*

Only if board expertise is high enough to influence the investment decision, can it have a positive impact on the CEO's implementation incentives. If the board fails to influence the investment decision, which occurs when $i_B < i - \delta_1$, its expertise actually hurts the CEO's incentives to implement the project. In this case the investment decision is solely triggered by the CEO reporting G. Board information therefore does not affect the average (invested) project quality (which is always $Pr[\theta = 1|G]$), but only makes the board's perceived project quality and thereby the CEO's compensation more volatile. Higher i_B increases such compensation volatility, therefore leads to a higher compensation cost demanded by a risk-averse CEO. This intuition is related to the literature demonstrating that a coarser information system can serve as a commitment device when the principal cannot commit to not use information in a sequential rationally manner (Creme [1995], Arya, Glover, and Sivaramakrishnan[1997], Arya. et. al [2000] among others).

For the opposite case where the investment decision is solely based on board signal, i.e., $i_B > i + \delta_2$, the result is reversed. In this case, higher board expertise not only improves the average (invested) project quality ($Pr[\theta = 1|H]$), but also reduces the volatility of the board's perceived project quality and thereby the CEO's compensation. (Specifically, the project quality difference between the two investing states, $Pr[\theta = 1|G, H]$ and $Pr[\theta = 1|B, H]$, decreases in i_B.) Both forces make it easier to motivate the risk-averse CEO to implement the project.

How does board expertise affect firm value? Presumably, the board with higher expertise can help the firm set better strategies and/or make better decisions, therefore should improve firm value. However this is not always the case. When board expertise is not high enough to influence the investment decision, it may actually hurt firm value.

Proposition 4 *Suppose k_1 is sufficiently small. Board expertise decreases firm value when $i_B < i - \delta_1$.*

If board expertise is not high enough to influence the investment decision, its impact on firm value is mainly through the effect on CEO incentives. Although board expertise increases the CEO's incentives to *evaluate* the project, its impact on the CEO's incentives to *implement* the project is negative (if the board fails to influence the investment decision), as we argued in Lemma 2. Therefore for firms who frequently encounter projects that require relatively easier first-stage investigation but costly second-stage implementation, board expertise will decrease firm value.

In a related study, Levit [2012] also shows that board expertise may decrease firm value, but through different mechanism. Specifically, in Levit [2012], higher board expertise hurts the CEO's information acquisition effort, thereby decreases firm value. In our paper, board expertise actually improves the CEO's information acquisition effort, but makes the motivation of the second-stage implementation effort harder. When the motivation of implementation effort is more important, the overall effect of board expertise on firm value is negative.

6 Alternative Information Structure

In our main analysis, we assume that the precision of the board's signal depends on the board's expertise i_B, the CEO's evaluation effort a_1, and the CEO's reporting behavior, as in $(Info - Main)$. To demonstrate that our main results are not driven by this assumption, we study alternative information structure in this section.

One alternative is to assume that the precision of the board's signal is solely determined by the board's expertise i_B. The idea is that the board evaluates the project independently, hence the board's precision is not affected by whether the CEO has carefully evaluated the project and/or truthfully reported his findings. As we will prove in the Appendix, all the main results hold here except for Proposition 3, when the board's expertise is high enough such that the investment decision is fully determined by the board's information. In that case, the CEO's role reduces to implementing the project alone, hence there is no need to motivate the CEO to evaluate the project. Furthermore, since the CEO is uninformed if not evaluate the project, the board will ignore the CEO's report when compensating the CEO for his implementation effort.[14] The results can be summarized as follows:

Proposition 5 (Alternative Information Structure) *Suppose the precision of the board's signal depends solely on its expertise, that is,*

$$Pr[m = H|\theta = 1, s, \hat{s}] = Pr[m = L|\theta = 0, s, \hat{s}] = 0.5 + i_B. \qquad (Info - Alt)$$

Then:

(1) The optimal investment decision is the same as characterized in Proposition 1.

(2) For $i_B \leq i + \delta_2$, the optimal contract is the same as characterized in Proposition 2. The two reporting constraints are slack.

(3) For $i_B > i + \delta_2$, the investment is undertaken if and only if the board's signal is H. There is no need to motivate the CEO's evaluation effort. And the optimal contract is:

$$W^*_{GH} = W^*_{BL} = W^*_{BH} = W^*_{GL} = 0,$$
$$\overline{W}^*_{\hat{s}H} = -\frac{1}{r}Ln\left(1 - \frac{1 - e^{-rk_2}}{\Pr[\theta = 1|H]}\right) = -\frac{1}{r}Ln\left(1 - \frac{1 - e^{-rk_2}}{0.5 + i_B}\right), \quad for\ \hat{s} \in \{G, B\}.$$

[14]The important assumption here is that the CEO is completely uninformed if he doesn't evaluate the project. If we assume instead that the CEO is endowed with some information about the project, then to ensure that the CEO exerts the implementation effort, the board has to tailor the compensation contract to the CEO's private information. Then the CEO will have incentives to deflate his report in order to boost his compensation. To discourage the CEO's deflating reporting incentives, the board will need to reward the CEO for reporting G. That is, the CEO's truth-telling constraint (TT_G) has to be binding.

7 Conclusion

Boards of directors have become more active in influencing firms' courses of actions. We investigate how board expertise affects executive incentives and firm value in a project investment setting. To achieve a higher probability of a success, the CEO engages in a sequence of tasks: firstly expends effort to evaluate a potential project, then reports his assessment of the project to the board, and finally expends effort to implement the project. We show that high board expertise helps motivate the CEO to exert evaluation effort, but may inadvertently create incentives for the CEO to under-report his assessment and may weaken the CEO's incentives in project implementation. Higher board expertise can either improve or hurt firm value.

To focus on the main trade-offs, we silent some features for boards of directors. For example, we focus on the CEO's strategic reporting behavior but assume the board is always truthful. There are studies that focus on the board's incentives in communicating its information to the CEO but assume the CEO always truthfully discloses his information (e.g., Adams and Ferreira 2007). The interplay between the two parties' strategic reporting behavior will be interesting to explore. Another interesting feature for boards of directors is that there are committees in charge of different functions: executive compensation, project review, etc. How information (relevant for decision making or for performance evaluation) is transmitted and utilized among different committees is another fruitful venue to explore.

Appendix: Proofs of the Main Results

Proof of Proposition 1

The board's optimization program at Date 5 is:

$$d^*_{\hat{s}m} \in \underset{d\in\{0,1\}}{\operatorname{argmax}} \qquad d \cdot [Pr[\theta = 1|\hat{s}, m] (X - Q_{\hat{s}m}) - I] - W_{\hat{s}m}$$

The solution is:

$$d^*_{\hat{s}m} = 1 \qquad \text{if and only if} \qquad Pr[\theta = 1|\hat{s}, m] (X - Q_{\hat{s}m}) - I > 0.$$

We first argue that $\frac{d(Pr[\theta=1|\hat{s},m](X-Q_{\hat{s}m})-I)}{d\ Pr[\theta=1|\hat{s},m]} > 0$. For that purpose, we need prove the following lemma.

Lemma 3 $\frac{d\ Pr[\theta=1|\hat{s},m]Q_{\hat{s}m}}{d\ Pr[\theta=1|\hat{s},m]} < 0$.

Proof: Note that

$$\begin{aligned} Pr[\theta = 1|\hat{s}, m]Q_{\hat{s}m} &= Pr[\theta = 1|\hat{s}, m] \left[-\frac{1}{r} Ln \left(1 - \frac{1 - e^{-rk_2}}{\Pr[\theta = 1|\hat{s}, m]} \right) \right] \\ &= -\frac{1}{r} \left\{ \underbrace{Pr[\theta = 1|\hat{s}, m] Ln \left(1 - \frac{1 - e^{-rk_2}}{\Pr[\theta = 1|\hat{s}, m]} \right) + (1 - Pr[\theta = 1|\hat{s}, m]) \, Ln(1)}_{\Phi} \right\} \end{aligned}$$

The term inside the brace, Φ, can be interpreted as the expected utility of a risk-averse individual with utility function $Ln(\cdot)$ who is facing a lottery

$$\begin{cases} 1 - \frac{1-e^{-rk_2}}{\Pr[\theta=1|\hat{s},m]} & \text{with probability } Pr[\theta = 1|\hat{s}, m] \\ 1 & \text{with probability } 1 - Pr[\theta = 1|\hat{s}, m] \end{cases}$$

The mean of the lottery is e^{-rk_2}. At the same time, as $Pr[\theta = 1|\hat{s}, m]$ increases, the spread becomes smaller. The risk-averse individual always prefer the lottery with the smaller spread. Therefore, $\frac{d\ \Phi}{d\ Pr[\theta=1|\hat{s},m]} > 0$. Hence $\frac{d\ Pr[\theta=1|\hat{s},m]Q_{\hat{s}m}}{d\ Pr[\theta=1|\hat{s},m]} < 0$. ■

By Lemma 3,

$$\frac{d\,(Pr[\theta = 1|\hat{s}, m]\,(X - Q_{\hat{s}m}) - I)}{d\ Pr[\theta = 1|\hat{s}, m]} = X - \frac{d\ Pr[\theta = 1|\hat{s}, m]Q_{\hat{s}m}}{d\ Pr[\theta = 1|\hat{s}, m]} > 0.$$

Define p^c as

$$p^c \left(X + \frac{1}{r} Ln \left(1 - \frac{1 - e^{-rk_2}}{p^c} \right) \right) - I = 0. \tag{8}$$

Therefore,

$$d^*_{\hat{s}m} = \begin{cases} 1 & \text{if } Pr[\theta = 1|\hat{s}, m] > p^c \\ 0 & \text{if } Pr[\theta = 1|\hat{s}, m] \leq p^c \end{cases}$$

Because $X = 2I$, it is clear that $p^c > \frac{1}{2}$.

Next, as (4) has shown:

$$\begin{aligned}
\Pr[\theta = 1|\hat{s} = G, m = H] &= \frac{1}{1 + \frac{(0.5-i)(0.5-i_B)}{(0.5+i)(0.5+i_B)}}, \text{ is increasing in } i_B \\
\Pr[\theta = 1|\hat{s} = B, m = H] &= \frac{1}{1 + \frac{(0.5+i)(0.5-i_B)}{(0.5-i)(0.5+i_B)}}, \text{ is increasing in } i_B \\
\Pr[\theta = 1|\hat{s} = G, m = L] &= \frac{1}{1 + \frac{(0.5-i)(0.5+i_B)}{(0.5+i)(0.5-i_B)}}, \text{ is decreasing in } i_B \\
\Pr[\theta = 1|\hat{s} = B, m = L] &= \frac{1}{1 + \frac{(0.5+i)(0.5+i_B)}{(0.5-i)(0.5-i_B)}}, \text{ is decreasing in } i_B
\end{aligned}$$

If $i_B < i$, the ranking of the posteriors is:

$$Pr[\theta = 1|\hat{s} = G, H] > Pr[\theta = 1|\hat{s} = G, L] > \frac{1}{2} > Pr[\theta = 1|\hat{s} = B, H] > Pr[\theta = 1|\hat{s} = B, L].$$

Define δ_1 such that for $i_B = i - \delta_1$, $Pr[\theta = 1|\hat{s} = G, L] = p^c$. Since $Pr[\theta = 1|\hat{s} = G, L]$ is decreasing in i_B, then for $i_B < i - \delta_1$, $Pr[\theta = 1|\hat{s} = G, L] > p^c$. As a result, $d^*_{GH} = d^*_{GL} = 1$ and $d^*_{BH} = d^*_{BL} = 0$. For $i_B \geq i - \delta_1$, $Pr[\theta = 1|\hat{s} = G, L] \leq p^c$, and therefore $d^*_{GL} = d^*_{BH} = d^*_{BL} = 0$.

If $i_B > i$, the ranking of the posteriors is:

$$Pr[\theta = 1|\hat{s} = G, H] > Pr[\theta = 1|\hat{s} = B, H] > \frac{1}{2} > Pr[\theta = 1|\hat{s} = G, L] > Pr[\theta = 1|\hat{s} = B, L].$$

Define δ_2 such that for $i_B = i + \delta_2$, $Pr[\theta = 1|\hat{s} = B, H] = p^c$. Since $Pr[\theta = 1|\hat{s} = B, H]$ is increasing in i_B, then for $i_B > i + \delta_2$, $Pr[\theta = 1|\hat{s} = B, H] > p^c$. As a result, $d^*_{GH} = d^*_{BH} = 1$ and $d^*_{GL} = d^*_{BL} = 0$. For $i_B \leq i + \delta_2$, $Pr[\theta = 1|\hat{s} = B, H] \leq p^c$, and therefore $d^*_{BH} = d^*_{GL} = d^*_{BL} = 0$.

Specifically, δ_1 and δ_2 are determined, respectively, by

$$\frac{1}{1+\frac{(0.5-i)(0.5+i-\delta_1)}{(0.5+i)(0.5-i+\delta_1)}} = p^c, \tag{9}$$

$$\frac{1}{1+\frac{(0.5+i)(0.5-i-\delta_2)}{(0.5-i)(0.5+i+\delta_2)}} = p^c. \tag{10}$$

■

Proof of Proposition 2

If $i_B \leq i+\delta_2$, then by Proposition 1, no investment is undertaken upon (B,H), i.e., $d^*_{BH}=0$. Therefore, $D(a_1=1, s=G, \hat{s}=B, H)=U_{BH}$. The optimization program $\mathcal{P}^{d^*_{BH}=0}$ is thus

$$\min_{\{U_{\hat{s}m}\in R\}} CC_{a_1} = \underbrace{(0.25+i_Bi)}_{Pr[G,H]=Pr[B,L]}(W_{GH}+W_{BL}) + \underbrace{(0.25-i_Bi)}_{Pr[B,H]=Pr[G,L]}(W_{BH}+W_{GL})$$

subject to

$$\underbrace{(0.5+2i_Bi)}_{Pr[H|s=G,a_1=1,\hat{s}=G]} U_{GH} + \underbrace{(0.5-2i_Bi)}_{Pr[L|s=G,a_1=1,\hat{s}=G]} U_{GL} \geq 0.5U_{BH}+0.5U_{BL} \tag{TT_G}$$

$$\underbrace{(0.5-2i_Bi)}_{Pr[H|s=B,a_1=1,\hat{s}=B]} U_{BH} + \underbrace{(0.5+2i_Bi)}_{Pr[L|s=B,a_1=1,\hat{s}=B]} U_{BL} \geq 0.5U_{GH}+0.5U_{GL} \tag{TT_B}$$

$$EU \geq 0.5U_{GH}+0.5U_{GL} \tag{$IC-a_1-1$}$$

$$EU \geq 0.5U_{BH}+0.5U_{BL} \tag{$IC-a_1-2$}$$

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

where $EU = e^{rk_1}\left[(0.25+i_Bi)(U_{GH}+U_{BL})+(0.25-i_Bi)(U_{BH}+U_{GL})\right]$.

First, we argue that the solution to program $\mathcal{P}^{d^*_{BH}=0}$ is the same as that to the following program $\mathcal{P}'$:

$$\min_{\{U_{\hat{s}m}\in R\}} \quad CC_{a_1} = (0.25+i_Bi)\left[\Phi(U_{GH})+\Phi(U_{BL})\right]+(0.25-i_Bi)\left[\Phi(U_{BH})+\Phi(U_{GL})\right]$$

subject to

$$(0.5 + 2i_B i)(U_{GH} + U_{BL}) + (0.5 - 2i_B i)(U_{GL} + U_{BH}) \geq 0.5(U_{BH} + U_{BL} + U_{GL} + U_{GH}) \tag{TT}$$

$$EU \geq 0.25(U_{BH} + U_{BL} + U_{GL} + U_{GH}) \tag{IC'$-a_1$}$$

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

Where the constraint (TT) derives from $(TT_G) + (TT_B)$, and $(IC' - a_1)$ derives from $(IC - a_1 - 1) + (IC - a_1 - 2)$. Clearly, the constraints in program $\mathcal{P}'$ is more relax than the constraints in the original program $\mathcal{P}^{d^*_{BH}=0}$.

A close observation of program $\mathcal{P}'$ suggests that the optimal solution must entail that $U_{GH} = U_{BL}$ and $U_{BH} = U_{GL}$. The reason is that the program is symmetric in terms of U_{GH} and U_{BL}: if we switch U_{GH} and U_{BL}, the program is exactly the same. Similarly, the program is also symmetric between U_{GL} and U_{BH}.

Given $U_{GH} = U_{BL}$ and $U_{BH} = U_{GL}$, the constraint (TT) is exactly the same as (TT_G) and (TT_B), and 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 $\mathcal{P}^{d^*_{BH}=0}$, and will be the solution to the original program $\mathcal{P}^{d^*_{BH}=0}$.

Now, let's solve for Program $\mathcal{P}'$. With $U_{GH} = U_{BL}$ and $U_{BH} = U_{GL}$, and substituting EU, Program $\mathcal{P}'$ can be reduced to:

$$\min_{\{U_{\hat{s}m} \in R\}} \quad CC_{a_1} = (0.5 + 2i_B i)\Phi(U_{GH}) + (0.5 - 2i_B i)\Phi(U_{GL})$$

subject to

$$4i_B i (U_{GH} - U_{GL}) \geq 0 \tag{TT}$$

$$e^{rk_1}\left[(0.5 + 2i_B i)U_{GH} + (0.5 - 2i_B i)U_{GL}\right] \geq 0.5(U_{GL} + U_{GH}) \tag{IC'$-a_1$}$$

$$e^{rk_1}\left[(0.5 + 2i_B i)U_{GH} + (0.5 - 2i_B i)U_{GL}\right] \geq -e^{r \cdot 0} = -1 \tag{IR}$$

We first argue that the constraint (TT) is always slack. Prove by contradiction. Suppose (TT) is binding, then $U_{GH} = U_{GL}$, which will violate constraint $(IC' - a_1)$.

Let μ and λ denote the Lagrangian Multipliers for evaluation effort constraints

$(IC' - a_1)$ and (IR) constraint respectively. The first-order conditions are

$$\begin{aligned} \Phi'(U_{GH}) &= \mu[e^{rk_1} - \frac{0.5}{0.5 + 2i_B i}] + \lambda e^{rk_1} \\ \Phi'(U_{GL}) &= \mu[e^{rk_1} - \frac{0.5}{0.5 - 2i_B i}] + \lambda e^{rk_1} \end{aligned}$$

Clearly, $\mu > 0$. Suppose not, instead $\mu = 0$, then it follows that $U_{GH} = U_{GL}$, which will violate constraint $(IC' - a_1)$.

At the same time, (IR) constraint is always binding. Suppose (IR) constraint is slack, then the board can multiply all utility terms by $e^{-r\varepsilon}$. Then all the constraints will continue to satisfy and the board can save wage cost by ε.

With the binding $(IC' - a_1)$ and (IR) constraints, we can solve for the choice variables:

$$\begin{aligned} U_{GH} &= U_{BL} = -1 + \frac{1 - e^{-rk_1}}{4i_B i} \\ U_{BH} &= U_{GL} = -1 - \frac{1 - e^{-rk_1}}{4i_B i}. \end{aligned}$$

■

Proof of Proposition 3

If $i_B > i + \delta_2$, then by Proposition 1, $d^*_{BH} = 1$, and the CEO's option value is

$$\begin{aligned} O(a_1 = 1, s = G, \hat{s} = B, H) &\equiv \max\left\{0, e^{rk_2}\left[(0.5+i)\overline{U}_{BH} + (0.5-i)U_{BH}\right] - U_{BH}\right\} \\ &= \max\left\{0, e^{rk_2}\left[\frac{(0.5+i)(e^{-rk_2} - 1)}{\Pr[\theta = 1|\hat{s} = B, H]} + 1\right] U_{BH} - U_{BH}\right\} \\ &= \max\left\{0, (1 - e^{rk_2})\left[\frac{0.5+i}{\Pr[\theta = 1|\hat{s} = B, H]} - 1\right] U_{BH}\right\} \\ &= \max\left\{0, \frac{0.5+i}{\Pr[\theta = 1|\hat{s} = B, H]} - 1\right\}(1 - e^{rk_2})U_{BH}. \end{aligned}$$

The cost-minimizing program $\mathcal{P}^{d^*_{BH}=1}$ is thus similar to program $\mathcal{P}^{d^*_{BH}=0}$ in the proof of Proposition 2, with the only difference being the (TT_G) constraint. Specifically, given $O(a_1 = 1, s = G, \hat{s} = B, H) \geq 0$, the (TT_G) constraint in $\mathcal{P}^{d^*_{BH}=1}$ is harder to satisfy than the (TT_G) constraint in $\mathcal{P}^{d^*_{BH}=0}$.

Suppose the (TT_G) constraint in $\mathcal{P}^{d^*_{BH}=1}$ is slack, then the optimal solution of program $\mathcal{P}^{d^*_{BH}=1}$ is the same as that of program $\mathcal{P}^{d^*_{BH}=0}$. Substituting the solution in Proposition 2 to the current (TT_G) constraint and rearranging the terms, the current (TT_G) constraint is reduced to

$$1-e^{-rk_1} \geq 0.5\max\left\{0, \frac{0.5+i}{\Pr[\theta=1|\hat{s}=B,H]}-1\right\}(e^{rk_2}-1)\left(1+\frac{1-e^{-rk_1}}{4i_Bi}\right). \quad (11)$$

Therefore, if $Z \equiv \frac{1-e^{-rk_1}}{1+\frac{1-e^{-rk_1}}{4i_Bi}} - 0.5(e^{rk_2}-1)\cdot\max\left\{0, \frac{0.5+i}{\Pr[\theta=1|\hat{s}=B,H]}-1\right\} \geq 0$, the (TT_G) constraint is indeed slack, and the optimal solution of program $\mathcal{P}^{d^*_{BH}=1}$ is the same as characterized in Proposition 2.

On the other hand, if $Z<0$, then the (TT_G) constraint in program $\mathcal{P}^{d^*_{BH}=1}$ must be binding. Prove by contradiction. Suppose the (TT_G) constraint is instead slack, then the optimal solution is the same as characterized in Proposition 2, and the (TT_G) constraint can be reduced to (11). If $Z<0$, the (TT_G) constraint is violated. A contradiction. ■

Proof of Lemma 2

Part (i): When $i_B < i-\delta_1$, the optimal investment policy depends solely on the CEO's report, hence

$$\begin{aligned}
CC_{a_2}(i_B<i-\delta_1) = \quad & \underbrace{0.5(0.5+i)(0.5+i_B)}_{Pr[\theta=1,s=G,H]}\left[-\frac{1}{r}Ln\left(1-\frac{1-e^{-rk_2}}{Pr[\theta=1|\hat{s}=G,H]}\right)\right] \\
& +\underbrace{0.5(0.5+i)(0.5-i_B)}_{Pr[\theta=1,s=G,L]}\left[-\frac{1}{r}Ln\left(1-\frac{1-e^{-rk_2}}{Pr[\theta=1|\hat{s}=G,L]}\right)\right] \\
= \quad & -\frac{1}{r}0.5(0.5+i)\left\{(0.5+i_B)Ln\left(1-\frac{1-e^{-rk_2}}{Pr[\theta=1|\hat{s}=G,H]}\right)\right. \\
& \left.+(0.5-i_B)Ln\left(1-\frac{1-e^{-rk_2}}{Pr[\theta=1|\hat{s}=G,L]}\right)\right\}
\end{aligned}$$

The term inside the brace

$$\Omega \equiv (0.5+i_B)Ln\left(1-\frac{1-e^{-rk_2}}{Pr[\theta=1|\hat{s}=G,H]}\right)+(0.5-i_B)Ln\left(1-\frac{1-e^{-rk_2}}{Pr[\theta=1|\hat{s}=G,L]}\right)$$

is the expected utility of a risk-averse individual with utility function $Ln(\cdot)$ who is facing the following lottery:

$$\begin{cases} 1-\frac{1-e^{-rk_2}}{Pr[\theta=1|\hat{s}=G,H]} & \text{with probability } 0.5+i_B \\ 1-\frac{1-e^{-rk_2}}{Pr[\theta=1|\hat{s}=G,L]} & \text{with probability } 0.5-i_B \end{cases}$$

The mean of the lottery is $1-\frac{1-e^{-rk_2}}{0.5+i}$, which is independent of i_B. At the same time, as i_B increases, the spread, $\frac{1-e^{-rk_2}}{Pr[\theta=1|\hat{s}=G,L]}-\frac{1-e^{-rk_2}}{Pr[\theta=1|\hat{s}=G,H]}$, becomes larger. That is, as i_B increases, the lottery becomes a Mean-Preserving-Spread of the original lottery. Therefore, Ω is decreasing in i_B, which leads to $\frac{\partial CC_{a_2}(i_B<i-\delta_1)}{\partial i_B}>0$.

Part (ii): When $i_B>i+\delta_2$, the optimal investment policy depends solely on the board's information, hence

$$\begin{aligned} CC_{a_2}(i_B>i+\delta_2) = & \underbrace{0.5(0.5+i)(0.5+i_B)}_{Pr[\theta=1,s=G,H]}\left[-\frac{1}{r}Ln\left(1-\frac{1-e^{-rk_2}}{Pr[\theta=1|\hat{s}=G,H]}\right)\right] \\ & +\underbrace{0.5(0.5-i)(0.5+i_B)}_{Pr[\theta=1,s=B,H]}\left[-\frac{1}{r}Ln\left(1-\frac{1-e^{-rk_2}}{Pr[\theta=1|\hat{s}=B,H]}\right)\right] \\ = & -\frac{1}{2r}\left\{(0.5+i)(0.5+i_B)Ln\left(1-\frac{1-e^{-rk_2}}{Pr[\theta=1|\hat{s}=G,H]}\right)\right. \\ & \left.+(0.5-i)(0.5+i_B)Ln\left(1-\frac{1-e^{-rk_2}}{Pr[\theta=1|\hat{s}=B,H]}\right)+(0.5-i_B)Ln(1)\right\} \end{aligned}$$

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

$$\begin{cases} 1-\frac{1-e^{-rk_2}}{Pr[\theta=1|\hat{s}=G,H]} & \text{with probability } (0.5+i)(0.5+i_B) \\ 1-\frac{1-e^{-rk_2}}{Pr[\theta=1|\hat{s}=B,H]} & \text{with probability } (0.5-i)(0.5+i_B) \\ 1 & \text{with probability } 0.5-i_B \end{cases}$$

It is readily to verify that the mean of the above lottery is e^{-rk_2}, independent of i_B. Furthermore, as i_B increases, both $1-\frac{1-e^{-rk_2}}{Pr[\theta=1|\hat{s}=G,H]}$ and $1-\frac{1-e^{-rk_2}}{Pr[\theta=1|\hat{s}=B,H]}$ move towards 1. At the same time, the distant between the two, $\frac{1-e^{-rk_2}}{Pr[\theta=1|\hat{s}=B,H]}-$

$\frac{1-e^{-rk_2}}{Pr[\theta=1|\hat{s}=G,H]}$, is also decreasing in i_B. That is, as i_B increases, the three mass points get closer to each other. Therefore, a risk-averse individual always prefers the lottery with a higher i_B, which implies $\frac{\partial CC_{a_2}(i_B>i+\delta_2)}{\partial i_B} < 0$.

■

Proof of Proposition 4

If $i_B < i - \delta_1$, then by Proposition 1, $d^*_{Gm} = 1$ and $d^*_{Bm} = 0$ for $m \in \{H, L\}$. Therefore,

$$\begin{aligned} FV &\equiv \left[\sum_{\hat{s}=s\in\{G,B\},m\in\{H,L\}} Pr[s,m]\cdot d^*_{\hat{s}m}\cdot\{Pr[\theta=1|s,m]X-I\} \right] - CC \\ &= 0.5\left[(0.5+i)X-I\right] - CC_{a_1} - CC_{a_2}. \end{aligned}$$

By Proposition 2,

$$CC_{a_1} = -\frac{1}{r}\left\{(0.5+2i_Bi)Ln\left(1-\frac{1-e^{-rk_1}}{4i_Bi}\right)+(0.5-2i_Bi)Ln\left(1+\frac{1-e^{-rk_1}}{4i_Bi}\right)\right\}.$$

Taking derivative with respect to i_B, we get

$$\begin{aligned} \frac{d\ CC_{a_1}}{d\ i_B} &= -\frac{1}{r}\left\{2iLn\left(1-\frac{1-e^{-rk_1}}{4i_Bi}\right)-2iLn\left(1+\frac{1-e^{-rk_1}}{4i_Bi}\right)\right\} \\ &\quad -\frac{1}{r}\left\{(0.5+2i_Bi)\frac{\frac{1-e^{-rk_1}}{4ii_B^2}}{1-\frac{1-e^{-rk_1}}{4i_Bi}}-(0.5-2i_Bi)\frac{\frac{1-e^{-rk_1}}{4ii_B^2}}{1+\frac{1-e^{-rk_1}}{4i_Bi}}\right\}. \end{aligned}$$

It is straightforward that

$$\lim_{k_1\to 0}\frac{d\ CC_{a_1}}{d\ i_B} = 0.$$

Therefore, for $k_1 \to 0$,

$$\frac{d\ FV(i_B<i-\delta_1)}{d\ i_B} = -\frac{d\ CC_{a_2}(i_B<i-\delta_1)}{d\ i_B} < 0.$$

■

Proof of Proposition 5

Comparing

$$Pr[m = H|\theta = 1, s, \hat{s}] = Pr[m = L|\theta = 0, s, \hat{s}] = 0.5 + i_B, \qquad (Info - Alt)$$

with

$$Pr[m = H|\theta = 1, s, \hat{s}] = Pr[m = L|\theta = 0, s, \hat{s}] = 0.5 + i_B \cdot \mathbb{1}_{\hat{s}=s} \cdot a_1, \; (Info - Main)$$

it is clear that on the equilibrium path (i.e., the CEO evaluates the project and truthfully reports), the precision of the board's signal is the same across the two assumptions. Therefore, the players' on-equilibrium-path payoffs under $(Info - Alt)$ is the same as those under $(Info - Main)$.

Part (1): we first argue that the optimal investment decision under $(Info - Alt)$ is the same as that under $(Info - Main)$. The reason is that the optimal investment decision is calculated based on $\Pr[\theta = 1 \mid \hat{s}, m] = \Pr[\theta = 1 \mid s, m, a_1 = 1, \hat{s} = s]$, which is the same across the two assumptions $(Info - Alt)$ and $(Info - Main)$.

Part (2): If $i_B \leq i + \delta_2$, then by Proposition 1, $d^*_{Bm} = 0$ for $m \in \{H, L\}$. Therefore, $D(a_1, s, \hat{s} = B, m) = U_{Bm}$. Furthermore, under $(Info - Alt)$, it is readily verified that

$$\begin{aligned}
\Pr[\theta = 1|s = B, m, a_1 = 1, \hat{s} = G] &< \Pr[\theta = 1|s = G, m, a_1 = 1, \hat{s} = G], \\
\Pr[\theta = 1|s, m, a_1 = 0, \hat{s} = G] &< \Pr[\theta = 1|s = G, m, a_1 = 1, \hat{s} = G].
\end{aligned}$$

Therefore, $O(a_1 = 1, s = B, \hat{s} = G, m) = O(a_1 = 0, s, \hat{s} = G, m) = 0$ for $m \in \{H, L\}$.

For the probability terms, note that under $(Info - Alt)$, the precision of the board's signal is independent of the CEO's report $\hat{s}$, therefore,

$$\begin{aligned}
Pr[H|s = G, a_1 = 1, \hat{s}] &= Pr[L|s = B, a_1 = 1, \hat{s}] = 0.5 + 2i_B i, \quad \text{for} \quad \hat{s} \in \{G, B\}, \\
Pr[L|s = G, a_1 = 1, \hat{s}] &= Pr[H|s = B, a_1 = 1, \hat{s}] = 0.5 - 2i_B i, \quad \text{for} \quad \hat{s} \in \{G, B\}, \\
\sum_{s \in \{G,B\}} Pr[s, m|a_1 = 0, \hat{s}] &= Pr[m|a_1 = 0, \hat{s}] = 0.5, \qquad \text{for} \;\; \hat{s} \in \{G, B\} \text{ and } m \in \{H, L\}.
\end{aligned}$$

Hence, the board's optimization program under $(Info - Alt)$ is

$$\min_{\{U_{\hat{s}m} \in R\}} \quad CC_{a_1} = (0.25 + i_B i)\left[\Phi(U_{GH}) + \Phi(U_{BL})\right] + (0.25 - i_B i)\left[\Phi(U_{BH}) + \Phi(U_{GL})\right]$$

subject to

$$(0.5 + 2i_B i)U_{GH} + (0.5 - 2i_B i)U_{GL} \geq (0.5 + 2i_B i)U_{BH} + (0.5 - 2i_B i)U_{BL} \tag{TT_G}$$

$$(0.5 - 2i_B i)U_{BH} + (0.5 + 2i_B i)U_{BL} \geq (0.5 - 2i_B i)U_{GH} + (0.5 + 2i_B i)U_{GL} \tag{TT_B}$$

$$EU \geq 0.5U_{GH} + 0.5U_{GL} \tag{$IC - a_1 - 1$}$$

$$EU \geq 0.5U_{BH} + 0.5U_{BL} \tag{$IC - a_1 - 2$}$$

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

where $EU = e^{rk_1}\left[(0.25 + i_B i)(U_{GH} + U_{BL}) + (0.25 - i_B i)(U_{BH} + U_{GL})\right].$

Following the same proof strategies as in the proof of Proposition 2, we can show that the solution to the board's optimization program under $(Info - Alt)$ is exactly the same as the solution to $\mathcal{P}^{d^*_{BH}=0}$ in the proof of Proposition 2.

Part (3): If $i_B > i + \delta_2$, the investment is undertaken if the board's signal is H, independent of the CEO's signal. Then there is no need to motivate the CEO's evaluation effort. Furthermore, we assume that the CEO is uninformed if not evaluate the project, therefore

$$\Pr[\theta = 1|s = G, H, a_1 = 0] = \Pr[\theta = 1|s = B, H, a_1 = 0] = \Pr[\theta = 1|H] = 0.5 + i_B.$$

Hence, the board will compensate the CEO for his implementation effort based on $\Pr[\theta = 1|H]$.

References

Adams, R. and D. Ferreira. 2007. A theory of friendly boards. *The Journal of Finance* 62 (1): 217-250.

Adams, R., B. Hermalin and M. Weisbach. 2010. The role of boards of directors in corporate governance: a conceptual framework and survey. *Journal of Economic Literature* 48 (1): 58-107.

Aghion, P. and J. Tirole. 1997. Real and formal authority in organizations. *Journal of Political Economy* 105 (1): 1-29.

Arya, A., J. Glover, and K. Sivaramakrishnan. 1997. The Interaction Between Decision and Control Problems and the Value of Information. *The Accounting Review* 72: 561-574.

Arya, A., J. Fellingham, J. Glover, and K. Sivaramakrishnan. 2000. Capital Budgeting, the Hold-Up Problem, and Information System Design. *Management Science* 46: 205-216.

Arya, A., J. Glover and S. Radhakrishnan. 2006. The Controllability Principle in Responsibility Accounting: Another Look. *Essays in Accounting Theory in Honour of Joel S. Demski*: 183-198. Springer New York.

Arya, A., J. Glover and S. Sunder. 1998. Earning Management and The Revelation Principle. *Review of Accounting Studies* 3: 7-34.

Balakrishnan, R. 1991. Information Acquisition and Resource Allocation Decisions. *The Accounting Review* 66 (1): 120-139.

Baldenius, T., N. Melumad, and X. Meng. 2014. Board composition and CEO power. *Journal of Financial Economics* 112 (1): 53-68.

Bebchuk, L. and J. Fried. 2004. Pay without Performance: the Unfulfilled Promise of Executive Compensation. Cambridge and London: Harvard University Press.

Bushman, R. and R. Indjejikian, 1993. Accounting income, stock price, and managerial compensation.*Journal of Accounting and Economics* 16(1): 3-23.

Dutta, S., and Reichelstein, S. 2005. Stock Price, Earnings, and Book Value in Managerial Performance Measures. *The Accounting Review* 80(4): 1069-1100.

Drymiotes, G. 2007. The monitoring role of insiders. *Journal of Accounting and Economics* 44: 359-377.

Drymiotes, G. and K. Sivaramakrishnan. 2012. Board Monitoring, Consulting, and Reward Structures. *Contemporary Accounting Research* 29 (2): 453-486.

Faleye, O., R. Hoitash and U. Hoitash. 2014. Industry Expertise on Corporate Boards. Working Paper, Northeastern University.

Frydman, C. and D. Jenter. 2010. CEO Compensation. *Annual Review of Financial Economics* 2: 75-102.

Fudenberg, D. and J. Tirole. 1990. Moral hazard and renegotiation in agency contracts. *Econometrica* 58 (6): 1279-1319.

Gigler, F. and T. Hemmer. 2004. On the Value of Transparency in Agencies with Renegotiation. *Journal of Accounting Research* 42(5): 871-893.

Guner, B., U. Malmendier and G. Tate. 2008. Financial expertise of directors. *Journal of Financial Economics* 88 (2): 323-354.

Harris, M. and A. Raviv. 2008. A Theory of Board Control and Size. *Review of Financial Studies* 21 (4): 1797-1832.

Holmström, B. 2005. Pay without performance and the managerial power hypothesis: a comment. *Journal of Corporation Law* 30 (4): 703–715.

Indjejikian, R. 1999. Performance Evaluation and Compensation Research: An Agency Perspective. *Accounting Horizons* 13 (2): 147–157.

Kumar, P. and K. Sivaramakrishnan. 2008. Who monitors the monitor? The effect of board independence on executive compensation and firm value. *The Review of Financial Studies* 21(3): 1371-1401.

Lambert, R. 1986. Executive effort and selection of risky projects. *Rand Journal of Economics* 17 (1): 77-88.

Laux, V. 2006. The ignored performance measure. *Journal of Economics & Management Strategy* 15 (3): 707-733.

Laux, V. 2008. Board Independence and CEO Turnover. *Journal of Accounting Research* 46: 137-171.

Laux, V. and Mittendorf, B. 2011. Board Independence, Executive Pay, and the Adoption of Pet Projects. *Contemporary Accounting Research* 28: 1467-1483.

Levit, D. 2012. Expertise, Structure, and Reputation of Corporate Boards. Working Paper. University of Pennsylvania.

Masulis, R., C. Ruzzier, S. Xiao and S. Zhao. 2012. Do Independent Expert Directors Matter? MPRA Working Paper No. 68200. https://mpra.ub.uni-muenchen.de/68200/.

Morse, A., V. Nanda and A. Seru. 2011. Are Incentive Contracts Rigged by Powerful CEOs? *Journal of Finance* 66(5): 1779–1821

Nanda, V. and B. Onal. 2016. Incentive Contracting When Boards Have Related Industry Expertise. *Journal of Corporate Finance* 41:1-22.

Raheja, C. 2005. Determinants of Board Size and Composition: A Theory of Corporate Boards. *Journal of Financial and Quantitative Analysis* 40 (2): 283-306

Song, F. and A. Thakor. 2006. Information Control, Career Concerns, and Corporate Governance. *Journal of Finance* 61 (4): 1845–1896.

Schwartz-Ziv,M. and M. Weisbach. 2013. What do boards really do? Evidence from minutes of board meetings. *Journal of Financial Economics* 108(2): 349–366.

Tian, J. 2014. Board monitoring and endogenous information asymmetry. *Contemporary Accounting Research* 31(1): 136–151.

Wang, C., F. Xie and M. Zhu. 2015. Industry expertise of independent directors and board monitoring. *Journal of Financial and Quantitative Analysis* 50(5): 929-962.