Stock Option Vesting Conditions, CEO Turnover, and Myopic Investment

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Abstract

This paper analyzes the optimal design of stock option vesting conditions when the CEO faces a risk of being replaced at an interim date. First, I show that long vesting terms do not necessarily discourage but in fact can encourage short-termism. Second, the model demonstrates that the optimal vesting schedule involves balancing incentives for managerial effort with incentives for long-term investment. Due to this trade-off, overinvestment in myopic projects can arise from optimal contracting and is not necessarily an artifact of faulty pay arrangements. The study generates new empirical predictions regarding the determinants and impacts of stock option vesting terms in contract design.

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1 Introduction

The recent financial crisis has renewed interest in the relation between executive pay arrangements and managerial myopia in corporations. While there is agreement that linking executive pay to long-term performance mitigates managerial short-termism (e.g., Bebchuk and Fried 2010; Bhagat and Romano 2010), it is less clear how and to what extent such a link should be established.

The concern for myopic behavior in organizations has lead to a growing literature on the optimal mix of short-term and long-term pay for corporate executives (e.g., Bolton et al. 2006; Peng and Roell 2009; Edmans et al. 2010; Gopalan et al. 2010). Granting executives equity based compensation with long vesting periods is generally viewed as an effective means to link CEO pay to long-term firm performance and to alleviate short-termist behavior. This is not to say that optimal contracts consist solely of long-term equity compensation. Early vesting of equity awards can be part of an optimal contract because, for example, managers are risk-averse or have liquidity concerns, or incumbent shareholders are short-term oriented (see also Walker 2010).

In this paper, I depart from the existing literature by considering a setting in which the CEO is subject to being replaced at an intermediate date and examine the effects of CEO turnover on optimal contracting. The possibility of CEO turnover has implications not only for the relation between stock option vesting terms and myopic CEO behavior but also for the equilibrium level of myopia that arises in optimal contracting.

Specifically, I consider a setting in which a board hires a new CEO whose tasks are to acquire firm specific human capital to enhance his ability to perform in the firm and to decide how to allocate a fixed amount of resources between a short-term and a long-term project. Following Holmstrom (1982, 1999), I assume that the CEO's ability is unknown to all parties. Based on the firm's short-term performance, the board draws inferences about the CEO's talent and replaces him if necessary.

I first analyze a first-best setting in which the CEO's actions are observable and contractible. Although the long-term project is assumed to be strictly more profitable than the short-term project, it is generally not first-best optimal to invest exclusively in the long-term project. Short-term projects generate early results and thus provide timely feedback about CEO talent. This feedback enables the board to update beliefs about talent and to make timely CEO replacement decisions. As an example consider the promotion process in academia. When a new assistant professor is hired, the talent of the new hire is rather uncertain. Even when the goal of the department is to generate long-term ground-breaking research, it can still be optimal to also encourage less important shorter-term research projects in the beginning of the new colleagues's career. Early failures/successes provide early feedback about talent, which allows for timely replacement decisions.

Consider now the case where the CEO's actions are not observable. The board's task is to induce the CEO to work on acquiring firm specific expertise and to make an appropriate investment allocation. In the present setting, the optimal incentive contract consist solely of stock options.[1] The effectiveness of the option contract depends on the details of the vesting terms and exercising restrictions. The vesting period determines when the CEO has earned the option compensation. Thus, after vesting, the options belong to the CEO even when he leaves the firm. Exercising restrictions further restrict the CEO's ability to exercise options and to sell the underlying shares

[1] The option contract studied here is weakly optimal in the sense that there is no other more general contract that yields a higher payoff to shareholders.

even after they have vested. Given that extended vesting terms already restrict the exercising of options, the literature typically does not distinguish between vesting terms and exercising restrictions.[2] However, this distinction is important if the CEO is subject to replacement at an intermediate date. While in the present setting it is always optimal to place restrictions on the CEO's ability to exercise options that vest at an early date, the optimal design of the vesting conditions, which is the focus of this paper, is more subtle.

Granting stock options with long vesting periods implies that the CEO forfeits his option compensation when fired at an interim date due to poor performance. Consequently, a long vesting horizon biases the CEO in favor of remaining with the firm. This is beneficial from an effort incentive perspective because the threat of losing his position and forfeiting unvested options provides the CEO with strong incentives to do a good job. But at the same time, the threat of option forfeiture distorts the CEO's investment decision toward short-term projects. The CEO knows that the board will rely on short-term results to update beliefs about managerial talent when deciding whether or not to replace the incumbent. The combination of long vesting periods and potential interim CEO turnover therefore ties CEO pay to short-term firm performance. As a consequence, and in contrast to conventional views, extended vesting periods do not necessarily discourage but in fact can encourage short-termism.

The board can reduce the CEO's short-term focus by allowing a fraction of the stock options to vest early. Early vesting in combination with restricted exercising has two positive effects on the CEO's investment decision: First, the CEO will put less weight on short-term results because he retains the options that have already vested even when he is fired due to poor performance; second, given that the (ousted) CEO

[2] See, e.g., Peng and Roell (2009), Edmans et al. (2010), Gopalan et al. (2010).

is unable to immediately exercise his vested options, he has an additional incentive to focus on long-term results ex ante. Note that the combination of early vesting and restricted exercising is strictly preferred over cash severance payments, because severance pay can only replicate the first effect, but not the second.

In principle, by fine tuning the vesting terms, the board can fully eliminate managerial myopia and induce the first-best allocation of resources. However, this is in general not optimal because early vesting lowers the penalty associated with being fired and hence adversely affects the CEO's effort choice as discussed before. Consequently, when designing the optimal vesting terms, the board balances the desire to effectively induce managerial effort with the desire to induce appropriate investment decisions. This trade-off leads to optimal contracts that (i) allow a positive fraction of the CEO's stock options to vest early and (ii) induce the CEO to allocate excessive resources to the short-term project relative to first-best. One immediate implication of this result is that managerial myopia is not necessarily an artifact of faulty pay arrangements or impatient shareholders but can arise endogenously from optimal contracting when shareholders face a multitask agency problem in the spirit of Holmstrom and Milgrom (1991). Regulatory intervention that attempts to curtail myopic behavior in organizations, for example by imposing restrictions on minimum vesting periods, can be counterproductive and further foster short-termism.

This analysis shows that the effect of vesting conditions on the CEO's investment horizon depends crucially on whether or not the CEO is concerned about potential dismissal prior to the vesting of the equity. In firms in which turnover is not a threat because, for example, the CEO is well entrenched and already has established that he is the right person to run the firm, the standard argument applies and long vesting periods effectively increase the weight placed on long-term performance. However, in firms in which the CEO is not entrenched and is of uncertain talent (as assumed in my model) because, for example, he is a relatively new (outside) hire, the standard argument no longer holds. The analysis therefore suggests that when studying the link between equity vesting terms and investment decisions, empirical studies should distinguish between these two types of firms. Assuming that boards optimally design compensation contracts, the model predicts that both the fraction of stock options that vest early and the level of myopic investment is larger in firms in which the incumbent is a new hire with uncertain talent than in firms in which the incumbent is well established and entrenched.

The model provides several additional predictions for firms with non-entrenched executives. First, in firms and industries that are more focused on long-term investment opportunities (such as pharmaceutical or energy companies), the board allows a larger fraction of the CEO's option package to vest early. Early vesting reduces the sensitivity of CEO pay to short-term performance and shifts the CEO's attention toward longer-term investments. Second, firms that allow a larger fraction of options to vest early also pay their executives larger stock option awards. This follows because early vesting dilutes ex ante effort incentives and hence has to be combined with larger stock option grants to maintain incentives. Third, in firms with more valuable long-term investment opportunities, the likelihood of forced CEO turnover at an early stage is higher. This follows because if the board induces executives to allocate resources away from short-term toward longer-term projects, the performance in the short run declines, which results in a downward revision of the perception of CEO talent.

Section 2 discusses related studies. Section 3 outlines the model and Section 4 analyzes the first-best case. Section 5 presents the main results and Section 6 provides a discussion and empirical predictions. Section 7 concludes. All proofs are in the appendix.

2 Related Studies

There is a growing theoretical literature on the optimal vesting terms for executive equity compensation. Brisley (2006) shows that allowing executives to cash out their stock options early can alleviate excessive managerial risk-aversion in project selection. Bolton, Scheinkman, and Xiong (2006) consider a speculative stock market, where incumbent shareholders benefit from selling stock to overconfident investors at an interim date. The optimal contract therefore allows the unwinding of options in the short run to encourage executives to boost interim stock prices at the detriment of long-term value. Laux (2010) demonstrates that granting executives discretion over the timing of stock option exercises renders them willing to abandon poorly performing projects at an early stage. The current study contributes to this literature by analyzing the effects of vesting terms on the CEO's effort and investment choices in a setting with forced CEO turnover.[3]

Myopic behavior in organizations has been discussed extensively in other settings. For example, Narayanan (1985), Stein (1989), Bebchuk and Stole (1993), and Fisher and Verrecchia (2000) show that managers' desire to enhance short-term stock prices or personal reputation can lead to equilibria where managers overinvest in myopic projects at the detriment of long-term firm value. In contrast to these studies, the current model adopts an optimal contracting approach and analyzes the trade-off

[3]Other studies that consider the optimal mix of short-term and long-term pay for executives include Edmans et al. (2010), Peng and Roell (2009), and Gopalan et al. (2010).

between encouraging investment in long-term projects and inducing productive effort. One implication of this trade-off is that the optimal contract that maximizes long-term firm value induces the CEO to overinvest in myopic projects relative to first-best.[4]

Von Thadden (1995) studies contracting between an entrepreneur and an outside investor and determines conditions under which it is infeasible to implement the preferred long-term investment project (when also a short-term project is available) due to the threat of early project termination by the investor. In this setting, inducing long-term investment is hindered by the fact that the entrepreneur can only be rewarded for long-term success if the project is not terminated at an earlier stage. In contrast, in the present model, not the project is terminated but the incumbent CEO is fired, which allows the board to link the incumbent's pay to the long-term consequences of his investment decision even when he is dismissed at an intermediate date. The reason why the board does not fully eliminate overinvestment in myopic projects in the present paper is that the board has to balance the benefits of efficient investment with the cost of inducing managerial effort. This trade off is absent in von Thadden (1995) because the entrepreneur chooses the contract that maximizes his own payoff (keeping the investor at his reservation utility) and hence is not concerned about restricting his own rents. Finally, my model differs from von Thadden (1995) in that it focuses on stock option pay arrangements and on the effects of vesting conditions on investment and effort decisions.

[4]Other studies that analyze contracting and myopic behavior include Feltham and Xie (1992), Dutta and Gigler (2002), Goldman and Slezak (2006). However, these articles consider settings in which CEO pay can only be tied to a short-term performance measure, such as an interim earnings report or interim stock price. Using short-term measures as a means to induce productive effort simultaneously induces the CEO to manipulate these measures (e.g., by engaging in earnings manipulation) at the expense of long-term firm value.

3 Model

Consider a setting with three risk-neutral parties: shareholders, the board of directors, and the CEO. The board of directors represents the interests of shareholders and is responsible for designing the incentive contract for the CEO and replacing the CEO if necessary.

Timing: There are three dates t_0, t_1, and t_2. In the beginning of the game (date t_0), the board hires a new CEO and offers him an incentive pay plan. After signing the contract, the CEO works on acquiring firm specific expertise and decides how to allocate a fixed amount of resources among a short-term and a long-term project. The CEO's effort and investment choices influence the firm's cash flows at dates t_1 and t_2, where t_1 represents the short-run and t_2 the long-run horizon of the firm. At date t_1, short-term cash flows x_1 are realized and the board decides whether or not to replace the incumbent with a new CEO. In case the incumbent is retained, long-term cash flows are realized and the game ends. In case the incumbent is replaced, the board hires a new CEO and offers him a pay plan. After accepting the contract, the new CEO works on acquiring firm specific expertise. At date t_2, long-term cash flows, x_2, are realized and the game ends.

Effort choice: After the CEO is hired and signed the contract (the details of the contract are discussed below), he can take an unobservable action, $e = \{e_L,\ e_H\}$, to enhance his expected ability to perform in the firm. This action can be viewed as an investment in firm specific human capital or expertise. If the CEO chooses the high action, $e = e_H$, he will be a good fit, $F = G$, with probability $p > 0$ and a bad fit, $F = B$, with probability $(1 - p)$. If the CEO shirks and chooses the low action, $e = e_L$, he will be a bad fit, $F = B$, for sure. While it is common knowledge that high effort increases the CEO's expected ability, neither the CEO nor the board can observe the realization of F. The private cost associated with effort e is given by $v(e)$. For simplicity and without loss of generality, I assume that $v(e_H) = k$ and $v(e_L) = 0$.

If the incumbent CEO is replaced after short-term cash flows are realized (as discussed in detail below) the board hires a replacement. Similar to the initial CEO, the new CEO can choose an unobservable action, $e_N = \{e_L, e_H\}$, to increase his expected ability to perform in the firm. As before, the new CEO can be either good, $T_N = G$, or bad, $T_N = B$, with $Pr[T_N = G|e_N = e_H] = p$ and $Pr[T_N = G|e_N = e_L] = 0$. The personal cost of effort is given by $v_N(e_N)$, with $v_N(e_H) = k_N$ and $v_N(e_L) = 0$. Assume that the effort cost is sufficiently small such that shareholders always wish to induce the incumbent CEO and, in case of CEO turnover, the new CEO to invest in firm specific human capital. Given that the replacement CEO cannot succeed if he does not invest in firm specific expertise, the new CEO is not able to capture any rents and the shareholders' expected cost of inducing $e_N = e_H$, is simply k_N. Thus, k_N can be interpreted as a direct cost of replacing the incumbent CEO because this cost only occurs in case of CEO turnover.

Investment and cash flows: The CEO has one dollar of capital available and can invest in a long-term and a short-term project. Assume that the cost of capital is zero. Let $I \leq 1$ denote the capital allocated to the long-term project. Consequently, $1 - I$ is the amount invested in the short-term project. Assume that the CEO's investment decision is non-observable and non-contractible.

The firm generates cash flows in two subsequent periods, i.e., at t_1 and t_2. The cash flow in period t_i $(i = 1, 2)$, denoted $x_i \in \{X_i, 0\}$, is either high, $x_i = X_i > 0$, or low, $x_i = 0$. The probability of success in period t_i depends on the capital allocation and the fit of the CEO in charge in that period. If the CEO in charge is a bad fit, then cash flows in this period are low for sure. If the CEO in charge is a good fit, the probability of success is a function of the initial investment decision. Allocating more capital to the short-term (long-term) project increases the expected return in the first-period (second-period). Specifically, the probability of success at date t_1 is $(a_1 + s_1(1 - I))$ and the probability of success at date t_2 is $(a_2 + s_2 I)$, where $a_1, a_2, s_1, s_2 \in (0, 0.5)$ are exogenous parameters. Thus, given the CEO in charge is a good fit, the expected return of investment over both periods is $(a_1 + s_1(1 - I)) X_1 + (a_2 + s_2 I) X_2$. The parameter $a_1(a_2)$ represents the probability of success at t_1 (t_2) that is independent of the investment decision and due to the firm's typical operations. Consequently, first-period cash flows are informative about the CEO's talent even when the CEO exclusively invests in the long-term project $(I = 1)$.

I assume that short-term cash flows, x_1, are paid out immediately to shareholders as dividends. Using the alternative assumption that the firm retains the cash flows x_1 until the final period (date t_2), would have no effect on the cost of the incentive scheme or the equilibrium decisions but would render the optimal stock option plan slightly more complex.[5]

To focus on dysfunctional myopic behavior, I assume that the long-term project is strictly more productive than the short-term project, that is, $s_2 X_2 - s_1 X_1 > s_1 k_N$. Otherwise, for $s_2 X_2 - s_1 X_1 < s_1 k_N$, the incentive friction with respect to the investment decision becomes trivial and the optimal contract achieves the first-best outcome (see the appendix for details).

CEO replacement: When the board observes the realization of the first-period outcome, x_1, it decides whether or not to replace the incumbent with a new CEO.

[5] Specifically, if there are no intermediate dividend payments and X_1 is relatively large compared to X_2, the optimal contract may require the resetting of stock options to provide optimal incentives.

The board is unable to precommit to a specific replacement policy up front and hence replaces the CEO whenever this is ex post optimal. Conditional on observing short-term success, $x_1 = X_1$, the board knows that the incumbent is a good fit and hence retains him. Conditional on observing short-term failure, $x_1 = 0$, the board revises the probability that the incumbent is a good fit downwards to $Pr[F = G|x_1 = 0] = \frac{p(1-s_1(1-I)-a_1)}{(p(1-s_1(1-I)-a_1)+(1-p))} < p$. Throughout the paper, I focus on parameter constellations for which it is pareto efficient to replace the incumbent in case of short-term failure. Otherwise, if it is efficient to always retain the incumbent, the model becomes trivial. This assumption requires that conditional on short-term failure, $x_1 = 0$, the expected cash flows under a new CEO minus the additional effort cost k_N exceed the expected cash flows under the incumbent CEO. Note that the probability of long-term success depends on the initial capital allocation even when a new CEO takes over. Thus, replacement is optimal at date t_1 if and only if

$$p\,(a_2 + s_2 I)\,X_2 - k_N > Pr[F = G|x_1 = 0]\,(a_2 + s_2 I)\,X_2. \tag{1}$$

Condition (1) can be simplified to $\frac{p(1-p)(a_1+s_1(1-I))}{(p(1-s_1(1-I)-a_1)+(1-p))}\,(a_2 + s_2 I)\,X_2 > k_N$.[6] Thus, the direct cost of replacing the incumbent, represented by k_N, cannot be too large to ensure that CEO turnover is ex post efficient when $x_1 = 0$.

Contracting: The company is publicly traded and the value of the assets-in-place is exogenously given by $A > 0$. There is one issued share of stock, which is held by

[6] When making the replacement decision, the board will also take into consideration the difference in pay for the incumbent CEO when he is dismissed and when he is retained. However, this will not have an effect on CEO turnover: conditional on observing bad news, if the incumbent's expected compensation is higher when he stays in the firm than when he leaves, then it is even more beneficial for shareholders to replace the incumbent and if the opposite is true, then the incumbent would voluntarily leave the firm to make room for a new CEO.

initial shareholders. The CEO is protected by limited liability such that payments to the CEO must be nonnegative. The reservation utility of the CEO is normalized to zero.

I consider contracts where the only available incentive instrument is stock options.[7] Restricting attention to stock option plans is without loss of generality because there is no other more general contract that can yield a higher payoff to shareholders (see the Appendix for details). In fact, in the current setting, it is natural to consider stock option plans instead of, say, state contingent bonus payments for one reason: As discussed in the main part of the paper, the optimal contract restricts the CEO's freedom to exercise his (vested) options regardless of whether or not he loses his position. A state contingent bonus plan can replicate these incentives only if the board promises to reward the CEO for results that are realized long after he has been fired.

The CEO's compensation contract is publicly observable and has the form $c = (\beta, E, \alpha, \beta_V, \beta_E)$. The contract specifies the number of options granted to the CEO in t_0, denoted β, the exercise price, denoted E, and the fixed salary, denoted α. Note that the fixed salary is always zero in the optimal solution and hence is omitted in what follows. The board determines the terms and conditions under which the options vest and may be exercised. Specifically, let β_V denote the number of options that vest early, i.e., at date t_1. The remaining options, $\beta - \beta_V$, vest at t_2. In addition, let β_E denote the number of already vested options that can be exercised at t_1. The remaining options $(\beta - \beta_E)$ can be exercised at t_2. Upon vesting, the CEO owns the stock options. Thus, if fired at date t_1, the CEO retains the options that have already

[7] This includes stock compensation because stock is equivalent to an option with an exercise price of zero.

vested (β_V) and forfeits the remaining options ($\beta - \beta_V$). An alternative to early vesting ($\beta_V > 0$) is accelerated vesting upon termination. Under accelerated vesting provisions, a fraction of the CEO's options vest immediately when he is dismissed. In the setting discussed here, accelerated vesting is just another form of early vesting and has identical effects.[8]

4 First-Best Solution

In this section, I consider the optimal investment decision in a first-best world where the CEO's choices of e and I are observable and contractible. In this case, the board can implement any levels of e and I through a forcing contract. To ensure participation, the board needs to compensate the incumbent CEO (and, in case of CEO turnover, the replacement CEO) for his effort cost.

The board's expected utility can be written as

$$U_{Board} = (s_1(1-I) + a_1)\, pX_1 + (s_2 I + a_2)\, pX_2 - k \tag{2}$$
$$+ (s_2 I + a_2)\, X_2 \,(s_1(1-I) + a_1)\, p(1-p) - (1 - p\,(s_1(1-I) + a_1))\, k_N.$$

The first line in (2) captures the shareholders' expected payoff (including the initial effort cost) if the board does not have the option to replace the incumbent CEO at date t_1. The second line in (2) captures the ex ante value of the option to replace the CEO. The ex ante value of the replacement option can be rewritten to

$$\Pr[x_1 = 0] \left(\frac{p\,(1-p)\,(a_1 + s_1(1-I))}{(p\,(1 - s_1(1-I) - a_1) + (1-p))}\,(a_2 + s_2 I)\, X_2 - k_N \right), \tag{3}$$

[8] In his study of 179 turnover cases, Yermack (2006) finds that departing executives generally forfeit stock options and shares that have not yet vested unless the executives have attained a minimum retirement age.

where $\Pr[x_1 = 0] = (p(1 - s_1(1 - I) - a_1) + (1 - p))$ is the probability that the CEO will be removed at date t_1 and the term in brackets in (3) is the ex post value of CEO turnover in the event of poor short-term performance. Note that the term in brackets in (3) is positive due to assumption (1).

Taking the first-order condition of (2) with respect to I yields the first-best investment decision

$$I^{FB} = \frac{1}{2} - \frac{1}{2}\frac{s_1 a_2 - s_2 a_1}{s_1 s_2} + \frac{1}{2}\frac{s_2 X_2 - s_1 X_1 - s_1 k_N}{s_1 s_2 X_2 (1 - p)}, \tag{4}$$

which can be rewritten to

$$I^{FB} = \left[\frac{1}{2} - \frac{1}{2}\frac{s_1 a_2 - s_2 a_1}{s_1 s_2} - \frac{1}{2}\frac{s_1 k_N}{s_1 s_2 X_2 (1 - p)}\right] + \frac{1}{2}\frac{s_2 X_2 - s_1 X_1}{s_1 s_2 X_2 (1 - p)}. \tag{5}$$

Note that the second-order condition for a maximum is satisfied and given by

$$-2X_2 p s_1 s_2 (1 - p) < 0.$$

The term in square brackets in (5) represents the level of I that maximizes the ex ante value of the replacement option. In the absence of this term, that is, if CEO turnover is not possible or not optimal, then the first-best investment level is a corner solution and determined by $I = 1$ since the long-term project is strictly more profitable than the short-term project.

Based on the firm's short-term performance, the board draws inferences about the incumbent CEO's talent and decides whether or not to replace him with a new CEO. While good interim performance is a clear signal that the CEO is a high talent, observing poor performance is less informative: short-term failure is either the result of low talent or the result of a long-term oriented investment strategy. However, by allocating more capital to the myopic project, the board can increase the information content of first-period cash flows, because early failure becomes a stronger signal that the CEO's talent is low. To see this formally, note that the probability that the CEO is a high talent given poor interim performance, $Pr[F = G|x_1 = 0] = \frac{p(1-s_1(1-I)-a_1)}{(p(1-s_1(1-I)-a_1)+(1-p))}$, declines with short term investment $(1-I)$. As a result, larger investments in myopic projects reduce the likelihood that good-type CEOs are mistakenly replaced and result in improved turnover decisions.

However, this does not imply that the ex ante value of the replacement option is maximized if the board invests solely in the myopic project. Given that CEO turnover increases the expected probability of having a talented CEO in charge of the second period, the board wishes to shift production from the first period to the second period by investing more in the long-term project.

Thus, an increase in the short-term investment has two opposing effects on the ex ante value of the replacement option: it increases the information content of the short-term result leading to better replacement decisions, but decreases the advantage of having a talented CEO in charge of the second period by shifting production away from the second period.

Proposition 1 *In the first-best solution it holds that $I^{FB} \leq 1$. Assuming an interior solution, the first-best investment in the short-term project increases (I^{FB} declines) if X_2/X_1 declines, s_2/s_1 declines, k_N increases, and a_2/a_1 increases.*

The first-best investment in the long-term project increases with long-term cash flows X_2. The reasoning behind this result is more subtle than is apparent at first glance because an increase in X_2 involves direct and indirect effects. The direct effect is clear; if X_2 increases, the long-term project becomes more productive relative to the short-term project which leads to an increase in I^{FB}. There is also an indirect effect that works in the opposite direction. If X_2 increases, it becomes more important to have a talented CEO in charge of the second period, which makes it optimal to increase the level of short-term investment to improve the turnover decision. However, the first effect always dominates the second, resulting in a positive relation between X_2 and I^{FB}.

When k_N increases, replacing the incumbent CEO becomes more costly to the firm. Thus, for larger values of k_N, the board allocates more capital to the short-term project to reduce the probability that talented executives are accidentally replaced.

An increase in a_2 increases the second period production. Thus, for large values of a_2, it becomes more important that the CEO in charge in the long-run is a good fit. As a result, the board allocates more capital to the short-term project to induce a better replacement decision at t_1, implying that I^{FB} declines with a_2. An increase in a_1 increases first-period production and hence renders the short-term result, x_1, more informative about CEO talent ($Pr[F = G|x_1 = 0]$ declines with a_1). Thus, for larger values of a_1, the board is able to make better replacement decisions which increases the probability that the CEO in charge of the second period is a good fit. To exploit the fact that the long-run CEO is likely a high-talent, the board shifts capital from the short-term project to the long-term project; hence I^{FB} increases with a_1.

5 Main Results

I now consider the original setting in which the CEO's actions are unobservable. The board's task is to design a compensation contract that induces the CEO to work on acquiring firm specific expertise and to make an appropriate investment decision. Consider the contract outlined in the model section, $c = (\beta, E, \beta_V, \beta_E)$. I first discuss a benchmark case where early vesting of the CEO's stock options is prohibited, i.e., where $\beta_V = 0$. I then analyze the optimal contract.

5.1 Benchmark: Long-Term Vesting

As a benchmark it is useful to study the case where early vesting is not permitted, $\beta_V = 0$. This contract can be viewed as a simple long-term option plan because the options vest and can be exercised only after long-term cash flows, x_2, are realized. The goal of this section is to show that such a contract fails to induce appropriate investment decisions when the CEO faces a risk of being replaced at an intermediate date.

The CEO obtains β options in the beginning of the game. Due to the long vesting horizon, the CEO forfeits his option compensation if he is fired at date t_1. If he is retained, the value of his option compensation at date t_2 is $\beta(A + x_2 - E)$ since intermediate cash flows x_1 have already been cashed out to initial shareholders.

The level of the exercise price, E, must be sufficiently high to ensure that the CEO's stock options have value if and only if the firm succeeds in the long run; that is, it must hold that $E \geq A$ (recall A are the assets in place). For simplicity, I assume in what follows that $E = A$. Thus, in case of first-period and second-period success, the value of the CEO's option compensation is βX_2.

The CEO's ex ante utility if he chooses high effort, $e = e_H$, can now be stated as

$$U_{CEO}^{NV}(\beta) = p\left(s_1(1-I) + a_1\right)\left(s_2 I + a_2\right)\beta X_2 - k. \tag{6}$$

If the CEO shirks and chooses low effort, $e = e_L$, short-term cash flows will be low with certainty, which leads to his replacement and the forfeiture of his equity compensation. Given that the CEO cannot reap any benefits by shirking he is not able to obtain any rents in equilibrium and the effort incentive constraint is identical to the CEO's participation constraint and given by $U_{CEO}^{NV}(\beta) \geq 0$. To ensure participation (and high effort) the board must ensure that the expected value of the option award equals the cost of effort, $U_{CEO}^{NV}(\beta) = 0$.

Consider now the CEO's optimal investment decision, denoted I^{NV}. Taking the first-order condition of (6) with respect to I leads to

$$I^{NV} = \frac{1}{2} - \frac{1}{2}\frac{s_1 a_2 - s_2 a_1}{s_1 s_2}. \tag{7}$$

Condition (7) shows that the long-term equity contract discussed here is not effective in encouraging the CEO to focus on the firm's long-term goals. The incumbent knows that the board will rely on short-term results to update beliefs about CEO talent when making the replacement decision. Given that the CEO forfeits unvested options when fired, the combination of long vesting periods and potential replacement ties CEO pay to short-term performance, creating an incentive to allocate excessive resources to the myopic project.

Comparing the CEO's investment choice, I^{NV}, with the first-best investment level, I^{FB}, leads to the next proposition.

Proposition 2 *Long-term vesting conditions ($\beta_V = 0$) induce the CEO to underinvest in the long-term project relative to first-best, $I^{NV} < I^{FB}$.*

When the CEO makes his investment decision, he only takes into consideration the effect of I on the joint probability that both periods succeed and ignores the effects of I on the projects' returns and the firm's expected cost of CEO turnover. Given that investing in the long-term project is strictly more profitable than investing in the short-term project, $s_2 X_2 - s_1 X_1 > s_1 k_N$, the CEO underinvests in the long-term project if the board relies on stock option grants with long vesting periods.

5.2 Optimal Vesting Schedule

I now turn to the optimal stock option contract c. As will become clear later, it is always optimal to require the CEO to hold his (vested) options until long-term cash flows are realized. Thus, in the optimal contract it holds that $\beta_E = 0$.

As in the previous section, to ensure that the CEO's options have a positive value if and only if the firm succeeds in the long run, the exercise price must satisfy $E \geq A$. For simplicity, I assume again that $E = A$. If the first period succeeds, the CEO is retained and the value of his options in case of long-term success is given by $\beta(A + X_2 - E) = \beta X_2$. When the CEO is fired due to short-term failure, he retains the options that have already vested, which have a value of $\beta_V(A + X_2 - E) = \beta_V X_2$ in case the new CEO succeeds in the long-run.

Given the contract in place, the CEO's utility in case he chooses to work, $e = e_H$, is given by

$$\begin{aligned} U_{CEO} &= (s_1(1-I)+a_1)\,p\,(s_2 I + a_2)\,\beta X_2 \\ &\quad + (1 - p\,(s_1(1-I)+a_1))\,p\,(s_2 I + a_2)\,\beta_V X_2 - k. \end{aligned} \tag{8}$$

If the CEO chooses to shirk, $e = e_L$, he will be removed in the first period due to poor performance. However, the CEO is still able to reap a reward if some of his options have already vested and if the replacement CEO is successful in the long run. The CEO's expected payoff in case he shirks is thus given by $p\,(s_2 I + a_2)\,\beta_V X_2$, where $p\,(s_2 I + a_2)$ represents the probability that the replacement CEO will be successful in the second period. Note that if the incumbent decides to shirk he will invest solely in the long-term project, $I = 1$, to maximize the chances that the replacement CEO succeeds. Hence, to encourage the incumbent to choose high effort, it must hold that

$U_{CEO} \geq p\left(s_2 + a_2\right)\beta_V X_2$, which can be rewritten as

$$\left(s_1(1-I)+a_1\right)p\left(s_2 I + a_2\right)\left(\beta - p\beta_V\right)X_2 - p\beta_V X_2 s_2\left(1-I\right) - k \geq 0. \qquad (9)$$

Condition (9) shows that from an effort incentive perspective, it is optimal to rely on stock option grants with long vesting terms. The long vesting horizon ensures that the CEO forfeits his (unvested) options when he loses his position due to poor interim performance. The threat of forfeiting option compensation effectively motivates the incumbent to deliver high effort.

In contrast, when the contract allows a positive number of options to vest early, $\beta_V > 0$, the CEO is able to reap a reward even when he shirks $(e = e_L)$. The larger β_V, the larger is the expected reward for failure, and the lower is the CEO's ex ante incentive to expand effort. Thus, increasing the number of options that vest early is not only directly costly (because the CEO takes home a larger expected pay for failure) but also indirectly because it must be combined with a larger total option grant to maintain effort incentives. However, as shown next, early vesting also has a positive incentive effect in that it improves the CEO's investment decision.

Consider the CEO's capital allocation decision assuming that in equilibrium $e = e_H$. Taking the first-order condition of (8) yields the CEO's optimal investment choice

$$I(\beta_V) = \frac{1}{2} - \frac{1}{2}\frac{s_1 a_2 - s_2 a_1}{s_1 s_2} + \frac{1}{2}\frac{\beta_V s_2}{s_1 s_2\left(\beta - p\beta_V\right)}. \qquad (10)$$

The second-order condition for a maximum is $-2s_1 s_2 p X_2\left(\beta - p\beta_V\right) < 0$ which is always satisfied given that in equilibrium it holds that $\left(\beta - \beta_V\right) > 0$ (see the appendix).

Condition (10) shows that the standard argument regarding the effects of vesting terms on executives' investment horizon does not necessarily apply if CEO turnover is taken into consideration. When the board increases the fraction of options that vest late (date t_2), the CEO forfeits a larger amount of options in case of early replacement, which ties CEO pay closer to short-term performance. The enhanced short-term pressure shifts the CEO's attention toward myopic projects away from more profitable long-term projects.

To alleviate the CEO's short-term focus created by the threat of replacement, the board has to allow a larger fraction of the options to vest early. Early vesting in combination with restricted exercising has two positive effects on the CEO's investment incentives: First, the CEO will put less weight on short-term results because he retains the options that have already vested even when he is replaced due to poor performance; second, given that the (ousted) CEO is required to hold his vested options for the long-run, the CEO has an additional incentive to focus on long-term results ex ante. Both effects reinforce each other and tilt the CEO's attention away from short-term goals toward long-term goals.

In the optimal solution, the effort incentive constraint in (9) holds as an equality. Solving the equation system (9) and (10) leads to the optimal bundle (β, β_V) that induces $e = e_H$ and I^* (the equilibrium investment level, I^*, is determined below).

Proposition 3 *In the optimal contract, the total number of options granted to the CEO, β, and the number of options that vest early, β_V, are given by*

$$\beta = \frac{s_2 + p\left(s_1 s_2\left(2I^* - 1\right) + \left(s_1 a_2 - s_2 a_1\right)\right)}{p s_2\left(a_1\left(s_2 + a_2\right) + s_1 s_2 (1 - I^*)^2\right)} \frac{k}{X_2}, \text{ and} \tag{11}$$

$$\beta_V = \frac{s_1 s_2\left(2I^* - 1\right) + s_1 a_2 - s_2 a_1}{p s_2\left(a_1\left(s_2 + a_2\right) + s_1 s_2\left(1 - I^*\right)^2\right)} \frac{k}{X_2}. \tag{12}$$

where I^* is the equilibrium long-term investment level.

What remains to be determined is the investment level that arises in equilibrium. The board can induce the CEO to implement the first-best capital allocation $I = I^{FB}$

by choosing $\frac{\beta_V}{\beta} = f^{FB} \equiv \frac{s_2X_2 - s_1X_1 - s_1k_N}{s_2X_2 - s_1pX_1 - s_1pk_N}$ (note that $f^{FB} < 1$). However, this is not optimal given that early vesting negatively affects the CEO's effort incentive as described above. Thus, when setting the vesting terms of the CEO's options, the board faces the following trade off: on one hand, an increase in the number of options that vest early, β_V, lilts the CEO's preferences away from short-term results toward long-term results, leading to an investment decision that is more closely aligned with shareholders' interests; on the other hand, an increase in β_V dilutes the CEO's incentive to work hard which increases the cost of the incentive system. This trade-off leads to an optimal contract that implements an equilibrium level of I that is lower than the first best level, $I^* < I^{FB}$.

Specifically, assuming an interior solution[9], the equilibrium investment level, denoted I^*, is characterized by

$$\begin{aligned} &ps_2X_2 - ps_1X_1 + \left(s_2\left(s_1(1-I)+a_1\right) - s_1\left(s_2I + a_2\right)\right)pX_2(1-p) - s_1pk_N \\ &-2ks_1\frac{\left(a_1 + (1-I)\,s_1\right)\left(a_2 + s_2I\right)\left(a_2+s_2\right)}{\left(s_2a_1 + a_1a_2 + s_1s_2\left(1-I\right)^2\right)^2} = 0. \end{aligned} \tag{13}$$

Note that the second-order condition for a maximum is satisfied as long as X_2 is sufficiently large.

Comparing the equilibrium condition (13) with the first-best capital allocation specified in (4) leads to the next proposition.

Proposition 4 *In equilibrium, the CEO overinvests in the short-term project relative to first-best, $I^* < I^{FB}$.*

[9] The solution is interior as long as k is not too large. Otherwise, if k satisfies $8k\frac{s_1^2 l_2(a_2+l_2)}{(s_1a_2+s_1l_2+l_2a_1)^2} > p\left(l_2X_2 - s_1X_1 - s_1k_N\right)$, then a corner solution occurs in which the board focuses exclusively on minimizing the cost of inducing effort and ignores the induced investment decision. If this is the case, the board sets $\beta_V = 0$ and the induced investment level is identical to the one determined in the benchmark case, $I^* = I^{NV}$. See the Appendix for details.

Intuitively, the board finds it optimal to induce overinvestment in the short-term project, $I^* < I^{FB}$, to reduce the cost of the compensation contract. A further increase in the number of options that vest early, β_V, would shift the investment decision closer to the first-best level but the associated increase in the compensation cost would more than outweigh this benefit. Thus, the model demonstrates that overinvestment in myopic projects is not necessarily evidence of faulty pay arrangements or impatient shareholders but can arise endogenously from optimal contracting between long-term oriented shareholders and executives.

6 Discussion and Empirical Implications

6.1 The Role of Forced CEO Turnover

The model shows that the effect of vesting conditions on the executives' investment horizon depends crucially on whether or not the CEO is subject to being replaced in case of poor interim performance. Assume for the moment that the board will always retain the incumbent CEO even when short-term performance is poor. This is the case, for example, if the incumbent has already established that he is the right person to run the firm, if replacing the CEO is very costly, or if the incumbent is well entrenched. In this situation, it is optimal to induce the CEO to invest exclusively in the long-term project because the board is no longer concerned about the information content of the interim cash flows. This can effectively be done by granting the CEO stock options with long vesting periods.

However, in firms in which timely CEO turnover is crucial because, for example, the incumbent CEO is a relatively new hire (maybe from outside the firm) with uncertain talent or fit, the optimal investment strategy and the optimal design of vesting periods become more subtle.

The model therefore suggests that when studying the determinants of vesting schedules, empirical studies should distinguish between these two types of firms. Assuming that boards optimally design compensation contracts, the model predicts that both the fraction of stock options that vest early and the level of myopic investment is larger in firms in which the incumbent is a new hire with uncertain talent than in firms in which the incumbent is well established and entrenched.

The empirical predictions that follow refer only to firms in which early replacement is a concern for incumbent CEOs, that is, condition (1) is satisfied as assumed in the model.

6.2 Investment Strategy and CEO pay

The model generates predictions regarding the determinants of the optimal vesting schedule. Conditions (11) and (12) show that the fraction $f = \beta_V/\beta$ of options that vest early is a positive function of the long-term investment level I^*. This follows because if the board wishes to induce the CEO to put greater emphasis on the firm's long-term goals, the contract has to allow a larger fraction of options to vest early.

Clearly, the equilibrium investment in long-term projects, I^*, is larger for firms and industries that have more valuable long-term investment opportunities such as energy and pharmaceutical firms (where X_2/X_1 is relatively large). The model's predictions are therefore as follows: First, in firms with more valuable long-term investment opportunities, the board allows a larger proportion of options to vest early, which, in turn, shifts the CEO's focus toward more profitable long-term investment projects. Second, in firms in which the fraction of options that vest early is larger, the total number of stock options granted to the incumbent is larger as well. This follows because early vesting dilutes ex ante effort incentives and hence needs to be combined with a larger stock option grant to restore incentives.

6.3 Investment Strategy and CEO Turnover

The model demonstrates a link between the firm's investment strategy and the quality and likelihood of CEO turnover. An increase in the level of short-term investment renders short-term results more informative about the incumbent's talent and enables the board to make better CEO replacement decisions. Specifically, for larger short-term investments, bad news in the first period are a stronger signal that the incumbent CEO is a low talent, reducing the probability that good-type CEOs are accidentally fired.

The model generates the following two predictions. In firms and industries with a greater focus on long-term investment opportunities (where I^* is relatively large), (i) the likelihood of forced CEO turnover is higher, and (ii) the average talent of the CEO in charge in the long run is lower. The first prediction follows because if the board encourages executives to allocate resources away from short-term toward longer-term projects, the performance in the short run declines, which increases the incidence of forced CEO turnover. Heightened turnover implicates a higher likelihood that talented CEOs are accidentally removed, which explains the second prediction.

6.4 The Role of Turnover Cost

When the incumbent is fired after first-period failure, the board may need to make a quick replacement decision and hence may rely on an insider as a replacement. For example, the insider could be someone who worked side by side with the incumbent in the first period. Hiring an insider may not only be less time consuming but may also be associated with less costs because the insider already has acquired (to some extent) firm specific human capital; that is, k_N is lower for an insider than for an outsider. Thus, if the board has made sure that there is an insider who is readily available to replace the incumbent if necessary, the direct cost of CEO turnover is smaller for the firm. A smaller turnover cost, in turn, increases the equilibrium long-term investment level, I^* (see (13)). This follows because for smaller values of k_N, the board is less concerned about the cost of accidentally replacing a good-type CEO, and hence is less eager to distort the capital allocation toward the myopic project to reduce this cost.

Thus, the model predicts that in firms in which the direct cost of CEO turnover is smaller (e.g., firms with a well developed insider succession plan), (i) the level of myopic investment is smaller, (ii) the CEO turnover rate is higher, (iii) the CEO in charge of the second period is less likely to be a high talent, (iv) the board allows a larger fraction of the incumbent's options to vest early, and (v) the total option package of the incumbent CEO is larger than in firms in which the direct cost of CEO turnover is larger. Implication (iii) is especially interesting because it suggests that in firms in which the board carefully develops a CEO succession plan, the expected probability of having a high talent in the long run is smaller than in firms that do not have such a plan. The reason for this result is that the board, knowing that CEO turnover is associated with less frictions, wishes to focus more on long-term investments, which reduces the information content of short-term cash flows and hence increases the probability that good-type CEOs are accidentally fired.

6.5 The Role of Board Dependence

In the model discussed so far, the board is assumed to behave in the shareholders' best interests. However, in reality, boards may not be completely independent from management and hence may benefit from being friendly to executives. This feature can be modeled by assuming that the board derives some utility from the incumbent CEO's well-being. In particular, the board's preferences can then be stated as:

$$U_{Board} = (1 - \widehat{\delta})V + \widehat{\delta} U_{CEO}, \tag{14}$$

where $\widehat{\delta}$ is the weight the board places on the incumbent CEO's utility, U_{CEO}, and $(1 - \widehat{\delta})$ is the weight placed on firm value, V, which is determined by total expected cash flows minus executive pay.[10] Thus, the setting discussed in the main part of the paper is obtained by assuming that $\widehat{\delta} = 0$. Given that utility functions are unique only up to a positive linear transformation, it is without loss of generality to describe (14) as

$$U_{Board} = V + \delta U_{CEO},$$

where $\delta = \widehat{\delta}/(1 - \widehat{\delta})$. The parameter δ is interpreted as the level of board dependence; the larger δ, the more dependent is the board on the incumbent CEO and the higher is the weight the board places on CEO utility relative to firm value. In what follows, I restrict attention to $\delta < 1$. Otherwise, for $\delta > 1$, the board cares more about the CEO's interests than about shareholders' interests and transfers all profits from operations to the CEO.

As discussed previously, when choosing the optimal vesting schedule, the board balances the benefits of efficient resource allocation with the costs of the CEO's

[10] Other papers that use a similar characterization of board dependence are Drymiotes (2007), Kumar and Sivaramakrishnan (2008), and Laux and Mittendorf (2010).

compensation scheme (CEO rents). This trade-off leads to an optimal contract that induces the CEO to overinvest in the myopic project relative to first-best, $I^* < I^{FB}$ (see condition (13)). If the board is dependent on the CEO ($\delta > 0$), it still faces the same trade-off but is now less concerned about curtailing CEO rents and hence is relatively more interested in implementing efficient investment decisions. Specifically, for $\delta > 0$, the condition that determines the equilibrium investment level changes from (13) to

$$ps_2X_2 - ps_1X_1 + (s_2(s_1(1-I)+a_1) - s_1(s_2I+a_2))\,pX_2(1-p) - s_1pk_N \quad (15)$$
$$-(1-\delta)2ks_1\frac{(a_1+(1-I)s_1)(a_2+s_2I)(a_2+s_2)}{\left(s_2a_1+a_1a_2+s_1s_2(1-I)^2\right)^2} = 0.$$

Condition (15) shows that the equilibrium long-term investment, $I^*(\delta)$, is increasing in the level of dependence, δ, until it reaches $I^*(1) = I^{FB}$ (for $\delta = 1$, the board completely ignores the cost of CEO compensation and hence induces first-best investment).

Based on this analysis, the model predicts that in firms in which the board is more dependent on the CEO (δ is larger), (i) there is less myopic investment, (ii) the probability of CEO turnover is greater, (iii) the average quality of the CEO in charge of the second period is smaller, (iv) a larger fraction of the incumbent CEO's options vests early, and (v) the CEO's total stock option grant is larger.

Note that while board dependence shifts the level of long-term investment, $I^*(\delta)$, closer to the first-best level, I^{FB}, it is nevertheless optimal for shareholders to have a fully independent board in charge. Only an independent board considers the full cost of CEO pay and hence optimally balances investment efficiency with CEO rents.

7 Conclusion

This paper analyzes the effects of stock option vesting schedules on executives' incentives to engage in myopic behavior and deliver productive effort. Lengthening the vesting period of equity grants is usually viewed as an effective means to extend executives' investment horizon. However, if the incumbent is subject to potential replacement at an intermediate stage, long vesting periods can backfire and encourage myopic behavior. This follows because the CEO is concerned about forfeiting unvested stock options in case of dismissal and hence has an incentive to overinvest in short-term projects to boost the board's perception about his ability.

The board can address this issue by allowing a positive fraction of the executives' option compensation to vest early. Short vesting periods do not imply, however, that the CEO should also be allowed to unload his options immediately after vesting. To link CEO pay to the long-term goals of the firm, it is optimal to restrict the unloading of the options after vesting. The combination of early vesting and long holding periods effectively shifts the CEO's emphasis away from short-term results (because he can keep the options that have already vested even when fired) toward long-term results (because his initial actions affect his pay in the long-run even when removed at an intermediate date).

In principal, by choosing the appropriate number of options that vest early, the board can eliminate excessive myopia and induce the first-best allocation of resources. However, this is in general not optimal because early vesting is also associated with a cost for shareholders. Given that the CEO can keep the options that have already vested when fired due to poor performance, the CEO's incentive to work hard is muted ex ante. Thus, an increase in the fraction of options that vest early is not only directly costly (because the CEO can take home a positive expected compensation when fired) but also indirectly because it increases the total amount of options that must be granted to the CEO to provide sufficient effort incentives.

The optimal vesting schedule therefore amounts to balancing the desire to induce appropriate investment decisions with the desire to induce effort. This trade-off leads to a compensation package that endogenously biases the CEO toward overinvesting in myopic projects. Consequently, the model demonstrates that managerial myopia is not necessarily an artifact of faulty pay arrangements or impatient shareholders but can result from optimal contracting in a multitask agency setting.

Appendix

Consider a general contract $(B_{SS}, B_{FS}, B_{SF}, B_{FF})$, where B_{SS} is the pay to the CEO if $x_1 = X_1$ and $x_2 = X_2$, B_{FS} is the pay if $x_1 = 0$ and $x_2 = X_2$, B_{SF} is the pay if $x_1 = X_1$ and $x_2 = 0$, and B_{FF} is the pay if $x_1 = x_2 = 0$. It is straightforward to show that it is always optimal to set $B_{FF} = 0$.

Given this pay plan, the CEO's utility for $e = e_H$ can be stated as

$$\begin{aligned} U_{CEO} &= (s_1(1-I)+a_1)\,p\left((s_2I+a_2)\,B_{SS}+(1-(s_2I+a_2))\,B_{SF}\right) \\ &\quad +(1-p\,(s_1(1-I)+a_1))\,p\,(s_2I+a_2)\,B_{FS}-k. \end{aligned} \tag{16}$$

The CEO's effort incentive constraint is given by (recall, if the CEO chooses $e = e_L$, then he also chooses $I = 1$)

$$U_{CEO} \geq p\,(s_2 + a_2)\,B_{FS},$$

which can be written as

$$(s_1(1-I)+a_1)\,p\left((s_2I+a_2)\left(B_{SS}-pB_{FS}\right)+\left(1-s_2I-a_2\right)B_{SF}\right) \tag{17}$$
$$-pB_{FS}s_2\left(1-I\right)-k=0,$$

because it is always binding in equilibrium.

To obtain the CEO's investment choice, take the first-order condition on (16) which yields

$$\left(-s_1\left(s_2I+a_2\right)+s_2\left(s_1(1-I)+a_1\right)\right)p\left(B_{SS}-pB_{FS}-B_{SF}\right)-s_1pB_{SF}+pB_{FS}s_2=0. \tag{18}$$

The Lagrangian of the principal's optimization problem (P) is now as follows:

$$\underset{B_{SS},B_{SF},B_{FS},I}{\text{Max}}\ L=$$
$$(s_1(1-I)+a_1)\,p\left((s_2I+a_2)\left(X_1+X_2-B_{SS}\right)+\left(1-(s_2I+a_2)\right)\left(X_1-B_{SF}\right)\right)$$
$$+\left(p\left(1-s_1(1-I)-a_1\right)+(1-p)\right)p\left(s_2I+a_2\right)\left(X_2-B_{FS}\right)$$
$$-\left(p\left(1-s_1(1-I)-a_1\right)+(1-p)\right)k_N$$
$$+\lambda\left((s_1(1-I)+a_1)\,p\left((s_2I+a_2)\left(B_{SS}-pB_{FS}\right)+\left(1-s_2I-a_2\right)B_{SF}\right)-pB_{FS}s_2\left(1-I\right)-k\right)$$
$$+\mu\left(\left(-s_1\left(s_2I+a_2\right)+s_2\left(s_1(1-I)+a_1\right)\right)p\left(B_{SS}-pB_{FS}-B_{SF}\right)-s_1pB_{SF}+pB_{FS}s_2\right),$$

where λ is the Lagrangian multiplier associated with the effort incentive constraint (17) and μ is the multiplier associated with the investment decision constraint (18).

The necessary conditions for a solution to (P) include:

$$\frac{\partial L}{\partial I}=0,\ \frac{\partial L}{\partial B_j}\leq 0,\ B_j\geq 0,\ \text{and}\ \frac{\partial L}{\partial B_j}B_j=0,\ \text{for all}\ j=SS,FS,SF.$$

There are three cases that need to be considered, which are discussed below. Before analyzing each case, it is instructive to provide a brief summary: In the first case, it is shown that if $ps_2X_2 - ps_1X_1 - ps_1k_N \leq 0$, then there are no incentive frictions and the optimal contract achieves the first-best outcome. To focus on non-trivial solutions, I exclude this case in the main part of the paper (see Section 3). In the second case, it is shown that for $p(s_2X_2 - s_1X_1 - s_1k_N) \geq 8k\frac{s_1^2 s_2(a_2+s_2)}{(s_1a_2+s_1s_2+s_2a_1)^2}$ there exists an interior solution in which the board balances the cost of inducing effort against the desire to induce efficient investment. This case is the main focus of the paper. Finally, in the third case, it is shown that for

$$0 < p(s_2X_2 - s_1X_1 - s_1k_N) < 8k\frac{s_1^2 s_2(a_2+s_2)}{(s_1a_2+s_1s_2+s_2a_1)^2},$$

the board implements a corner solution. In that case, the CEO's effort cost is relatively high such that it becomes optimal for the board to focus exclusively on minimizing the cost of inducing effort and to ignore the induced investment decision.

Case 1: Assume that in the optimal solution to (P) it holds that $B_{SS} > 0$ and $B_{SF} > 0$. In this case, it must be that $\frac{dL}{dB_{SS}} = 0$ and $\frac{dL}{dB_{SF}} = 0$, which implies that $\lambda = 1$ and $\mu = 0$.

Substituting $\lambda = 1$ and $\mu = 0$ into $\frac{dL}{dB_{FS}}$ yields $-pa_2 - ps_2 < 0$, implying that $B_{FS} = 0$. Solving (17) and (18) and using $B_{FS} = 0$, yields the optimal payments B_{SS} and B_{SF}

$$B_{SF} = k\frac{s_1s_2(1-2I) - s_1a_2 + s_2a_1}{s_2p((s_1(1-I)+2a_1)s_1(1-I)+a_1^2)}, \quad (19)$$

$$B_{SS} = k\frac{s_1s_2(1-2I) - s_1a_2 + s_2a_1 + s_1}{(s_1(1-I)+a_1)^2 ps_2}. \quad (20)$$

Note that since $B_{FS} = 0$, it follows from the effort incentive constraint (17) that the CEO is not able to obtain a rent in equilibrium; that is, he is kept at his reservation utility $U_{CEO} = 0$. This can be confirmed by noting that the expected pay to the CEO (using (19) and (20)) equals the cost of effort;

$$(s_1(1-I)+a_1)\,p\left(\left(s_2I+a_2\right)B_{SS}+\left(1-\left(s_2I+a_2\right)\right)B_{SF}\right)=k.$$

Substituting (19), (20), $B_{FS}=0$, $\lambda=1$, and $\mu=0$, into $\frac{dL}{dI}=0$ yields

$$I=\frac{1}{2}-\frac{1}{2}\frac{s_1a_2-s_2a_1}{s_1s_2}+\frac{1}{2}\frac{s_2X_2-s_1X_1-s_1k_N}{s_1s_2X_2\left(1-p\right)},$$

which is the first-best investment level, I^{FB}.

Due to the nonnegativity constraint, it must hold that $B_{SF}\geq 0$ and $B_{SS}\geq 0$ for $I=I^{FB}$. The pay B_{SF} in (19) is nonnegative for $I=I^{FB}$ if $-\frac{s_2X_2-s_1X_1-s_1k_N}{X_2(1-p)}\geq 0$. If this is the case, B_{SS} in (20) is also nonnegative. This discussion leads to the following lemma.

Lemma 1 *If* $ps_2X_2-ps_1X_1-ps_1k_N\leq 0$, *the solution to* (P) *is first-best and described by (19), (20),* $B_{FS}=0$, $I^{*}=I^{FB}$, *and* $U_{CEO}=0$.

Case 2: Assume now that in the optimal solution to (P) it holds that $B_{SS}>0$ and $B_{FS}>0$. In this case, it must hold that $\frac{dL}{dB_{SS}}=0$ and $\frac{dL}{dB_{FS}}=0$, which yields

$$\lambda = s_1\frac{s_2^2I^2+2s_2Ia_2+a_2^2}{s_2\left(s_1s_2+s_2a_1+a_1a_2-2s_1s_2I+s_1I^2s_2\right)}, \tag{21}$$

$$\mu = -\frac{-\left(s_2^2I+a_2^2\right)s_1\left(1-I\right)-s_1a_2s_2\left(1-I^2\right)-\left(a_2+s_2I\right)a_1\left(s_2+a_2\right)}{s_2\left(s_1s_2+s_2a_1+a_1a_2-2s_1s_2I+s_1I^2s_2\right)}. \tag{22}$$

Substituting (21) and (22) into $\frac{dL}{dB_{SF}}=0$ yields

$$\frac{dL}{dB_{SF}}=-p\frac{s_2a_1^2+a_1^2a_2+s_1^2\left(1-I\right)^2\left(s_2+a_2\right)+\left(s_2s_1+s_1a_2\right)2a_1\left(1-I\right)}{a_1\left(a_2+s_2\right)+s_1s_2\left(1-I\right)^2},$$

which is negative; hence, $B_{SF}=0$.

Substituting $B_{SF}=0$ into the two incentive constraints (17) and (18) and solving for B_{SS} and B_{FS} yields

$$B_{SS} = \frac{s_2 + p\left(s_1 s_2\left(2I-1\right) + \left(s_1 a_2 - s_2 a_1\right)\right)}{p s_2\left(a_1\left(s_2+a_2\right) + s_1 s_2 (1-I)^2\right)} k, \tag{23}$$

$$B_{FS} = \frac{s_1 s_2\left(2I-1\right) + s_1 a_2 - s_2 a_1}{p s_2\left(a_1\left(s_2+a_2\right) + s_1 s_2\left(1-I\right)^2\right)} k. \tag{24}$$

Substituting (23), (24), $B_{SF}=0$, (21), and (22) into $\frac{dL}{dI}=0$ gives the equilibrium investment level, which is determined by

$$\frac{dL}{dI} = p s_2 X_2 - p s_1 X_1 + \left(s_2\left(s_1(1-I)+a_1\right) - s_1\left(s_2 I + a_2\right)\right) p X_2 (1-p) \tag{25}$$

$$-s_1 p k_N - 2 k s_1 \frac{\left(a_1 + \left(1-I\right) s_1\right)\left(a_2 + s_2 I\right)\left(a_2+s_2\right)}{\left(s_2 a_1 + a_1 a_2 + s_1 s_2\left(1-I\right)^2\right)^2} = 0.$$

Note that this equation is identical to the condition in (13).

Due to the nonnegativity constraint, it must hold that $B_{FS}\geq 0$ and $B_{SS}\geq 0$. B_{FS} is nonnegative if the numerator in (24) is nonnegative; that is, if

$$s_1 s_2\left(2I-1\right) + s_1 a_2 - s_2 a_1 \geq 0. \tag{26}$$

If this is the case, then B_{SS} is also nonnegative. Condition (26) can be rewritten as

$$I \geq I^T \equiv \frac{1}{2} - \frac{1}{2}\frac{s_1 a_2 - s_2 a_1}{s_2 s_1}. \tag{27}$$

Substituting I^T, defined in (27), into (25), gives

$$\frac{dL}{dI} = p\left(s_2 X_2 - s_1 X_1 - s_1 k_N\right) - 8k \frac{s_1^2 s_2\left(a_2+s_2\right)}{\left(s_1 a_2 + s_1 s_2 + s_2 a_1\right)^2}.$$

If, for $I=I^T$, it holds that $\frac{dL}{dI}\geq 0$, then it holds that $I^*\geq I^T$ and condition (27) is satisfied in equilibrium.

Lemma 2 *If* $p\left(s_2 X_2 - s_1 X_1 - s_1 k_N\right) \geq 8k\frac{s_1^2 s_2 (a_2+s_2)}{(s_1 a_2 + s_1 s_2 + s_2 a_1)^2}$, *the solution to* (P) *is described by (23), (24),* $B_{SF}=0$, *(25),* $U_{CEO}>0$, *and* $I^*<I^{FB}$.

The payments B_{SS} and B_{FS} defined in (23) and (24) can be replicated by the stock option contract described in the main part of the paper by choosing β and β_V such that $\beta X_2 = B_{SS}$ and $\beta_V X_2 = B_{FS}$. What remains to be shown is that in equilibrium $\beta_V < \beta$ because the number of options that vest early cannot exceed the total option grant.

Using (23) and (24), the condition $\beta_V < \beta$ is satisfied if

$$ps_2 + \left(s_2\left(a_1 + s_1\left(1 - I\right)\right) - s_1\left(s_2 I + a_2\right)\right) p\left(1 - p\right) > 0. \tag{28}$$

Using the equilibrium condition (25), it can be shown that for $I = I^*$, condition (28) is satisfied.

Case 3: Assume now that in the optimal solution to (P) it holds that $B_{SS} > 0$, $B_{FS} = B_{SF} = 0$. In this case, it must be that $\frac{dL}{dB_{SS}} = 0$, $\frac{dL}{dB_{FS}} < 0$, and $\frac{dL}{dB_{SF}} < 0$. B_{SS} is determined by (17) and given by

$$B_{SS} = \frac{k}{p\left(s_1\left(1 - I\right) + a_1\right)\left(s_2 I + a_2\right)}. \tag{29}$$

Due to $B_{FS} = 0$, the CEO is not able to obtain an economic rent in equilibrium, $U_{CEO} = 0$. This can also be confirmed by noting that the expected CEO pay (using (29) and $B_{FS} = B_{SF} = 0$) is given by $(s_1(1 - I) + a_1)\, p\left(s_2 I + a_2\right) B_{SS} = k$.

Substituting $B_{FS} = B_{SF} = 0$ and (29) into the incentive constraint (18) and rearranging yields

$$I = \frac{1}{2} - \frac{1}{2}\frac{s_1 a_2 - s_2 a_1}{s_2 s_1}. \tag{30}$$

Solving the equation system $\frac{dL}{dB_{SS}} = 0$ and $\frac{dL}{dI} = 0$, and using (30) and $B_{FS} = B_{SF} = 0$ yields

$$\mu = \frac{1}{2}\frac{s_2 X_2 - s_1 X_1 - s_1 k_N}{s_1 s_2 B_{SS}} \text{ and } \lambda = 1. \tag{31}$$

Using (31), (30), and (29), it holds that

$$\frac{dL}{dB_{FS}} = -p\left(a_2+s_2\right)+p^2\frac{1}{8}\frac{1}{k}\frac{\left(s_2X_2-s_1X_1-s_1k_N\right)}{s_1^2}\frac{\left(s_1a_2+s_1s_2+s_2a_1\right)^2}{s_2}, \quad (32)$$

$$\frac{dL}{dB_{SF}} = -\frac{1}{8}\frac{p^2}{k}\frac{\left(s_2X_2-s_1X_1-s_1k_N\right)}{s_1}\frac{\left(s_1a_2+s_1s_2+s_2a_1\right)^2}{s_2^2}. \quad (33)$$

Hence, conditions $\frac{dL}{dB_{FS}}<0$ and $\frac{dL}{dB_{SF}}<0$ are satisfied if

$$p\left(s_2X_2-s_1X_1-s_1k_N\right)-8k\frac{s_1^2s_2\left(a_2+s_2\right)}{\left(s_1a_2+s_1s_2+s_2a_1\right)^2} < 0, \quad (34)$$

$$p\left(s_2X_2-s_1X_1-s_1k_N\right) > 0. \quad (35)$$

This analysis leads to the next lemma.

Lemma 3 *If (34) and (35) are satisfied, the solution to* (P) *is described by* $B_{FS}=B_{SF}=0$, *(29), (30),* $U_{CEO}=0$, *and* $I^*<I^{FB}$.

Note that the solution characterized in the above lemma is a corner solution. Intuitively, if (34) is satisfied, the CEO's effort cost is so high that it becomes optimal for the board to focus exclusively on minimizing the cost of inducing effort and to ignore the induced investment decision. The board minimizes the cost of inducing effort by choosing $B_{FS}=0$, which keeps the CEO at his reservation utility, $U_{CEO}=0$. This pay scheme can be replicated by the stock option contract described in the main part of the paper by choosing $\beta=\frac{B_{SS}}{X_2}$ and $\beta_V=0$.

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