Agency Conflicts and Short- vs. Long-Termism in Corporate Policies

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Abstract

We build a dynamic agency model in which the agent controls both current earnings via short-term investment and firm growth via long-term investment. Under the optimal contract, agency conflicts can induce short- and long-term investment levels beyond first best, leading to short- or long-termism in corporate policies. The paper analytically shows how firm characteristics shape the optimal contract and the horizon of corporate policies, thereby generating a number of novel empirical predictions on the optimality of short- vs. long-termism. It also demonstrates that combining short- and long-term agency conflicts naturally leads to asymmetric pay-for-performance in managerial contracts.

Keywords: Optimal short- and long-termism; Agency conflicts; Multi-tasking.

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Should firms target short-term objectives or long-term performance? The question of the optimal horizon of corporate policies has received considerable attention in recent years, with much of the discussion focusing on whether short-termism destroys value. The worry often expressed in this literature is that short-termism—induced for example by stock market pressure—may lead firms to invest too little (see Asker, Farre-Mensa, and Ljungqvist (2015), Bernstein (2015), or Gutierrez and Philippon (2017) for empirical evidence). Another line of argument recognizes however that while firms must invest in their future if they are to have one, they must also produce earnings today in order to pay for doing so. In line with this view, Giannetti and Yu (2018) find that firms with more short-term institutional investors suffer smaller drops in investment and have better long-term performance than similar firms following shocks that change an industry’s economic environment.

While empirical evidence relating short- or long-termism to firm performance is accumulating at a fast pace, financial theory has made little headway in developing models that characterize the optimal horizon of corporate policies or the relation between firm characteristics and this horizon. In this paper, we attempt to provide an answer to these questions through the lens of agency theory. To do so, we develop a dynamic agency model in which the agent controls both current earnings and firm growth (i.e., future earnings) through unobservable investment. In this multi-tasking model, the principal optimally balances the costs and benefits of incentivizing the manager over the short- or the long-term. As shown in the paper, this can lead to optimal short- or long-termism, depending on the severity of agency conflicts and firm characteristics. Additionally, we show that the same firm can find it optimal at times to be short-termist—i.e., favor current earnings—and at other times to be long-termist—i.e., favor growth. Our findings are generally consistent with the views expressed in The Economist\(^1\) that “long-termism and short-termism both have their virtues and vices—and these depend on context.”

We start our analysis by formulating a dynamic agency model in which an investor (the principal) hires a manager (the agent) to operate a firm. In this model, agency problems arise because the manager can take hidden actions that affect both earnings and firm growth. As in He (2009) or Bolton, Wang, and Yang (2017), earnings are proportional to firm size,\(^1\)

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\(^1\)See “The Tyranny of the Long-Term,” The Economist, November 22, 2014.
which is stochastic and governed by a (controlled) geometric Brownian Motion (i.e., subject to permanent growth shocks). In contrast with these models, earnings are also subject to moral hazard and short-term shocks that do not necessarily affect (or correlate with) long-term prospects (i.e., shocks to firm size). The agent controls the drifts of the earnings and firm size processes through unobservable investment. Notably, the agent can stimulate current earnings via short-term investment and firm growth via long-term investment.

Investment is costly and the manager can divert part of the funds allocated to investment, which requires the compensation contract to provide sufficient incentives to the agent. Under the optimal contract, the manager is thus punished (rewarded) if either cash-flow or firm growth is worse (better) than expected. Because the manager has limited liability, penalties accumulate until the termination of the contract, which occurs once the manager’s stake in the firm falls to zero. Since termination generates deadweight costs, maintaining incentive compatibility is costly. Based on these tradeoffs, the paper derives an incentive compatible contract that maximizes the value that the principal derives from owning the firm. It then analytically demonstrates that the optimal contract can generate short- or long-termism in corporate policies, defined as short- or long-term investment levels above first-best levels.

Our theory of short- and long-termism differs from existing contributions in two important respects. First, unlike most dynamic agency models, which generally focus either on short- or long-term agency conflicts, we consider a multi-tasking framework with both long- and short-term agency conflicts. We show that agency conflicts over different horizons interact, which can generate short- and long-termism in corporate policies. Second, unlike most models on short-termism, we do not assume that focusing either on the short or the long term is optimal. In our model, the optimal corporate horizon is determined endogenously and reflects both agency conflicts and firm characteristics. These unique features allow us to generate a rich set of testable predictions about firms’ optimal investment rates and the horizon of corporate policies.

A first result of the paper is to show that short- or long-termism can only arise when the firm is exposed to a dual moral hazard problem. To understand why this condition is necessary, consider first long-termism. In our model, positive growth shocks lead to a permanent increase in earnings (and risk) and to a greater misalignment between shareholders’ interests
and management’s incentives by diluting the manager’s stake within the firm. To offset these adverse dilution effects and reduce agency costs, the manager’s promised wealth must increase sufficiently in response to positive growth shocks. We show that when the firm is exposed to both long- and short-term moral hazard, the contract optimally grants the manager a larger stake in the firm, which increases potential dilution effects. The principal then counteracts these dilution effects by tying the agent’s compensation more to long-term performance (i.e., long-term shocks), which leads to higher powered long-run incentives. The incentive compatibility condition with respect to long-term investment, which associates higher-powered incentives to higher levels of investments, in turn implies that the firm must also increase long-term investment, possibly beyond first-best levels. Our analysis demonstrates that long-termism is more likely to arise when the firm’s cash flow is more volatile or when its investment technology is less efficient.

A second result of the paper is to show that short-termism can only arise if the firm is exposed to a dual moral hazard problem and there are direct externalities between short- and long-term investment. Notably, we show that a necessary condition for short-termism is that shocks to firm size and shocks to cash flows are correlated. When this correlation is negative—an assumption supported in the data (see, e.g., Chang, Dasgupta, Wong, and Yao (2014))—we additionally show that short-termism occurs when the agent’s stake in the firm is low and the risk of termination and agency costs are high. Indeed, in such instances, the benefits of long-term growth are limited. By contrast, stimulating short-term investment increases earnings and reduces the risk of termination and agency costs. Interestingly, a recent study by Barton, Manyika, and Williamson (2017) finds using a data set of 615 large- and mid-cap US publicly listed companies from 2001 to 2015 that “the long-term focused companies surpassed their short-term focused peers on several important financial measures.” While our model does indeed predict that firm performance should be positively related to the corporate horizon, it in fact suggests the reverse causality.

As in prior contributions, incentives are provided in the optimal contract by making

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2 Interestingly, this causality issue is already discussed in The Economist, Schumpeter’s article “Corporate short-termism is a frustratingly slippery idea” who writes: “Do short-term firms become weak or do weak firms rationally adopt strategies that might be judged short term?” Similarly, Barton et al. (2017) write in their own study “one caveat: we’ve uncovered a correlation between managing for the long term and better financial performance; we haven’t shown that such management caused that superior performance.”
compensation contingent on firm performance. In previous dynamic contracting models, the optimal contract generates just enough incentives to the agent (i.e., incentive compatibility constraints are tight) because incentive provision comes with the threat of termination and is therefore costly to implement. A distinctive feature of our model is that the optimal contract introduces exposure to permanent shocks that is not needed to incentivize investment. In particular, the agent is provided minimal long-run incentives when the firm is close to financial distress and higher powered long-run incentives after positive past performance, when sufficient slack has been accumulated. In this region, incentives have option-like features and increase after positive performance.

To understand this result, note that when the manager’s stake is large and therefore subject to substantial dilution risk upon unexpected firm growth, it becomes optimal to mitigate these adverse dilution effect through high powered incentive pay. This generates the distinct prediction that extra pay-for-performance is introduced when the manager’s stake in the firm and dilution risk are large enough. We show indeed that in such instances the principal can eliminate dilution risk by fully exposing the manager’s wealth to permanent shocks, while maintaining incentive compatibility. When this is the case, long-run incentives are effectively costless and the manager is exposed to permanent, growth shocks beyond the level needed to incentivize long-term investment. In other words, positive permanent shocks lead to additional pay-for-performance and negative permanent shocks eventually eliminate this extra sensitivity to performance implied by the optimal contract. Our model therefore provides a rationale for the asymmetry of pay-for-performance observed in the data (see, e.g., Garvey and Milbourn (2006) and Francis, Iftekhar, Kose, and Zenu (2013)).

Our paper relates to the growing literature on short-termism. Influential contributions in this literature include Stein (1989), Bolton, Scheinkman, and Xiong (2006) or Aghion and Stein (2008) in which stock market pressure leads managers to boost short-term earnings at the expense of long-term value. In related work, Thakor (2018) builds a model in which short-termism is efficient as it limits managerial rent extraction and leads to a better allocation of managers to projects. Narayanan (1985) develops a model in which short-term projects privately benefit managers by enhancing reputation and increasing wages. Von Thadden (1995) studies a dynamic model of financial contracting in which the fear of early project
termination by outsiders leads to short-term biases of investment. Marinovic and Varas (2018) and Varas (2017) develop dynamic contracting models in which the manager can undertake inefficient actions to boost short-run performance at the expense of the long-run. Likewise, Zhu (2018) develops a model of persistent moral hazard in which the agent can choose between a short- and long-term action and characterizes the contract that implements the long-term action. In contrast with these models, we do not assume that focusing either on the short or the long term is optimal and there is no intrinsic conflict between short- and long-termism in our setup.

Hoffmann and Pfeil (2018) build a model in which the agent privately observe cash flows that he can divert and/or invest to increase the likelihood of adoption of future technologies. Hoffmann, Rivera, and Wong (2018) use a dynamic agency model to show that shareholder-debtholder conflicts may make short-termism optimal for shareholders. None of these models addresses the issue of short- vs. long-termism in corporate policies. In addition, these models do not generate optimal long-termism or asymmetric pay-for-performance. Our modeling of cash flows with permanent and transitory shocks is similar to that in Décamps, Gryglewicz, Morellec, and Villeneuve (2017). Their model does not feature agency conflicts.

Our paper is more generally related to the growing literature on dynamic contracting. Most contributions in this literature study agency conflicts over the short run, using a stationary environment characterized by identically and independently distributed cash flow shocks; see for example DeMarzo and Sannikov (2006), Biais, Mariotti, Plantin, and Rochet (2007), Sannikov (2008), Zhu (2012), Miao and Rivera (2016), Malenko (2018), or Szydlowski (2018). Likewise, Biais, Mariotti, Rochet, and Villeneuve (2010) and DeMarzo, Fishman, He, and Wang (2012) study dynamic contracting models with time-varying firm size in which cash-flow shocks are short-lived. In these models, the manager can affect current but not directly future firm performance. In contrast, He (2009) and He (2011) focus on agency conflicts over the long run by considering a framework in which the manager can affect firm growth. In these last two models, instantaneous earnings are not subject to short-term moral

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3While Hoffmann and Pfeil (2018) find that overinvestment is more likely for firms with a superior investment technology, our model implies that overinvestment rather arises when the investment technology is inefficient. In Hoffmann and Pfeil (2018) firm size remains constant over time, thereby ruling out potential dilution of the managerial stake, so that the mechanism leading to over-investment differs from ours.

4In a similar setting, Gryglewicz and Hartman-Glaser (2018) show that agency conflicts over the long-run
hazard. Our model combines both strands of the literature in a unified framework in which the optimal horizon of corporate policies arises endogenously. Our framework is also related to Ai and Li (2015) and Bolton et al. (2017), which study optimal investment under limited commitment. These models do not feature moral hazard. Ai and Li (2015) demonstrate that shareholders’ limited commitment can lead to overinvestment in a model in which firms are subject to permanent shocks. In contrast, we assume full commitment of shareholders (the principal) and identify agency frictions as a potential driver of overinvestment.

Section 1 presents the model and its solution. Section 2 analyzes the implications of the model for optimal investment. Section 3 derives predictions on the horizon of corporate policies. Section 4 focuses on asymmetric pay-for-performance. Section 5 shows the robustness of our results to alternative model specifications. Section 6 concludes.

1 The Model

1.1 Assumptions

Throughout the paper, time is continuous and uncertainty is modeled by a probability space \((\Omega, \mathcal{F}, \mathbb{F}, \mathbb{P})\) with the filtration \(\mathbb{F} = \{\mathcal{F}_t : t \geq 0\}\), satisfying the usual conditions. We consider a principal-agent model in which the risk-neutral owner of a firm (the principal) hires a risk-neutral manager (the agent) to operate the firm’s assets. In the model, firm performance depends on investment, which can be targeted towards the short- or long-run and entails a monetary cost. Agency problems arise because investment decisions are delegated to the manager, who can take divert part of the resources allocated to investment.

The firm employs capital to produce output, whose price is normalized to one. At any time \(t \geq 0\), earnings are proportional to the capital stock \(K_t\)—i.e., the firm employs an “\(AK\)” technology—and subject to permanent (long-term) and transitory (short-term) shocks. Permanent shocks change the long-term prospects of the firm and influence cash flows permanently by affecting firm size. Following He (2009), DeMarzo et al. (2012), and Bolton, Chen, and Wang (2011), we consider that the firm’s capital stock (firm size) \(\{K_t\}_{t \geq 0}\) can lead to the early exercise of real options.
evolves according to the controlled geometric Brownian motion process:

\[ dK_t = (\ell_t \mu - \delta) K_t dt + \sigma_K K_t dZ^K_t, \]  

where \( \mu > 0 \) is a constant, \( \delta > 0 \) is the rate of depreciation, \( \sigma_K > 0 \) is a constant volatility parameter, \( \{Z^K\} = \{Z^K_t\}_{t \geq 0} \) is a standard Brownian motion, and \( \ell_t \) is the firm’s long-term investment choice. For the problem to well defined, we consider that \( \ell_t \in [0, \ell_{\text{max}}] \) with \( \ell_{\text{max}} < \frac{r+\delta}{\mu} \) where \( r \geq 0 \) is the constant discount rate of the firm owner. In addition to these permanent shocks, cash flows are subject to short-term shocks that do not necessarily affect long-term prospects. Specifically, cash flows \( dX_t \) are proportional to \( K_t \) but uncertain and governed by:

\[ dX_t = K_t dA_t = K_t \left(s_t \alpha dt + \sigma_X dZ^X_t\right), \]  

where \( \alpha \) and \( \sigma_X \) are strictly positive constants, \( s_t \in [0, s_{\text{max}}] \) is the firm’s short-term investment choice and \( \{Z^X\} = \{Z^X_t\}_{t \geq 0} \) is a standard Brownian motion. In the following, \( \{Z^X\} \) is allowed to be correlated with \( \{Z^K\} \) with correlation coefficient \( \rho \), in that:

\[ \mathbb{E}[dZ^K_t dZ^X_t] = \rho dt, \quad \text{with } \rho \in (-1, 1). \]  

Investment entails costs \( \mathcal{I}(K_t, s_t, \ell_t) \). We assume that the investment cost is homogeneous of degree one in capital \( K_t \), as in DeMarzo et al. (2012) or Bolton et al. (2011). That is, we have that \( \mathcal{I}(K_t, s_t, \ell_t) \equiv K_t \mathcal{C}(s_t, \ell_t) \), where we assume that \( \mathcal{C} \) is increasing and convex in its
arguments. Unless otherwise mentioned, we consider quadratic costs of investment

\[ C(s_t, \ell_t) = \frac{1}{2} \left( \lambda_s s_t^2 \alpha + \lambda_\ell \ell_t^2 \mu \right), \]  

(4)

in which case we assume that \( s_{\text{max}}, \ell_{\text{max}} \) are large enough to ensure that investment is interior at all times. The assumption of quadratic investment cost is made merely for analytical parsimony, in that all our results in sections 1-4 hold true for any other cost function that is strictly convex in \( s, \ell \). This includes cost-functions where short- and long-run investment are substitutes or complements, which occurs when \( \frac{\partial^2 C(s, \ell)}{\partial s \partial \ell} \neq 0 \). We purposefully refrain from such a specification because interactions between short- and long-run investment arise endogeneously in our model and we are able to attribute these interactions entirely to the presence of moral hazard over different time-horizons.\(^7\)

The manager is protected by limited liability, does not accept negative payments from the principal \( dC_t \), and cannot be asked to cover the investment cost \( I(K_t, s_t, \ell_t) = K_t C(s_t, \ell_t) \) out of her own pocket. More specifically, the principal has to allocate funds to the manager before she can carry out the investment decisions \( s_t, \ell_t \). As a result, over \( [t, t+dt] \) the agent is paid \( dC_t + K_t C(s_t, \ell_t)dt \) and wage payments net of investment cost \( dC_t \) must be positive, i.e., \( dC_t \geq 0 \). At any time \( t \), the manager has full discretion over investment \( s_t, \ell_t \) and can divert from the funds \( K_t C(s_t, \ell_t) \) she is handed over from the principal. In particular, the manager can change recommended short-run (respectively long-run) investment \( s_t \) (respectively \( \ell_t \)) by any amount \( \varepsilon^s \) (respectively \( \varepsilon^\ell \)) and keep the difference between actual investment cost and allocated funds, i.e.,

\[ K_t \left[ C(s_t, \ell_t) - C(s_t - \varepsilon^s, \ell_t - \varepsilon^\ell) \right], \]

for herself. Because \( \{X\} \) and \( \{K\} \) are subject to Brownian shocks—as long as \( \sigma_X > 0 \) and \( \sigma_K > 0 \)—there is moral hazard over short- and long-term investment decision. For simplicity,

\(^7\) The cost of investment \( C \) could also be linear in \( s_t, \ell_t \). Optimal investment would accordingly follow a bang-bang solution, that is either full or no investment \( (s_t, \ell_t) \in \{0, s_{\text{max}}\} \times \{0, \ell_{\text{max}}\} \), in which case finite boundaries \( s_{\text{max}}, \ell_{\text{max}} \) would be needed to ensure a well-behaved solution. The upper bounds on the investment levels can be related to the maximum time the manager can spend on the job. The upper bound on long-term investment, i.e., \( \ell_{\text{max}} < \frac{r+\delta}{\mu} \), also naturally arises in our model as a necessary condition to obtain finite firm values. Equivalently, there are linear adjustment cost of investment up to some threshold—that is \( s_{\text{max}} \) for short-run and \( \ell_{\text{max}} \) for long-run investment—and infinite adjustment cost afterwards. We analyze this special case in section 4.
we assume that diversion does not entail efficiency losses.

In the baseline version of our model, we assume the agent has sufficient private funds so that she can in principle also boost firm investment, i.e., implement investment $\hat{s}_t > s_t$ or $\hat{\ell}_t > \ell_t$. While this assumption does not drive our main results, it offers several advantages. First, it considerably simplifies the analysis. Second, and most importantly, it allows us to connect more easily to the existing models of He (2009) and DeMarzo et al. (2012) and to clearly demonstrate how the combination of short- and long-run moral hazard induces short- and long-termism. We analyze the case of limited, i.e., zero, private wealth in section 5 and show that our results on short- and long-termism hold in this alternative setting.

As in DeMarzo and Sannikov (2006), Biais et al. (2007), or DeMarzo et al. (2012), the agent is more impatient than the principal and has a discount rate $\gamma > r$. As a result, the principal cannot indefinitely postpone payments to the agent. The agent possesses an outside option normalized to zero and maximizes the present value of her expected payoffs. Because the agent is protected by limited liability, her continuation value can never fall below her outside option in which case she would profit from leaving the firm. Her employment starts at time $t = 0$ and is terminated at an endogenous stopping time $\tau$ at which point the firm is liquidated. At the time of liquidation, the principal recovers a fraction $R \geq 0$ of assets, valued at $RK_\tau$. Liquidation is inefficient and generates deadweight losses.

Before proceeding, note that when $\sigma_K = 0$, we obtain the environment of the dynamic agency model of DeMarzo et al. (2012) or the financing frictions model of Bolton et al. (2011). Since there is no noise to hide the long-term investment choice, the long-term agency conflict is irrelevant in that case. By contrast, when $\sigma_X = 0$, we obtain the cash-flow environment used in the dynamic capital structure (Leland (1994) or Strebulaev (2007)) and real options literature (Carlson, Fisher, and Giammarino (2006) or Morellec and Schürhoff (2011)) as well as in the dynamic agency models of He (2009, 2011). Since there is no noise to hide the short-term investment choice, the short-term agency conflict is irrelevant in that case.

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8As in Albuquerque and Hopenhayn (2004) or Rampini and Viswanathan (2013), we could assume that the manager can appropriate a fraction of firm value so that the manager has reservation value $\theta K_\tau$, where $\theta \geq 0$ is a constant parameter. The entire analysis can be conducted by replacing 0 with $\theta$.

9We could equally assume that the firm can replace the manager instead of being liquidated when $w$ falls to zero. The model results would remain unchanged, as long as finding a new manager, i.e., replacement, is costly for the firm. For instance, one could assume some replacement cost $kK_\tau$, which could be microfounded by costly labor market search.
1.2 The Contracting Problem

To maximize firm value, the investor chooses short- and long-term investment \(\{s\}, \{\ell\}\) and offers a full-commitment contract to the agent at time \(t = 0\), which specifies wage payments \(\{C\}\), recommended investment \(\{s\}, \{\ell\}\), and a termination time \(\tau\). Because the agent cannot be paid any negative amount net of investment cost, the process \(\{C\}\) is non-decreasing in that \(dC_t \geq 0\) for all \(t \geq 0\). Moreover, the contract cannot request the agent to finance investment, so that she is handed over the investment cost \(I(K_t, s_t, \ell_t)\) at time \(t\) from the principal.

We let \(\Pi \equiv (\{C\}, \{s\}, \{\ell\}, \tau)\) represent the contract, where all elements are progressively measurable with respect to \(F\). With the agent’s actual investment choice \(\{\hat{s}\}, \{\hat{\ell}\}\), we call a contract incentive compatible if \(s_t = \hat{s}_t\) and \(\ell_t = \hat{\ell}_t\) for all \(t \geq 0\) and focus throughout the paper on incentive compatible contracts, where we denote the set of these contracts by \(\mathbb{IC}\). Since we only consider contracts of the set \(\mathbb{IC}\), we will not formally distinguish between recommended and actual investment.

For an incentive compatible contract \(\Pi\) let us define the agent’s expected payoff at time \(t \geq 0\), i.e., her continuation value, as

\[
W_t = W_t(\Pi) \equiv \mathbb{E}_t \left[ \int_t^\tau e^{-\gamma(u-t)} dC_u \right].
\]

\(W_t = W_t(\Pi)\) equals the promised value the agent gets if she follows the recommended path from time \(t \geq 0\) onwards. \(W_0 = W_0(\Pi)\) is the agent’s expected payoff at inception.

The principal receives the firm cash flows net of investment cost and pays the compensation to the manager. As a result, given the contract \(\Pi\), the principal’s expected payoff can be written as:

\[
\hat{P}(W, K) \equiv \mathbb{E} \left[ \int_0^\tau e^{-rt}(dX_t - K_t C(s_t, \ell_t) dt - dC_t) + e^{-r\tau }R K_{\tau} \bigg| W_0 = W, K_0 = K \right]. \quad (5)
\]

The objective of the principal is to maximize the present value of the firm cash flows plus termination value net of the agent’s compensation, where we make the usual assumption that the principal possesses full bargaining power. Denote the set of incentive compatible
contracts by \( \mathbb{IC} \). The investor’s optimization problem reads

\[
P(W, K) \equiv \max_{\Pi \in \mathbb{IC}} \hat{P}(W, K) \text{ s.t. } W_t \geq 0 \text{ and } dC_t \geq 0 \text{ for all } t \geq 0.
\]

(6)

With slight abuse of notation, we denote by \( \Pi \equiv (\{C\}, \{s\}, \{\ell\}, \tau) \) the solution to this optimization problem.

### 1.3 First-Best Short- and Long-Term Investment

We start by deriving the value of the firm and the optimal investment levels absent agency conflicts, i.e. when there is no noise to hide the agent’s action in that \( \sigma_X = \sigma_K = 0 \). Throughout the paper, we refer to this case as the first-best (FB) outcome.

Given the stationarity of the firm’s optimization problem, the choice of \( s \) and \( \ell \) is time-invariant absent agency conflicts and the first-best firm value reads

\[
P_{FB}(K) = \max_{(s, \ell) \in \{0, s_{\text{max}}\} \times \{0, \ell_{\text{max}}\}} \left[ \frac{K}{r + \delta - \mu \ell} \right] \equiv K p_{FB},
\]

where the short- and long-term investment choice \( \{s_{FB}, \ell_{FB}\} \) maximize firm value. We denote the scaled firm value absent moral hazard by \( p_{FB} \). Simple algebraic derivations lead to the following result:

**Proposition 1** (First-best firm value and investment choices). Assume the bounds \( i_{\text{max}} \) for \( i \in \{s, \ell\} \) are such that the first-best solution is interior. Then the following holds:

i) First-best short-term investment satisfies: \( s_{FB} = \frac{1}{\lambda_s} \).

ii) First-best long-term investment satisfies: \( \ell_{FB} = \frac{1}{\mu} \left[ r + \delta - \sqrt{(r + \delta)^2 - \frac{\mu \alpha}{\lambda_s \lambda_f}} \right] = \frac{p_{FB}}{\lambda_f} \).

### 1.4 Model Solution

We now solve the model with agency conflicts over the short and long term, that is assuming \( \sigma_K > 0 \) and \( \sigma_X > 0 \). Recall that the contract specifies the firm’s investment policy \( \{s\}, \{\ell\} \), payments to the agent \( C \), and a termination date \( \tau \) all as functions of the firm’s profit history. Given an incentive-compatible contract and the history up to time \( t \), the discounted expected
value of the agent’s future compensation is given by $W_t$. As in DeMarzo and Sannikov (2006) or DeMarzo et al. (2012), we can use the martingale representation theorem to show that the continuation payoff of the agent solves:

$$dW_t = \gamma W_t dt - dC_t + \beta^s_t (dX_t - \alpha s_t K_t dt) + \beta^l_t (dK_t - (\mu \ell_t - \delta) K_t dt).$$

(7)

This equation shows that the agent’s continuation value must grow at rate $\gamma$, in order to compensate for her time-preference. In addition, compensation must be sufficiently sensitive to firm performance, as captured by the processes $\beta^s_t = \frac{dW_t}{dX_t}$ and $\beta^l_t = \frac{dW_t}{dK_t}$, to maintain incentive compatibility. To understand why such a compensation scheme may align incentives, suppose that the agent decides to deviate from the recommended choice and chooses investment $\hat{s}_t = s_t - \varepsilon$ during an instant $[t, t + dt]$. By doing so, she keeps the amount of investment cost saved

$$K_t (C(s_t, \ell_t) - C(s_t - \varepsilon, \hat{\ell}_t)) dt \simeq K_t C_s (s_t, \ell_t) \varepsilon dt = K_t \alpha \lambda_s s_t \varepsilon dt.$$

At the same time however, she lowers mean cash flow by $K_t \alpha \varepsilon dt$, so that her overall compensation is reduced by $\alpha K_t \beta^s_t \varepsilon dt$. Therefore, the agent does not deviate from the prescribed short-run investment if $\beta^s_t = \lambda_s s_t$. Similarly, the agent does not deviate from the prescribed long-run investment if $\beta^l_t = \lambda_\ell \ell_t$. Both incentive compatibility constraints require that the agent has enough skin in the game, as reflected by sufficient exposure to firm performance.

The investor’s value function in an optimal contract, given by $P(W, K)$, is the highest expected payoff the investor may obtain given $K$ and $W$. While there are two state variables in our model, the scale invariance of the firm’s environment allows us to write $P(W, K) = K p(w)$ and reduce the problem to a single state variable: $w \equiv \frac{W}{K}$, the scaled promised payments to the agent as in He (2009) or DeMarzo, Fishman, He, and Wang (2012).

To characterize the optimal compensation policy and its effects on the investor’s (scaled) value function $p(w)$, note that it is always possible to compensate the agent with cash so that it costs at most $1$ to increase $w$ by $1$ and $p'(w) \geq -1$. In addition, as shown by (7), deferring compensation increases the growth rate of $W$ (and of $w$) and thus lowers the risk of liquidation, but is costly due to the agent’s impatience, $\gamma > r$. As a result, the optimal
contract sets $dc \equiv \frac{dC}{K}$ to zero for low values of $w$ and only stipulates payments to the manager once the firm has accumulated sufficient slack. That is, there exists a threshold $\bar{w}$ with

$$p'(\bar{w}) = -1 \quad \text{and} \quad dc = \max\{0, w - \bar{w}\},$$

(8)

where the optimal payout boundary is determined by the super-contact condition:

$$p''(\bar{w}) = 0.$$  
(9)

When $w$ falls to zero, the contract is terminated and the firm is liquidated so that

$$p(0) = R.$$  
(10)

When $w \in [0, \bar{w}]$, the agent’s compensation is deferred and $dc = 0$. The Hamilton-Jacobi-Bellman equation for the principal’s problem is then given by (see Appendix B):

$$(r + \delta)p(w) = \max_{s,\ell,\beta^s,\beta^\ell} \left\{ \alpha s - \mathcal{C}(s, \ell) + p'(w)w(\gamma + \delta - \mu\ell) + \mu\ell p(w) \\
+ \frac{p''(w)}{2} \left[ (\beta^s\sigma_X)^2 + \sigma^2_K(\beta^\ell - w)^2 + 2\rho\sigma_X\sigma_K\beta^s(\beta^\ell - w) \right] \right\},$$

(11)

subject to the incentive compatibility constraints on $\beta^s$ and $\beta^\ell$.

Due to the scale invariance, i.e., $P(W, K_0) = p(w)K_0$, the investor’s maximization problem at $t = 0$ can now be rewritten as

$$\max_{w_0 \in [0, \bar{w}]} p(w_0)K_0$$

with unique solution $w_0 = w^*$ satisfying

$$p'(w^*) = 0.$$  
(12)

As a consequence, the principal initially promises the agent utility $w^*K_0$ and expects a payoff $P(K_0w^*, K_0) = p(w^*)K_0$. For convenience, we normalize $K_0$ to unity in the following and
refer to $p(w^*)$ as expected payoff instead of scaled expected payoff. The following Proposition summarizes our results about the optimal contract. Its proof is deferred to Appendix B.

**Proposition 2** (Firm value and optimal compensation under agency).

Let $\Pi \equiv (\{C\}, \{s\}, \{\ell\}, \tau)$ denote the optimal contract solving problem (6). The following holds true:

1. There exist $\mathcal{F}$-progressive processes $\{\beta^s\}$ and $\{\beta^\ell\}$ such that the agent’s continuation utility $W_t$ evolves according to (7). The optimal contract is incentive compatible in that $\beta^s = \lambda^s s$ and $\beta^\ell = \lambda^\ell \ell$ where $\{s\}, \{\ell\}$ are the firm’s optimal investment decisions.

2. Firm value is proportional to firm size, in that $P(W, K) = K p(w)$. The scaled firm value $p(w)$ is the unique solution to equation (11) subject to (8), (9), and (10) on $[0, w]$. For $w > \overline{w}$ the scaled value function satisfies $p(w) = p(\overline{w}) - (w - \overline{w})$. Scaled cash payments $dc = \frac{4C}{K}$ reflect $w$ back to $\overline{w}$.

3. The function $p(w)$ is strictly concave on $[0, \overline{w}]$.

Before proceeding, note that $w$ serves as a proxy for the firm’s financial slack in our model, so that states where $w$ is close to zero—and the firm close to liquidation—correspond to financial distress. Since the firm has to undergo inefficient liquidation after a series of adverse shocks drive $w$ down to zero, the principal becomes effectively risk averse with respect to the volatility of $w$, so that the value function is strictly concave. That is $p''(w) < 0$ for $w < \overline{w}$. Put differently, the concavity of $p$ implies that the principal would like to minimize the volatility of $w$, while maintaining incentive compatibility.

Note also that overall value, $P(W, K) + W$, is split between the principal and the manager, where the manager obtains a fraction

$$S(w) = \frac{W}{P(W, K) + W} = \frac{w}{p(w) + w},$$

of overall value. Because of $S'(w) > 0$ for all $w \in (0, \overline{w})$, the scaled continuation value $w$ corresponds (monotonically) to the fraction of overall firm value that goes to the manager. Therefore, we also refer to $w$ as the agent’s or manager’s stake in the firm.$^{10}$ When the $^{10}$In fact, $S'(w) = p(w) - p'(w)w$ and $S''(w) = -wp''(w) > 0$ due to concavity of the value function. Since $S'(0) = R \geq 0$, it follows that $S'(w) > 0$ for all $w \in (0, \overline{w})$. 
manager’s stake \( w \) falls down to zero, she has no more incentives to stay and accordingly leaves the firm. In this case, deadweight losses are incurred due to contract termination.

## 2 Short- vs. Long-Run Incentives

This section examines the implications of agency conflicts for long- and short-term investment choices. For clarity of exposition, we assume that the correlation between short- and long-run shocks \( \rho \) is zero and that the parameters are such that investment levels \( s \) and \( \ell \) are interior. Section 3.2 analyzes the effects of non-zero correlation.

### 2.1 Short-term Investment and Incentives

Optimal short-term investment \( s = s(w) \) is obtained by taking the first-order condition in (11) after utilizing the incentive compatibility condition \( \beta^s = \lambda_s s \). This yields the following result:

**Proposition 3** (Optimal short-term investment). Optimal short-term investment is given by

\[
s(w) = \frac{\alpha}{\lambda_s \alpha - p''(w)(\lambda_s \sigma_X)^2}.
\]

Short-term investment is strictly lower than under first-best except at the boundary, in that \( s(w) < s^{SB} \) for \( w < \bar{w} \) and \( s(\bar{w}) = s^{FB} \). If \( \gamma - r \) and \( \sigma_K \) are sufficiently small, then \( s(w) \) increases in \( w \), i.e., \( \frac{\partial s(w)}{\partial w} > 0 \).

An important implication of Proposition 3 is that agency conflicts lead to underinvestment for the short run, i.e. \( s(w) < s^{FB} \) when \( \rho = 0 \). Upon increasing the investment rate \( s \), the firm does not only incur direct, monetary cost of investment but also agency costs, because higher \( s \) requires higher incentives \( \beta^s \). Consequently, the agent’s stake becomes more volatile, which raises the risk of costly liquidation and therefore leads to endogeneous agency costs or incentive costs of investment. These agency costs decrease in the level of
financial slack $w$ and vanish at the payout boundary $\bar{w}$ where $p''(\bar{w}) = 0$, at which point the firm’s short-run investment reaches first-best, $s(\bar{w}) = s^{FB}$.

2.2 Long-term Incentives and Investment

Next, we characterize the firm’s optimal long-term investment. Using the HJB equation (11) and the incentive compatibility condition $\beta^\ell = \lambda^\ell \ell$, we get the following result:

**Proposition 4 (Optimal long-term investment).** Optimal long-term investment is given by

$$
\ell(w) = \frac{\mu(p(w) - p'(w)w)}{\lambda^\ell \mu} - \frac{-p''(w)w\lambda^\ell \sigma^2_K}{\lambda^\ell (\lambda^\ell \sigma_K)^2}.
$$

The firm always underinvests for the long-term close to the boundary, in that there exists $\varepsilon > 0$ such that $\ell(w) < \ell^{FB}$ for $w \in [\bar{w} - \varepsilon, \bar{w}]$.

To get some intuition for the results in Proposition 4, let us consider the costs and benefits from marginally increasing long-term investment $\ell$:

$$
\frac{\partial p(w)}{\partial \ell} \propto \frac{\mu(p(w) - p'(w)w)}{\lambda^\ell \mu} - \lambda^\ell \ell + \frac{p''(w)\ell(\lambda^\ell \sigma_K)^2}{\lambda^\ell (\lambda^\ell \sigma_K)^2} - \frac{-p''(w)w\lambda^\ell \sigma^2_K}{\lambda^\ell (\lambda^\ell \sigma_K)^2}.
$$

Consider first the costs of raising long-term investment. The above expression shows that, in addition to the direct cost of investment, the firm incurs an agency cost. This agency cost arises because increasing long-run investment requires higher long-run incentives $\beta^\ell$ and therefore makes $w$ more volatile. The agency cost of investment depends on the principal’s effective risk aversion $-p''(w)$ and decreases optimal investment $\ell(w)$.

Consider next the benefits of raising long-term investment. The first difference between optimal short- and long-term investment is that the direct benefit of long-term investment is time-varying and given by $p(w) - p'(w)w$. Note that long-term investment expenditures today lead to a higher average cash-flow rate in the future. However, due to the possibility of firm liquidation owing to the moral hazard problem, the firm cannot perpetually enjoy
this increase in the cash-flow rate, so that the benefit of long-term investment $p(w) - p'(w)w$ is strictly lower than $p^{FB}$. Ceteris paribus, this lowers the firm’s investment rate $\ell(w)$. Relatedly, long-term investment is more profitable when the firm holds more financial slack and the distance to liquidation is far, that is $p(w) - wp'(w)$ increases in $w$.

A second difference is that investment in $\ell(w)$ offers an additional benefit compared to investment in $s(w)$: It mitigates the dilution of the agent’s stake $w$. Since $p''(w) \leq 0$, this effect unambiguously increases long-term investment. To understand the source of this effect, first note that by Ito’s Lemma, the dynamics of the agent’s stake are given by:

$$dw = (\gamma + \delta - \mu \ell)wdt + \beta^s \sigma_X dZ^X + (\beta^\ell - w)\sigma_K dZ^K,$$

so that the instantaneous variance of $dw$ satisfies

$$\Sigma(w) \equiv \frac{V(dw)}{dt} = (\beta^s \sigma_X)^2 + (\beta^\ell - w)^2 \sigma_K^2.$$

From equation (16), we see that a positive permanent shock $dZ^K > 0$ has two opposing effects on the manager’s incentives. First, the agent is rewarded for strong performance via the sensitivity $\beta^\ell$ and is promised higher future payments $W$. This increases $w = \frac{W}{K}$ (via its numerator) by $\beta^\ell \sigma_K dZ^K$, which equals $\lambda \ell(w)\sigma_K dZ^K$. Second, firm size $K$ grows more than expected, thereby reducing the agent’s stake $w = \frac{W}{K}$ (via its denominator) by $-w\sigma_K dZ^K$. We refer to the reduction of the agent’s stake upon a positive shock $dZ^K > 0$ as dilution and the volatility generated by this effect, i.e. $-w\sigma_K$, as dilution risk. Altogether, we have that $dw/dZ^K = (\beta^\ell - w)\sigma_K$. Because performance-based compensation and dilution move $w$ in opposite directions, long-run incentives $\beta^\ell$ mitigate the dilution effect which, ceteris paribus, lowers risk (see equation (17)) and is thus beneficial. This makes contracting for long-term investment cheaper and increases $\ell(w)$.

More generally, our model suggests that the manager’s compensation should increase with firm size. Indeed, an increase in firm size (due to a positive permanent shock $dZ^K > 0$) raises both the firm’s future cash-flow rate and the magnitude of future cash-flow shocks. As

---

11 As illustrated in Appendix B, the below dynamics is under an auxiliary measure $\tilde{P}$ rather than under the physical measure $P$. The choice of the probability measure does not matter, since $w$ has the same volatility under both measures and volatility is the only quantity we study in in the following discussion.
a result, the firm becomes not only more profitable but also more risky (in absolute terms). Both effects call for an increase in the manager’s continuation value, which better aligns the manager’s and the principal’s interests and facilitates contracting for long-term investment.

It is illustrative to look at this effect from the perspective of agency costs. As long as $\beta^\ell < w$, raising $\beta^\ell$ lowers the volatility and instantaneous variance $\Sigma(w)$ of $w$ and therefore the risk of liquidation, so that the effective (marginal) agency cost of long-run investment is pinned down by the net change in risk, that is by

$$
-\frac{p''(w)\ell(\lambda^\ell\sigma_K)^2}{\text{Agency cost (}>0)} + \frac{p''(w)w\lambda^\ell\sigma_K^2}{\text{Reducing dilution risk (<0)}} = -\frac{p''(w)\sigma_K^2\lambda^\ell(\lambda^\ell - w)}{\text{Effective agency cost (}\leq 0).}
$$

(18)

As is the case with the agency cost of investment, the benefits of mitigating dilution risk depend on how much volatility in $w$ matters for the investor’s value function, i.e., on principal’s effective risk-aversion $-p''(w)$. Therefore, it is most beneficial to alleviate dilution via long-run incentives $\beta^\ell$ when the concavity of the scaled value function is the largest. The effect disappears at $w = \overline{w}$ where $p''(\overline{w}) = 0$. When $w$ is close to $\overline{w}$ and therefore $p''(w) \simeq 0$ and $p'(w) \simeq -1$, the firm always underinvests, because direct benefits of investment $p(w) - wp'(w) \simeq p(w) + w < p^{FB}$ are reduced by the presence of moral hazard and agency-induced firm liquidation, which implies $\ell(w) = (p(w) + w)/\lambda^\ell < p^{FB}/\lambda^\ell = \ell^{FB}$.

3 Short- and Long-Termism in Corporate Policies

Because the manager’s ability to divert funds decreases the benefits of investment, each moral hazard problem working in isolation leads to underinvestment relative to the first-best levels. The novel insight of our model is that a simultaneous moral hazard problem over both the short- and long-run can generate overinvestment. We call overinvestment for the long-run, i.e. $\ell > \ell^{FB}$, long-termism and overinvestment for short-run, i.e. $s > s^{FB}$, short-termism. Below we analyze and contrast the circumstances that lead to long-termism and short-termism. We find that long-termism can arise irrespective of whether the different sources of cash-flow risk are correlated while short-termism requires $\rho \neq 0$. 
3.1 Long-Termism

Proposition 4 and equation (14) reveal that moral hazard decreases long-run investment via the direct benefit channel and the agency cost channel. The firm can potentially overinvest to reduce dilution risk. In the next proposition, we show that the last effect can dominate the former two effects and present sufficient conditions for overinvestment to arise.

Proposition 5 (Long-termism). The following holds true:

i) Long-termism, i.e. \( \ell(w) > \ell^{FB} \), arises only if \( \sigma_X > 0 \) and \( \sigma_K > 0 \).

ii) Assume \( \sigma_X > 0 \) and \( \sigma_K > 0 \). Then, there exist \( w^L \) and \( w^H \) with \( 0 < w^L < w^H < \bar{w} \) such that \( \ell(w) > \ell^{FB} \) for \( w \in (w^L, w^H) \), provided that \( \mu \) and \( \gamma - r \) are sufficiently low. The firm underinvests, i.e. \( \ell(w) < \ell^{FB} \), when \( w < w^L \) or \( w > w^H \), that is when \( w \) is close to zero or close to \( \bar{w} \).

iii) Higher volatility \( \sigma_X > 0 \) or \( \sigma_K > 0 \) favors long-termism: If \( \mu \) is sufficiently low and parameters are such that \( \sup \{ \ell(w) : 0 \leq w \leq \bar{w} \} = \ell^{FB} \), then there exists \( \varepsilon > 0 \) such that \( \sup \{ \ell(w) : 0 \leq w \leq \bar{w} \} > \ell^{FB} \) if \( \sigma_X \) or \( \sigma_K \) increases by \( \varepsilon \).

The first part of Proposition 5 states that long-termism can only arise when firm cash flows are subject to both transitory and permanent shocks, that is when \( \sigma_X > 0 \) and \( \sigma_K > 0 \), and the firm is exposed to a simultaneous moral hazard problem over both the short- and long-run. When permanent cash-flow shocks are removed from the model, i.e., \( \sigma_K = 0 \), long-term investment \( \ell \) is observable and contractible. In addition, there is no risk of dilution of the agent’s stake as all shocks are purely transitory in nature. Under these circumstances, long-term investment satisfies

\[
\ell(w) = \frac{p(w) - wp'(w)}{\lambda_\ell} < \frac{p^{FB}}{\lambda_\ell} = \ell^{FB}
\]

Because short-run agency lowers the direct benefits of long-run investment, the firm always underinvests for the long-term.

To see why transitory shocks, or equivalently moral hazard over the short-term, are essential for long-termism, we start with the following observation. Since the direct benefit of long-term investment under moral hazard is below the first-best level, it follows from
equation (15) that a necessary condition for overinvestment in $\ell(w)$ is that the dilution effect exceeds the agency cost effect. Using equation (18), this is equivalent to requiring that the effective (marginal) agency cost is negative. Thus, overinvestment in $\ell$ or long-termism arises only if

$$-p''(w)(\lambda_\ell w)\lambda_\ell \sigma_K^2 < 0 \iff w > \lambda_\ell = \beta_\ell,$$

that is, if the manager’s stake is large relative to her long-term incentives. When $\sigma_X = 0$, the firm faces no transitory cash-flow risk and therefore optimally grants the manager a relatively low stake, which puts a limit on potential dilution effects. More specifically, if it were that $w > \beta_\ell = \lambda_\ell$, it follows from (17) that the firm would profit from decreasing $w$ by making infinitesimal payouts $dc > 0$ and thus reducing the risk in $w$ by

$$\Sigma(w) - \Sigma(w - dc) \simeq (w - \lambda_\ell)dc > 0.$$

This strategy would reduce the risk the manager is exposed to, and still provide sufficient incentives. Consequently, $\sigma_X = 0$ implies that $w \leq \lambda_\ell$ for all $w$, the effective agency cost of long-term investment is positive, and the firm underinvests in $\ell$.

When both $\sigma_X$ and $\sigma_K$ are strictly positive, the above argument does not work as the firm also needs to account for short-run risk and incentives. In order to decrease termination risk, it can then be optimal for the firm to delay payments to the manager further, even if $w \simeq \beta_\ell$ and the manager’s stake is barely exposed to permanent cash-flow risk. This can lead to $w$ exceeding $\beta_\ell$, that is, to a negative effective agency cost and to overinvestment in $\ell$. The mechanism is as follows. When the agent holds a large stake $w$, the risk of dilution identified above generates additional termination risk, which diminishes the risk reduction induced by postponing payouts. The principal can mitigate these adverse dilution effects by tying the agent’s compensation more to long-term performance, which leads to higher long-run incentives $\beta_\ell$. The incentive compatibility condition $\beta_\ell = \lambda_\ell$ then implies that the firm must also increase long-term investment.

\footnote{In fact, the inequality is strict: $w < \beta_\ell = \lambda_\ell(w)$. To get some intuition, note that in case $\beta_\ell = w$, the firm becomes riskless. The benefits of reducing $w$ by an infinitesimal amount $dc > 0$ are proportional to $(\gamma - r)o(dc)$ and therefore of order $o(dc)$, while the cost—stemming from the additional risk of liquidation—are of order $o((dc)^2)$. Consequently, the firm would never set $\beta_\ell = w$, so that $\beta_\ell = \lambda_\ell(w) > w$ for all $w \in [0, \bar{w}]$. This result is established in He (2009).}
The second part of Proposition 5 shows that long-termism arises when the asset growth rate $\mu$ is low, that is, when long-run investment is sufficiently inefficient. Proposition 5 therefore offers a potential explanation for the puzzling empirical evidence that in recent years capital is not allocated to the industries with the best growth opportunities (as recently documented by Lee, Shin, and Stulz (2018)). Additionally, long-termism arises when cash flow is sufficiently volatile in either time-horizon, i.e., $\sigma_X > 0$ and $\sigma_K > 0$ are large, and when the agent is sufficiently patient, i.e., $\gamma - r > 0$ is low.

The intuition for these findings is as follows. As explained above, long-termism requires the dilution effect to exceed the agency cost effect, which happens when the manager’s stake is large relative to her long-term incentives, $w > \beta^f$. When this is the case, the effective agency cost is negative. Both higher cash-flow risk ($\sigma_X$ and $\sigma_K$) and lower cost of delaying payouts ($\gamma - r$) increase the value of deferred compensation so that $\overline{w}$ rises, leading to an (average) increase in the manager’s stake within the firm. On the other hand, low asset growth rate decreases contracted long-term investment $\ell$ and accordingly long-term incentives $\beta^f$.

To generate long-termism, the agency-cost-based motives for overinvestment must also exceed the preference for underinvestment that arises because of the diminished direct benefit of investment. Recall that the marginal direct benefit of long-run investment under moral hazard equals $\mu(p(w) - p'(w)w)$ and is below its first-best counterpart while the marginal direct cost $\lambda \mu$ is at the first-best level. Since both the direct benefit and cost are proportional to $\mu$, this motive to underinvest is quantitatively low when $\mu$ is low and can then be overcome by the agency-cost-based preference for overinvestment.

Figure 1 presents a quantitative example illustrating long-termism. The parameters satisfy the conditions set in Proposition 5 and are as follows. We set the discount rate parameters to $r = 4.6\%$ and $\gamma = 4.8\%$ and the depreciation rate to $\delta = 12.5\%$, similar to DeMarzo et al. (2012). The volatility parameter of the long term shock is set to $\sigma_K = 20\%$, in line with Kogan (2004), while the volatility parameter of the short-term shock is set to $\sigma_X = 25\%$, in line with DeMarzo et al. (2012). The drift parameter for the profitability/productivity process is set to $\alpha = 25\%$. The left plot shows that the firm underinvests in the short run for all $w$. The middle plot shows that the firm overinvests in the long run for intermediate values of $w$. This is when the dilution effect, whose magnitude is proportional to $p''(w)w\sigma^2_K$,
Figure 1: Numerical example of long-termism. The first two panels depict optimal investment as functions of $w$. The third panel at the right displays effective agency cost $A(w) = -p''(w)(\lambda_t \ell(w) - w)$. The parameters are $\alpha = 0.25$, $\sigma_K = 0.25$, $\sigma_X = 0.2$, $\rho = 0$, $\mu = 0.025$, $r = 0.046$, $\gamma = 0.048$, $\delta = 0.125$, $\lambda_s = \lambda_t = 1$, $R = 0.25$.

is the strongest. The right plot also shows that long-termism is related to a negative effective agency cost. Conversely, according to Proposition 5, long-termism never arises in financial distress, i.e. when $w$ is close to 0, or when the firm is expected to make direct payments to the manager, i.e. when $w$ is close to $\bar{w}$.

3.2 Correlated Cash-Flow Shocks and Short-Termism

As shown in Proposition 3, short-termism cannot occur in our baseline model with independent shocks, that is when $\rho = 0$. By contrast, when permanent and transitory cash-flow shocks are correlated, direct externalities between short- and long-term investment and incentives arise. These externalities can lead to corporate short-termism, i.e. to $s > s^{FB}$, as we demonstrate below.

To start with, note that when shocks are correlated, optimal short- and long-term investment are given by:

\[
\begin{align*}
s(w) &= \frac{\alpha + p''(w)\rho \sigma_X \sigma_K \lambda_s \ell(w) - w}{\lambda_s \alpha - p''(w)(\lambda_s \sigma_X)^2} \\
\ell(w) &= \frac{\mu \left( p(w) - p'(w)w \right) + p''(w)\rho \sigma_X \sigma_K \lambda_t \lambda_s \ell(w) - p''(w)w \lambda_t \sigma_K^2}{\lambda_t \mu - p''(w)(\lambda_t \sigma_K)^2}
\end{align*}
\]

Compared to equations (13) and (14), new terms appear that affect optimal investment
levels and incentives. Since \( s(w) \) depends on \( \ell(w) \) and vice versa, there are direct externalities between investment levels and incentives. Intuitively, when the two sources of risk are positively correlated, exposing the manager’s continuation payoff to both transitory and permanent shocks creates additional volatility and is therefore costly. Conversely, when the correlation is negative, exposure to both shocks partially cancels out, thereby reducing the volatility of the manager’s continuation payoff \( w \).

From equation (20), the externality of \( s(w) \) on \( \ell(w) \) is negative (positive) if \( \rho > 0 \) (\( \rho < 0 \)). The magnitude of the externality scales with the curvature of the value function \( p''(w) \)—i.e., the principal’s effective risk-aversion—and is therefore relatively weaker once \( w \) is sufficiently large and the risk of termination is sufficiently remote.

Likewise, equation (19) demonstrates that the choice of long-term investment \( \ell(w) \) also feeds back into the choice of short-term investment \( s(w) \). However, the externality effect in the numerator of \( s(w) \) in (19) has two separate components:

\[
p''(w)\rho \sigma_X \sigma_K \lambda_s \left( \lambda_\ell \ell(w) - w \right) = p''(w)\rho \sigma_X \sigma_K \lambda_s \lambda_\ell \ell(w) - p''(w)\rho \sigma_X \sigma_K \lambda_s w .
\] (21)

This decomposition shows that when the correlation between shocks is non-zero, incentives for the short-run are also used to counteract the dilution in the manager’s stake arising upon positive permanent shocks \( dZ^K > 0 \). As discussed in section 3.1, with no correlation, the principal counteracts this dilution effect by tying the manager’s compensation to permanent shocks and increasing long-term incentives. When the two sources of cash-flow risk are positively (negatively) correlated, it is possible to reduce dilution risk also by means of higher (lower) short-term incentives.

Notably, when \( \rho < 0 \) and \( w \) is low, positive risk externalities of short- and long-term incentives emerge and may dominate dilution effects of short-term incentives. In this case, short-termism, \( s(w) > s^{FB} \), can become optimal.

**Proposition 6** (Short-termism under distress with \( \rho < 0 \)). The following holds true:

i) **Short-termism arises only if** \( \sigma_X > 0 \), \( \sigma_K > 0 \), and \( \rho \neq 0 \). **Conversely, if either** \( \sigma_X = 0 \), \( \sigma_K = 0 \), or \( \rho = 0 \), short-termism cannot arise and \( s(w) \leq s^{FB} \) for all \( w \).
Figure 2: Numerical example of short-termism. The parameters are $\alpha = 0.25$, $\sigma_X = 0.15$, $\sigma_K = 0.5$, $\rho = -0.75$, $\mu = 0.025$, $r = 0.046$, $\gamma = 0.047$, $\delta = 0.125$, $\lambda_s = 1.15 > \lambda_\ell = 0.25$, $R = 0.75$.

\begin{itemize}
  \item[ii)] Assume $\sigma_X > 0$, $\sigma_K > 0$ and $\rho < 0$. Then, there exist $w_L < w_H$ with $s(w) > s^{FB}$ for $w \in (w_L, w_H)$, provided $\sigma_X$ is sufficiently small. When $\lambda_\ell$ is sufficiently small, the set $\{w \in [0, w_H]: s(w) > s^{FB}\}$ is convex and contains zero and $s(w)$ decreases on this set.
\end{itemize}

While long-termism occurs mainly for large values of the manager’s stake $w$ with the objective to alleviate the excessive dilution risk via long-run incentives $\beta^\ell$, short-termism is more likely to occur for low values of $w$ when the correlation between shocks is negative. When the agent’s stake $w$ is small, dilution risk is negligible and positive externalities between short- and long-term incentives induce more short-term investment. In addition, short-termism can arise when cash-flow risk $\sigma_X$ is small so that short-run agency cost is sufficiently low and does not dominate the externality effect.

Figure 2 provides an example of short-termism when the correlation between long- and short-term shocks is negative. Consistently with Proposition 6, the firm overinvest in the short-run when in distress and $w$ is close to 0. Figure 2 further illustrates that both short- and long-termism may but need not to happen within the same firm, depending on the level of financial slack as measured by $w$. In distress, the firm overinvests in generating (short-term) profits, while after a strong performance, the firm overinvests in (long-term) growth. While the effects of absolute short-termism appear to be quantitatively small, the effects of relative short-termism $\frac{s(w)/s^{FB}}{\ell(w)/\ell^{FB}}$, which determines whether investment is distorted toward the short-term compared to first-best, can be quantitatively large. Absent agency fictions, this ratio equals by construction one and a value above (below) one indicates an investment...
distortion towards the (long-) short-run.

Our focus on the case of negative correlation is due to the finding in Chang et al. (2014) that the correlation coefficient between permanent and transitory cash-flow shocks $\rho$ is on average negative. When this is the case, our model predicts that firms with a high risk of liquidation—i.e., firms that perform worse and have little financial slack—should find it optimal to focus on the short term (i.e., current earnings) while firms with a low risk of liquidation—i.e., cash-rich firms that perform well—should find it optimal to focus on the long term (i.e., asset growth). Interestingly, a recent study by Barton et al. (2017) finds using a data set of 615 large- and mid-cap US publicly listed companies from 2001 to 2015 that “the long-term focused companies surpassed their short-term focused peers on several important financial measures.” While our model does indeed predict that firm performance should be positively related to the corporate horizon, it, in fact, suggests the reverse causality.

For completeness, we also investigate optimal investment when the correlation between cash-flow shocks is positive. In this case, the firm can overinvest in both short- and long-term investment at the same time. This happens when the agent’s stake in the firm is large, thereby exposing the manager to a high risk of dilution. To reduce this dilution risk, the principal provides high-powered incentives to the manager. Importantly, when correlation is positive, unexpected asset growth $dZ^K > 0$ triggers on average unexpected cash flow $\rho dZ^K$, which leads a reward $(\beta^l + \rho \beta^s) dZ^K$ for the agent.\textsuperscript{13} Consequently, both short- and long-run incentives counteract the adverse dilution in the agent’s stake, so that the desire to mitigate dilution risk translates into high-powered incentives and, accordingly, to overinvestment for both time horizons. The next proposition characterizes this outcome.

**Proposition 7** (Short-termism with $\rho > 0$). Assume $\sigma_X > 0$, $\sigma_K > 0$ and $\rho > 0$. Then, there exist $w^L < w^H$ with $s(w) > s^{FB}$ for $w \in (w^L, w^H)$, provided $\sigma_X > 0$ and $\gamma - r$ sufficiently small. When $\mu \lambda_t$ is sufficiently small, the set $\{w \in [0, \bar{w}] : s(w) > s^{FB}\}$ is convex with $\inf\{w \in [0, \bar{w}] : s(w) > s^{FB}\} > 0$ and $\sup\{w \in [0, \bar{w}] : s(w) > s^{FB}\} = \bar{w}$.

\textsuperscript{13}To see this, one can decompose $dZ^X_t = \rho dZ^K_t + \sqrt{1-\rho^2} dZ^T_t$, where $\{Z^T\}$ is a standard Brownian Motion, independent of $\{Z^X\}$. Hence, $\mathbb{E}(Z^X_t | Z^K_t) = \rho Z^K_t$ or in differential form $\mathbb{E}(dZ^X_t | dZ^K_t) = \rho dZ^K_t$. 

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4 Asymmetric pay in executive compensation

We now turn to analyzing incentive provision. For clarity of exposition, we assume throughout the section that the correlation $\rho$ between short- and long-run shocks is zero and focus on a specification in which the investment cost $C$ is linear:

$$C(s, \ell) = \alpha \lambda_s s + \mu \lambda_\ell \ell. \quad (22)$$

As a consequence, investment follows a bang-bang solution, i.e., either full or no investment is optimal: $s \in \{0, s_{\text{max}}\}$ and $\ell \in \{0, \ell_{\text{max}}\}$. Equivalently, one could also specify that there is a linear adjustment cost to short-run (resp. long-run) investment up to some threshold $s_{\text{max}}$ (resp. $\ell_{\text{max}}$) and an infinite adjustment cost afterward. The Appendix shows that the results derived in this section also apply when the investment cost is convex.

Corner levels of investment are the only relevant cases in a model with binary effort choice (i.e., $s \in \{0, s_{\text{max}}\}$ or $\ell \in \{0, \ell_{\text{max}}\}$), as in He (2009), or in a model with effort cost functions that are linear in effort levels, as in Biais et al. (2007) or DeMarzo et al. (2012). As a result, considering a linear cost function $C$ allows us to directly compare our results with those in the models in which moral hazard is solely over the long- or the short-run and to clarify what outcomes are unique and novel to our model featuring both types of moral hazard.

Let us assume for simplicity that full short- and long-run investment is always optimal so that $s(w) = s_{\text{max}}$ and $\ell(w) = \ell_{\text{max}}$ for all $w$. When the investment cost is linear, incentive-compatibility requires

$$\beta^s \geq \lambda_s \text{ and } \beta^\ell \geq \lambda_\ell.$$

The objective of the principal when choosing the manager’s exposure to firm performance is to maximize the value derived from the firm, given a promised payment $w$ to the manager. To do so, the principal equivalently minimizes the agent’s exposure to shocks, while maintaining incentive compatibility (see equation (11)). Minimizing risk exposure amounts to minimizing the instantaneous variance of the scaled promised payments:

$$\Sigma(w) = (\beta^s \sigma_X)^2 + (\beta^\ell - w \sigma_K)^2 \text{ subject to } \beta^s \geq \lambda_s \text{ and } \beta^\ell \geq \lambda_\ell.$$
This leads to the following result:

**Proposition 8** (Asymmetric pay in executive compensation). When investment costs are linear and full investment is optimal, i.e. \( s = s_{\text{max}} \) and \( \ell = \ell_{\text{max}} \), we have that:

i) Incentives are given by \( \beta^s = \lambda_s \) and \( \beta^\ell = \lambda_\ell + \max\{0, w - \lambda_\ell\} \).

ii) \( \beta^\ell(w) > \lambda_\ell \) arises, only if \( \sigma_X > 0 \) and \( \sigma_K > 0 \).

iii) Assume \( \sigma_X > 0 \) and \( \sigma_K > 0 \). If \( \gamma - r, \ell_{\text{max}} \) or \( \lambda_\ell \) is sufficiently low, \( w > \lambda_\ell \) and \( \beta^\ell(w) > \lambda_\ell \) for \( w \in (\lambda_\ell, w] \).

The finding that the incentive compatibility constraint \( \beta^s \geq \lambda_s \) in Proposition 8 is tight is standard and intuitive. The principal needs to expose the agent to firm performance, but this is costly because this increases the risk of inefficient liquidation. Thus, the principal optimally exposes the agent to as little short-run risk as possible.

The finding that the incentive compatibility constraint \( \beta^\ell \geq \lambda_\ell \) is not necessarily tight stems from the fact that the principal optimally wants to expose the manager’s continuation payoff to long-run, permanent shocks. Indeed, and as noted above, a positive permanent shock \( dZ^K > 0 \) has two effects. First, the agent is rewarded for good performance and is promised higher future payments \( W \), which increases the stake \( w \) by \( \beta^\ell \sigma_K dZ^K \). Second, firm size \( K \) grows more than expected, thereby reducing the agent’s stake in the firm by \( -w \sigma_K dZ^K \). This second effect implies that the agent’s stake \( w \) is exposed to dilution risk, which can be alleviated using long-run incentives \( \beta^\ell \).

When \( w > \lambda_\ell \), the principal can fully eliminate dilution risk by setting \( \beta^\ell = w \), while maintaining incentive compatibility. Under these circumstances, long-run incentives are effectively costless and the manager is exposed to long-run shocks beyond the level needed to incentivize long-term investment. By contrast, incentive compatibility prevents the principal from eliminating long-run risk when \( \lambda_\ell > w \) and \( \beta^\ell = \lambda_\ell \). Importantly, there is no agency conflict over the long-run and the agent is paid for luck when \( \lambda_\ell = 0 \), that is for productivity shocks beyond her influence, just as in Hoffmann and Pfeil (2010) and DeMarzo, Fishman, He, and Wang (2012).

An important implication of Proposition 8 is that, in our model with dual moral hazard, the agent receives asymmetric performance pay. In particular, the agent is provided minimal
long-run incentives $\beta^\ell = \lambda^\ell > w$ for low $w$ and higher powered long-run incentives $\beta^\ell = w > \lambda^\ell$ after positive past performance, in which case sufficient slack $w$ has been accumulated. In this region, incentives have option-like features and increase after positive performance. Our findings are consistent with evidence on the asymmetry of pay-for-performance in executive compensation (see for example Garvey and Milbourn (2006) and Francis, Iftekhar, Kose, and Zenu (2013)). In contrast with the suggested explanations, the asymmetry in pay-for-performance is part of an optimal contract and is not due to managerial entrenchment.$^{14}$

Remarkably, asymmetric performance-pay and strong long-run incentives $\beta^\ell \geq \lambda^\ell$ can only arise when $\sigma_X > 0$ and $\sigma_K > 0$ and there is a moral hazard over both time horizons, the short- and long-run. When $\sigma_X = 0$, the principal does not grant the agent a stake $w$ larger than $\lambda^\ell$, in that payouts $dc > 0$ are made before the agent’s stake can grow sufficiently large. Our results therefore also differ from He (2009) where the firm becomes riskless and is run forever, once the principal eliminates the agent’s exposure to shocks.$^{15}$ By contrast, owing to transitory cash-flow shocks, the firm still faces liquidation risk in our model, even when all risk from permanent shocks is eliminated.

5 Robustness and Extensions

5.1 Agent’s limited wealth

Let us now consider what happens when the agent possesses zero wealth. For simplicity, we focus in the following on the case of quadratic investment cost, zero correlation and, without loss of generality, $\delta = 0$. Given prescribed investment levels $(s_t, \ell_t)$, if the agent were to increase short-term investment by some small amount $\varepsilon > 0$, she would require additional funds $\varepsilon C_s(s_t, \ell_t) = \lambda_s \alpha \varepsilon$. Due to the lack of private wealth, the only possibility is to curb long-term investment by $\varepsilon C_\ell(s_t, \ell_t) = \varepsilon \lambda_\ell \alpha \varepsilon$ and therefore (mis)-allocate this amount

$^{14}$In our model, the agent is essentially paid more for a positive shock than he is punished after a negative shock of the same size. Obviously, this statement is mathematically not exact since the agent’s sensitivity to shocks $dZ^K$ is locally symmetric, but carries some meaning for shocks over a larger time interval. For a stark intuition, imagine however that at time $t$ scaled continuation value equals $w_t = \lambda^\ell - \varepsilon$ and let $\Delta = 2\varepsilon > 0$. A shock $Z^K_{t+dt} - Z^K_t = \Delta > 0$ raises $w_{t+dt}$ beyond $\lambda^\ell$ and therefore increases the agent’s value by $W_{t+dt} - W_t > 2\varepsilon \lambda^\ell$. In contrast, a shock $Z^K_{t+dt} - Z^K_t = -\Delta < 0$ decreases the agent’s value by $2\varepsilon \lambda^\ell$.

$^{15}$In He (2009), full elimination of cash-flow shocks may only occur when $\gamma = r$. In our model, however, permanent cash-flow shocks may be eliminated through $\beta^\ell = w$, even if $\gamma > r$. 

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from the long-term towards short-term investment. The above reallocation boosts the cashflow rate by $K_t \alpha \varepsilon$, while lowering the growth rate of assets by $K_t \varepsilon \frac{\lambda s}{\lambda t \mu t}$, so that incentive compatibility requires $\beta_t^s \geq \beta_t^l \frac{\lambda s}{\lambda t \mu t}$. To preclude symmetric redirecting from investment funds from the short- towards the long-term, we get the reverse inequality. Combining these conditions implies:

$$\frac{\beta_t^s}{\lambda s t} = \frac{\beta_t^l}{\lambda t \ell t}. \quad (23)$$

The standard incentive conditions are additionally required to discourage the agent to divert from investment funds for her own consumption:

$$\beta_t^s \geq \lambda s t \text{ and } \beta_t^l \geq \lambda t \ell t. \quad (24)$$

By standard arguments, the HJB-equation describing the principal’s problem reads then:

$$rp(w) = \max_{s, t, \beta^s, \beta^l} \left\{ \alpha s - C(s, \ell) + p'(w)w(\gamma - \mu \ell) + \mu \ell p(w) + \frac{p''(w)}{2} \left[ (\beta^s \sigma X)^2 + \sigma_k^2 (\beta^l - w)^2 \right] \right\},$$

subject to the incentive constraints (23) and (24) and the usual boundary conditions.

To see why our results on short- and long-termism are practically unaffected by the assumption of limited wealth, let us substitute (23) into the HJB equation and eliminate $\beta^s$ and analyze the optimality conditions for the controls. Because

$$\frac{\partial p(w)}{\partial s} \propto \alpha - \lambda s \alpha s + \underbrace{\lambda t \ell t \frac{\beta^l \lambda s}{\lambda t \ell t} \sigma X^2 s}_{\text{Agency cost of investment } (<0)} ,$$

it is clear that $s(w) < s^{FB}$ for all $w \in [0, \bar{w})$ owing to the agency cost associated with short-term investment, which confirms the result of Proposition 3.

Next, note that

$$\frac{\partial p(w)}{\partial \ell} \propto \mu \left( p(w) - wp'(w) - \lambda t \ell \right) - \frac{p''(w)}{\ell} \left( \frac{\beta^l \lambda s}{\lambda t \ell} \sigma X \right)^2 + \frac{1_{\{\beta^l = \lambda t \ell \}} \sigma_k^2 p''(w) (\beta^l - w)}{\text{Effective Agency Cost of Investment } (>0)} . \quad (25)$$

Interestingly, by increasing long-term investment and owing to the convexity of the cost

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function, the principal makes misallocations of funds from the long- towards the short-term more costly for the agent and therefore provides effectively additional incentives for the manager to implement the prescribed investment allocation. The remaining terms in (25) are standard with the sole caveat that $\beta^{t} \geq \ell \lambda_{t}$ need not be tight, in which case long-term investment $\ell$ can be boosted without incurring additional agency cost.

To continue, observe that for $\mu$ sufficiently low, the first-term becomes negligible. If the incentive compatibility condition with respect to lung-term incentives is tight (such that $\beta^{t} = \lambda_{t} \ell$ ), then for $\gamma - r$ sufficiently low, we find $w < \bar{w}$ with $w > \lambda_{t} \ell^{FB}$, in which case $\frac{\partial p(w)}{\partial \ell} > 0$ for $\ell \leq \ell^{FB}$ and thus $\ell(w) > \ell^{FB}$. If $\beta^{t} > \lambda_{t} \ell$, then the right-hand side of (25) is strictly positive for a low growth rate $\mu$. In either case, we are able to recover our result from Proposition 5.

Moreover, one can solve for the optimal level of long-term incentives, which are now given by:

$$\beta^{t} = \max \left\{ \frac{1}{1+\pi^{2}} \right\} \text{ for } \pi = \frac{\lambda_{s} s \sigma_{X} \lambda_{t} \ell \sigma_{K}}{\lambda_{t} \ell}$$

As a consequence, the incentive constraint need not be binding for high levels of $w$, which leads to asymmetric performance-pay as in Proposition 8.

While not shown explicitly here, continuing this line of arguments, we could also recover our results of Propositions 6 and 7. In particular, the same forces drive short- and long-termism as in our baseline model. Conclusively, the assumption that the manager has unlimited wealth is indeed without loss of generality while simplifying the exposition.

### 5.2 Private investment cost

In the model, we assume that the principal bears the investment cost $C$ while the agent can divert funds for her private consumption. Alternatively, we could also assume that the effort (investment) cost $C$ is private to the manager. Under these circumstances, incentiviz-

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16This claim relies on the premise that $\lim_{\gamma \rightarrow r} \bar{w} = \infty$ and that $\bar{w}$ increases in $\sigma_{X}, \sigma_{K}$ and $\lambda_{s}$. These claims can be proven utilizing the proof technique used to establish the analogous claims in the baseline model.

17It is obvious that when either $\sigma_{X} = 0$ or $\sigma_{K} = 0$, we have only one relevant incentive constraint: either $\beta^{t} \geq \lambda_{s}$ or $\beta^{t} \geq \lambda_{t} \ell$. From there it is straightforward to verify that no long-termism can occur. The claim is slightly more involved for $\sigma_{X} = 0$. Then, the principal set $\beta^{t} = \max \left\{ w, \lambda_{t} \ell \right\}$. Arguments similar to ones used in the proof of Proposition 5 can then be used to show that $\lambda_{t} \ell(w) > w$ for all $w$, so that the problem becomes standard and agency cost of investment induce underinvestment.
ing investment $s, \ell$ requires compensating this private cost to the manager by increasing her continuation utility. This induces a positive drift component for the agent’s scaled continuation value $w$. Hence, ignoring all other effects, raising $s, \ell$ makes $w$ drift up and therefore reduces the likelihood of termination. As a consequence, additional investment/effort cost $C$ is actually beneficial for the principal when $p'(w) > 0$ equivalently when $w$ is low. As shown in Szydlowski (2018), this beneficial private cost effect might lead to overinvestment. We solve the model with private investment cost in the Appendix and demonstrate that short- and long-termism can arise in this model as well.

In our model, the manager does not finance investment expenditures from her own pockets and agency conflicts arise because of a misallocation or appropriation of funds allocated to investment. We believe that this setup is more realistic for most real-world environments. In addition, it allows us to clearly identify the drivers of short- and long-termism, compared to a model in which the cost of investment is private (see the Appendix for details).

6 Conclusion

We develop a continuous-time agency model in which the agent controls current earnings via short-term investment and firm growth via long-term investment. In this multi-tasking model, the principal optimally balances the costs and benefits of incentivizing the manager over the short- or the long-term. As shown in the paper, this can lead to optimal short- or long-termism, i.e. to short- or long-term investment levels above first best levels, depending on the severity of agency conflicts and firm characteristics. The model predicts that the nature of the risks facing firms is key in determining the corporate horizon. We show for example that the correlation between between shocks to earnings and to firm value leads to externalities between investment choices, which are necessary to generate short-termism. We additionally predict that firm performance should be positively related to the corporate horizon. In particular, firms should become more short-termist after bad performance.

Incentives are provided in the optimal contract by making the agent’s compensation contingent on firm performance. Because the firm is subject to long-run, permanent shocks, it is optimal to introduce exposure to long-run volatility that is not needed to incentivize
effort in the contract. In our model with multi-tasking, however, the principal needs to incentivize the manager to exert long-run effort. This generates the distinct prediction that extra pay-for-performance is introduced and the manager’s wealth is fully exposed to permanent shocks only when her stake in the firm is large enough. Notably, when her stake is low, the extra pay-for-performance effect is shut down and the incentive compatibility constraint is binding. In other words, positive permanent shocks lead to additional pay-for-performance and negative permanent shocks eventually eliminate this extra sensitivity to performance implied by the optimal contract. Our model therefore provides a rationale for the asymmetry of pay-for-performance observed in the executive compensation data.
Appendix

Without loss in generality, we consider throughout the whole Appendix that the depreciation rate of capital $\delta$ equals zero. To ensure the problem is well-behaved, we impose the following regularity conditions:

a) Square integrability of the payout process $\{C\}$:

$$
\mathbb{E}\left[\left(\int_0^T e^{-\gamma s}dC_s\right)^2\right] < \infty.
$$

b) The processes $\{s\}$ and $\{\ell\}$ are of bounded variation.

c) The sensitivities $\{\beta^s\}$ and $\{\beta^\ell\}$ are almost surely bounded, so that there exists $M > 0$ with $\mathcal{P}(\beta^K_t < M) = 1$ for each $t \geq 0$ and $K \in \{s, \ell\}$. We make this assumption for purely technical reasons and can choose $M < \infty$ arbitrarily large (enough), such that this constraint never binds at the optimum.

A Proof of Proposition 1

Proof. The first best investment levels $(s^{FB}, \ell^{FB})$ maximize

$$
\hat{p}(s, \ell) = \frac{1}{r + \delta - \mu \ell}[as - \mathcal{C}(s, \ell)].
$$

For the case of quadratic cost, straightforward calculations lead to the desired expressions for $s^{FB}, \ell^{FB}$ and $p^{FB} \equiv \hat{p}(s^{FB}, \ell^{FB})$, where $\ell^{FB}$ satisfies the relation $\mu p^{FB} = \mathcal{C}_\ell(s^{FB}, \ell^{FB}).$

B Proof of Proposition 2

B.1 Auxiliary Results

We first show that each investment path $\{(s), \{\ell\}\}$ induces a probability measure under certain conditions. To begin with, fix a probability measure $\mathcal{P}^0$ such that

$$
dX_t = \sigma_X K_t d\tilde{W}^X_t \quad \text{and} \quad dK_t = \sigma_K K_t d\tilde{W}^K_t
$$

with correlated standard Brownian motions $\{\tilde{W}^X\}, \{\tilde{W}^K\}$ under this measure, both progressive with respect to $\mathcal{F}$. The measure $\mathcal{P}^0$ corresponds to perpetual zero investment. Define $\tilde{W}_t \equiv (\tilde{W}^X_t, \tilde{W}^K_t)'$ and let the (unconditional) covariance matrix of $\tilde{W}_t$ under $\mathcal{P}^0$ be:

$$
\nabla^0(\tilde{W}_t) = \mathbb{E}^0(\tilde{W}_t \tilde{W}_t') = \begin{pmatrix} 1 & \rho \end{pmatrix} \times t \equiv Ct.
$$

In this equation, $\nabla^0(\cdot)$ denotes the variance operator with respect to the measure $\mathcal{P}^0$. Let us employ a Cholesky decomposition to write $\mathbf{M}^{-1}(\mathbf{M}^{-1})' = \mathbf{C}$ or equivalently $\mathbf{M}'\mathbf{M} = \mathbf{C}^{-1}$ for an invertible, deterministic matrix $\mathbf{M}$. Observe that

$$
\nabla^0(\mathbf{M}\tilde{W}_t) = \mathbb{E}^0(\mathbf{M}\tilde{W}_t \mathbf{M}'\tilde{W}_t') = \mathbf{M}\mathbf{C}\mathbf{M}' \cdot t = \mathbf{M}(\mathbf{M}'\mathbf{M})^{-1}\mathbf{M}' \cdot t = \mathbf{I} \cdot t,
$$

where $\mathbf{I} \in \mathbb{R}^{2 \times 2}$ denotes the identity matrix. Because the two components of $\tilde{W}_t$ are jointly normal and uncorrelated, they are also independent in that the process $\{\tilde{W}_t\}' \equiv \big\{\mathbf{M}\tilde{W}\big\}$ follows a

\[^{18}\text{For a matrix-valued random variable } Y : \Omega \to \mathbb{R}^{n \times k} \text{ we denote the transposed random variable by } Y' : \Omega \to \mathbb{R}^{k \times n}.\]
bidimensional standard Brownian motion. We can now apply Girsanov’s theorem to \( \{\tilde{W}^T\} \) where all components, by definition, are mutually independent.

As a first step, we define

\[
\Theta_t = \Theta_t(s, \ell) \equiv \left( \frac{\alpha_s}{\sigma_X}, \frac{\mu_\ell}{\sigma_K} \right) \quad \text{and} \quad \tilde{\Theta}_t = \tilde{\Theta}_t(s, \ell) \equiv M \Theta_t(s, \ell).
\]

Further, let

\[
\Gamma'_t = \Gamma'_t(s, \ell) \equiv \exp \left( \int_0^t \tilde{\Theta}_u \cdot d\tilde{W}_u^T - \frac{1}{2} \int_0^t ||\tilde{\Theta}_u||^2 du \right),
\]

where \( || \cdot || \) denotes the Euclidean norm in \( \mathbb{R}^2 \) and

\[
\int_0^t \tilde{\Theta}_u \cdot d\tilde{W}_u^T = \int_0^t \sum_{i=1,2} \tilde{\Theta}_{u,i} d\tilde{W}_{u,i} = \sum_{i=1,2} \int_0^t \tilde{\Theta}_{u,i} d\tilde{W}_{u,i}.
\]

Throughout the paper, we will assume that the processes \( \{s\}, \{\ell\} \) are such that the ‘Novikov condition’ is satisfied, in that

\[
\mathbb{E}^0 \left[ \exp \left( \frac{1}{2} \int_0^T ||\tilde{\Theta}_t||^2(s, \ell) dt \right) \right] < \infty.
\]

In fact, our regularity conditions imply the Novikov condition. Then, \( \{\Gamma'_t\} \) follows a martingale under \( \mathcal{P}^0 \) rather than just a local martingale. Due to \( \mathbb{E}^0 \Gamma'_0 = \mathbb{E}^0 \Gamma'_0 = 1 \), the process \( \{\Gamma'_t\} \) is a progressive density process and defines the probability measure \( \mathcal{P}^{s,\ell} \) via the Radon-Nikodym derivative

\[
\frac{d\mathcal{P}^{s,\ell}}{d\mathcal{P}^0}|_{\mathcal{F}_t} = \Gamma'_t.
\]

By Girsanov’s theorem

\[
\left\{ Z_t^T = \tilde{W}_t^T - \int_0^t \tilde{\Theta}_u du : t \geq 0 \right\}
\]

follows a bidimensional, standard Brownian motion under the measure \( \mathcal{P}^{s,\ell} \). The linearity of the (Riemann-) integral implies

\[
M\left( \begin{pmatrix} Z_t^X \\ Z_t^K \end{pmatrix} \right) = Z_t^T = M\left( \tilde{W}_t - \int_0^t \tilde{\Theta}_u du \right) = M\left( \frac{\tilde{W}_t^X}{\tilde{W}_t^K} + \left( \int_0^t \tilde{\Theta}_u,1 du \right) \right).
\]

Therefore, for each \( t \geq 0 \)

\[
dZ_t^X = \frac{dX_t - K_t \alpha_s dt}{K_t \sigma_X} \quad \text{and} \quad dZ_t^K = \frac{dK_t - K_t \mu_\ell dt}{K_t \sigma_K}
\]

are the increments of a standard Brownian motion under \( \mathcal{P}^{s,\ell} \) with instantaneous correlation \( \rho dt \). In the following, we say the measure \( \mathcal{P}^{s,\ell} \) is induced by the processes \( \{s\}, \{\ell\} \). Note that all probability measures of the family \( \{\mathcal{P}^{s,\ell}\}_{\{s\},\{\ell\}} \) are mutually equivalent, in that they share the same null sets.

### B.2 Proof of Proposition 2.1

**Proof.** Consider an incentive compatible contract \( \Pi \equiv \{(C), \{s\}, \{\ell\}, \tau\} \). Further, assume in the following without loss of generality that \( \mathbb{F} \) is the filtration generated by \( \{X\}, \{K\} \), in that \( \mathcal{F}_t = \sigma(X_s, K_s : 0 \leq s \leq t) \). Then, the agent’s continuation utility at time \( t \) (under the principal’s information) is defined by

\[
W_t(\Pi) \equiv \mathbb{E}^{s,\ell}_t\left[ \int_t^\tau e^{-\gamma(z-t)} dC_z + \int_t^\tau e^{-\gamma(z-t)} K_z (C(s_z, \ell_z) - C(s_z, \ell_z)) dz \right],
\]

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where \( \mathbb{E}^{s,\ell}_t(\cdot) \) denotes the conditional expectation given \( \mathcal{F}_t \), taken under the probability measure \( \mathcal{P}^{s,\ell} \) induced by \( \{s\} \) and \( \{\ell\} \). Define for \( t \leq \tau \):

\[
\Gamma_t(\Pi) \equiv \mathbb{E}^{s,\ell}_t[W_0(\Pi)] = \int_0^t e^{-\gamma s} dC_z + \int_0^t e^{-\gamma s} K_z (c(s_z, \ell_z) - c(\hat{s}_z, \hat{\ell}_z)) dz + e^{-\gamma t} W_t(\Pi). \tag{A1}
\]

By construction, \( \{\Gamma_t(\Pi) : 0 \leq t \leq \tau\} \) is a square-integrable martingale under \( \mathcal{P}^{s,\ell} \), progressive with respect to \( \mathbb{F} \). In the following, we will invoke incentive compatibility, i.e., \( s_t = \hat{s}_t, \ell_t = \hat{\ell}_t \), whenever no confusion is likely to arise.

Next, observe that any sigma-algebra is invariant under an injective transformation of its generator. In particular, let \( M \in \mathbb{R}^{2 \times 2} \) an invertible, deterministic matrix with \( \det(M) \neq 0 \) and note that

\[
F_t = \sigma(X_t, K_t : s \leq t) = \sigma(Z^1_t, Z^2_t : s \leq t) = \sigma(Z_s : s \leq t) = \sigma(M \cdot Z_s : s \leq t)
\]

with \( Z_t \equiv (Z^1_t, Z^2_t)^\prime \). Here,

\[
dZ^1_t \equiv \frac{dX_t - K_t \sigma X_t dt}{K_t \sigma X_t} \quad \text{and} \quad dZ^2_t \equiv \frac{dK_t - K_t \sigma K_t dt}{K_t \sigma K_t} \tag{A2}
\]

are the increments of a standard Brownian motion under the probability measure \( \mathcal{P}^{s,\ell} \). Note that \( dZ^1_t = dZ^X_t \) and \( dZ^2_t = dZ^K_t \) whenever \( a_t = \hat{a}_t \) for all \( a \in \{s, \ell\} \).

As in the previous section, let the covariance matrix \( \Sigma(Z_t) = C t \) and employ a Cholesky decomposition \( M' M = C^{-1} \). We have already shown that \( \{Z^T_t \equiv M Z_t : 0 \leq t \leq \tau\} \) follows a bidimensional, standard Brownian-motion under \( \mathcal{P}^{s,\ell} \), where both components are mutually independent. By the martingale representation theorem (see e.g. Shreve (2004)), there exists a bidimensional process \( \{b_t\}_{t \geq 0} \), progressively measurable with respect to \( \mathbb{F} \), such that

\[
d\Gamma_t(\Pi) = e^{-\gamma t} b'_t \cdot dZ^T_t = e^{-\gamma t} b'_t \cdot M M^{-1} \cdot dZ^T_t = e^{-\gamma t} K_t (\beta^s_t \sigma X dZ^1_t + \beta^\ell_t \sigma K dZ^2_t),
\]

where we exploit the linearity of the Itô integral—i.e. \( d(M Z^T_t) = M dZ^T_t \)—and set \((\beta^s_t \sigma X, \beta^\ell_t \sigma K) \equiv b'_t M / K_t \) for all \( t \). Combining with equation (A1), one can verify that

\[
d\Gamma_t(\Pi) = e^{-\gamma t} K_t (\beta^s_t \sigma X dZ^1_t + \beta^\ell_t \sigma K dZ^2_t)
\]

\[
= e^{-\gamma t} - \gamma e^{-\gamma t} W_t(\Pi) dt + e^{-\gamma t} dW_t(\Pi)
\]

and thus equation (7) holds after rearranging. Indeed, since the right hand side of (7) satisfies a Lipschitz-condition under the usual regularity conditions (i.e. square integrability of \( \{C\} \) and \( \{s\}, \{\ell\} \) of bounded variation), \( \{W\} \) is the unique strong solution to the stochastic differential equation (7).

Next, we provide necessary and sufficient conditions for the contract \( \Pi \) to be incentive compatible. For this purpose, let the recommended investment processes \( \{s\} \) and \( \{\ell\} \) and the expected payoff of the agent at time \( t \) be \( W_t \), when following the recommended strategy from time \( t \) onwards. Further, let \( \{\hat{s}\} \) and \( \{\hat{\ell}\} \) represent the actual investment processes, which may in principle differ from \( \{s\} \) and \( \{\ell\} \). We have

\[
W_t \equiv \mathbb{E}^{s,\ell}_t \left[ \int_t^T e^{-\gamma(z-t)} dC_z \right].
\]

Recall that \( \mathbb{E}^{s,\ell}_t \) denotes the expectation, conditional on the filtration \( \mathcal{F}_t \), taken under the probability
measure $\mathcal{P}^{s,\ell}$. As shown above, the process $\{W\}$ solves the stochastic differential equation:

$$dW_t = \gamma W_t dt + \beta_t^\ell (dX_t - K_t \alpha_s dt) + \beta_t^\ell (dK_t - K_t \mu_{\ell} dt) - dC_t.$$ 

We can rewrite this stochastic differential equation as

$$dW_t + dC_t = \gamma W_t dt + K_t \beta_t^\ell \left[ \alpha (s_t - s_t) dt + \sigma_X dZ_t^X \right] + K_t \beta_t^\ell \left[ \mu (\ell_t - \ell_t) dt + \sigma_K dZ_t^K \right]$$
with

$$dZ_t^X = \frac{dX_t - K_t \alpha_s dt}{K_t \sigma_X} \quad \text{and} \quad dZ_t^K = \frac{dK_t - K_t \mu_{\ell} dt}{K_t \sigma_K}.$$ 

Girsanov’s theorem implies now that $dZ_t^X = \frac{dX_t - K_t \alpha_s dt}{K_t \sigma_X}$ and $dZ_t^K = \frac{dK_t - K_t \mu_{\ell} dt}{K_t \sigma_K}$ are the increments of a standard Brownian motion under the measure $\mathcal{P}^{s,\ell}$ induced by $(\{\hat{s}\}, \{\hat{\ell}\})$.

Next, define the auxiliary gain process

$$g_t = g_t(\{\hat{s}\}, \{\hat{\ell}\}) \equiv \int_0^t e^{-\gamma z} dC_z - \int_0^t e^{-\gamma z} K_z (C(s_z, \hat{\ell}_z) - C(s_z, \ell_z)) dz + e^{-\gamma t} W_t$$
and recall that $W_\tau = 0$. Now, note that the agent’s actual expected payoff under the strategy $(\{\hat{s}\}, \{\hat{\ell}\})$ reads

$$W_0' \equiv \max_{\{\hat{s}\}, \{\ell\}} \mathbb{E}^{\hat{s},\hat{\ell}} \left[ \int_0^\tau e^{-\gamma z} dC_z - \int_0^\tau e^{-\gamma z} K_z (C(s_z, \hat{\ell}_z) - C(s_z, \ell_z)) dz \right]$$

$$= \max_{\{\hat{s}\}, \{\ell\}} \mathbb{E}^{\hat{s},\hat{\ell}} \left[ g_\tau(\{\hat{s}\}, \{\ell\}) \right].$$

We obtain

$$e^{\gamma t} g_t = K_t \left[ C(s_t, \ell_t) - C(s_t, \hat{\ell}_t) \right] dt$$
$$+ K_t \left[ \alpha \beta_t^s (s_t - s_t) + \mu \beta_t^\ell (\ell_t - \hat{\ell}_t) \right] dt + K_t \left[ \beta_t^s \sigma_X dZ_t^X + \beta_t^\ell \sigma_K dZ_t^K \right]$$
$$\equiv \mu_t^0 dt + K_t \left[ \beta_t^s \sigma_X dZ_t^X + \beta_t^\ell \sigma_K dZ_t^K \right].$$

It is now easy to see that, when choosing $\hat{s}_t = s_t, \hat{\ell}_t = \ell_t$, the agent can always ensure that $\mu_t^0 = 0$, in which case $\{g_z\}_{z \geq 0}$ follows a martingale under $\mathcal{P}^{s,\ell}$. Hence,

$$W_0' = \max_{\{\hat{s}\}, \{\ell\}} \mathbb{E}^{\hat{s},\hat{\ell}} \left[ g_\tau(\{\hat{s}\}, \{\ell\}) \right] \geq \mathbb{E}^{s,\ell} \left[ g_\tau(\{s\}, \{\ell\}) \right] = W_0.$$

The inequality is strict if and only if there exist processes $(\hat{s}, \hat{\ell})$ and a stopping time $\tau'$ with $\mathcal{P}^{s,\ell}(\tau' < \tau) > 0$ such that $\mu_{\tau'}^0 > 0$. This arises because then there also exists a set $A \subseteq [0, \tau) \times \Omega$ with

$$\mu_t^G (\omega) > 0 \quad \text{for all} \quad (t, \omega) \in A \quad \text{and} \quad \mathcal{L} \otimes \mathcal{P}^{s,\ell}(A) > 0,$$
where $\mathcal{L}$ is the Lebesgue-measure on on the Lebesgue sigma-algebra in $\mathbb{R}$. Because $\mathcal{P}^{s,\ell}(\tau < \infty)$ for
all admissible $\{\hat{s}\}, \{\hat{\ell}\}$ it follows that $e^{-\gamma t} \mu_t^\beta(\omega) > 0$ for all $(t, \omega) \in \mathcal{A}$. Whence,

$$W'_0 \geq \int_A e^{-\gamma z} \mu_z^2(\omega) d(\mathcal{L}(z) \otimes P^{\hat{s},\hat{\ell}}(\omega)) + W_0 > W_0.$$ 

In case $W'_0 > W_0$, either $\hat{s}_z(\omega) \neq s_z(\omega)$ or $\hat{\ell}_z(\omega) \neq \ell_z(\omega)$ on the set $A$, which has positive measure, so that $\Pi$ is not incentive compatible.

Hence, for $\Pi$ to be incentive compatible, it must for all $t \geq 0$ (almost surely) hold that

$$\max_{s_t, \ell_t} \left\{ \alpha \beta^p_t(s_t - s_t) + \mu \beta^\ell_t(\ell_t - \ell_t) + [C(s_t, \ell_t) - C(\hat{s}_t, \hat{\ell}_t)] \right\} = 0$$

or equivalently

$$(s_t, \ell_t) \in \arg \max_{s_t, \ell_t} \left\{ \alpha \beta^p_t(s_t - s_t) + \mu \beta^\ell_t(\ell_t - \ell_t) + [C(s_t, \ell_t) - C(\hat{s}_t, \hat{\ell}_t)] \right\}$$

for given $\beta^p_t, \beta^\ell_t$. After going through the maximization, we obtain that this is satisfied if $C(s_t, \ell_t) = \beta^p_t \alpha$ and $C_t(s_t, \ell_t) = \beta^\ell_t \mu$, in case $(s_t, \ell_t) \in (0, s_{\max}) \times (0, \ell_{\max})$. If $a_t \in \{s_t, \ell_t\}$ is not interior, in that $a_t = a_{\max}$ for $a \in \{s, \ell\}$, then $a_t = a_{\hat{a}}$ solves the above maximization problem if and only if $\beta^p_t \alpha \geq C(s_t, \ell_t)$, if $a_t = s_t$, or $\beta^\ell_t \mu \geq C(s_t, \ell_t)$, if $a_t = \ell_t$. It evidently suffices here to consider first-order optimality, so that the result follows.

**B.3 Proof of Proposition 2.2**

In this section, we proceed as follows. First, we represent $P(W, K)$ as a twice continuously differentiable solution of a HJB-equation and then show that there exists a function $p \in C^2$, such that $P(W, K) = K p(w)$ and $p(w)$ solves the 'scaled' HJB-equation (11). Second, we verify that $P(W, K)$ or equivalently $p(w)$ with corresponding payout threshold $\overline{w}$ and $w_0 = \overline{w}^*$ characterizes indeed the optimal contract $\Pi^*$. Since we focus on incentive compatible contracts, we will work in the following—unless otherwise mentioned—with the measure $P^* \cdot \omega^*$ induced by optimal investment $(\{s^*\}, \{\ell^*\})$. For convenience, we will denote this measure by $\mathcal{P}$, if no confusion is likely to arise. We follow an analogous convention concerning the expectation operator, where we will just write $\mathbb{E}_t(\cdot)$ instead of $\mathbb{E}^{s,\ell^*}(\cdot|F_t)$.

**B.3.1 Scaling of the value function**

Given the optimal control and stopping problem (6), suppose that the principal’s value function $P(W, K)$ satisfies the HJB-equation

$$r P = \max_{s_t, \ell_t, \beta^p, \beta^\ell} \left\{ \alpha s_K - K C(s_t, \ell_t) + P_W \gamma w + P_K \mu \ell K + \frac{1}{2} \left( P_{WW} \left[ (\beta^p \sigma_X K)^2 + (\beta^\ell \sigma_X K)^2 + 2 \rho \sigma_X \sigma_K (K^2 \beta^p \beta^\ell) \right] + 2 P_{WK} \left[ (\sigma_X K)^2 \beta^\ell + \rho \sigma_X \sigma_K K^2 \beta^p \right] \right) \right\}$$

in some region $S \subset \mathbb{R}^2$, subject to the boundary conditions

$$P(0, K) = R K, P(W, 0) = 0, P_W(\overline{W}, K) = -1, P_{WW}(\overline{W}, K) = 0.$$
where the expectation solution which implies the HJB-equation (11) and its boundary conditions.

In the following, we will assume that (11) admits an unique, twice continuously differentiable solution \( p(\cdot) \) on \([0, \overline{w}]\). A formal existence proof is beyond the scope of the paper and therefore omitted.\(^\text{19}\)

We first rewrite the principal’s problem (6) in a convenient manner. Let

\[ \Psi_t = (\rho \sigma_K t, \sigma_K t) \quad \text{and} \quad \tilde{\Psi}_t = M \Psi_t, \]

where \( M' M = C^{-1} \) and \( Ct \) is the covariance matrix of \((Z_t^X, Z_t^K)\). Next, define the equivalent, auxiliary probability measure \( \tilde{P} \) according to the Radon-Nikodym derivative

\[ \left( \frac{d\tilde{P}}{dP} \right) = \exp \left\{ \int_0^t \tilde{\Psi}_u du - \frac{1}{2} \int_0^t ||\tilde{\Psi}_u||^2 du \right\}. \]

By arguments similar to those in Appendix B.1, Girsanov’s theorem implies that

\[ \tilde{Z}_t^X = Z_t^X - \rho \sigma_K t \quad \text{and} \quad \tilde{Z}_t^K = Z_t^K - \sigma_K t \]

are both standard Brownian motions with correlation \( \rho t \) under \( \tilde{P} \). An application of Itô’s Lemma consequently yields that the scaled continuation value \( \{w\} \) evolves according to

\[ dw_t + dc_t = (\gamma - \mu t) w_t dt + \beta_t^s \sigma_t X d\tilde{Z}_t^X + (\beta_t^\ell - \Gamma_t) \sigma_t d\tilde{Z}_t^K \]

under \( \tilde{P} \). Finally, for \( \psi_t \equiv rt - \mu \int_0^t \ell_s dz \) we are able to rewrite the principal’s problem (6) as

\[ \max_{\{c\}, \{s\}, \{\ell\}, \{w\} \in \mathbb{R}^{+}} \tilde{E} \left[ \int_0^\tau e^{-\psi_t (\alpha s_t - C(s_t, \ell_t))} dt - \int_0^\tau e^{-\psi_t} dc_t + e^{-\psi_t} R \right| w_0 = w^* \],

where the expectation \( \tilde{E}[] \) is taken under the equivalent, auxiliary measure \( \tilde{P} \). Here, \( dc_t \equiv dC_t/K_t \equiv \max\{w_t - \overline{w}, 0\} \). The stated integral expression is implied by following Lemma.

**Lemma 1.** Suppose \( \{w\} \) is the unique, strong solution to the stochastic differential equation

\[ dw_t = \delta_t dt + \Delta_t w_t dt - dc_t + (\beta_t^s - \Gamma_t) \sigma_t d\tilde{Z}_t^X + \beta_t^\ell \sigma_t X d\tilde{Z}_t^X \]

for \( t \leq \tau \), standard Brownian motions \( \{Z_t^X\}, \{Z_t^K\} \) with correlation \( \rho \) and progressive processes \( \{\delta\}, \{\Delta\}, \{\beta^s\}, \{\beta^\ell\} \) of bounded variation.\(^\text{20}\) Assume that \( dw_t = 0 \) for \( t > \tau \) where \( \tau = \min\{t \geq 0 : w_t = 0\} \). Furthermore, \( dc_t = \max\{w_t - \overline{w}, 0\} \) with threshold \( \overline{w} > 0 \). Let now \( g : [0, \overline{w}] \to \mathbb{R} \) of bounded variation. Then the twice continuously differentiable function \( f : [0, \overline{w}] \to \mathbb{R} \) (i.e. \( f \in C^2 \))

\(^{19}\)Indeed, the possible discontinuities of the functions \( s(\cdot), \ell(\cdot) \) cause technical complications. If \( s_{\max}, \ell_{\max} \) are sufficiently large, this problem is not present anymore. Then, the existence and uniqueness of the solution follow from the Picard-Lindelöf theorem, since the required Lipschitz condition is evidently satisfied.

\(^{20}\)We call a process \( \{Y\} \) ’of bounded variation’ if it can be written as the difference of two almost surely increasing processes. Similarly, a function \( F \in \mathbb{R}^{[a, b]} \) is called ’of bounded variation’ if it can be written as the difference of two increasing functions on the interval \([a, b]\).
Applying Itô’s Lemma, we obtain

\[ r_t f(w_t) = g(w_t) + f'(w_t)\delta_t + \Delta_t w_t + f''(w_t)\left[\sigma_K^2(\beta_t^\ell - w_t)^2 + (\beta_t^s\sigma X)^2 + 2\rho\sigma X\beta_t^s(\beta_t^\ell - w_t)\right] \quad (A3) \]

with boundary conditions \( f(0) = R, f'(\overline{w}) = -1 \) if and only if

\[
f(w) = \mathbb{E} \left[ \int_0^\tau e^{-\int_0^t r_u du} g(w_t) dt - \int_0^\tau e^{-\int_0^t r_u du} dc_t + e^{-\int_0^\tau r_u du} R \right| w_0 = w ]
\]

for a progressive discount rate process \( \{r\} \) of bounded variation.

Proof. Suppose \( f(\cdot) \) solves (A3). Define

\[ h_t \equiv \int_0^t e^{-\int_0^s r_u du}g(w_s)dz - \int_0^t e^{-\int_0^s r_u du} dc_z + e^{-\int_0^t r_u du} f(w_t). \]

Applying Itô’s Lemma, we obtain

\[
e^{\int_0^t r_u du} dh_t = \left\{ g(w_t) - r_t f(w_t) + \frac{f''(w_t)}{2}\left[\sigma_K^2(\beta_t^\ell - w_t)^2 + (\beta_t^s\sigma X)^2 + 2\rho\sigma X\beta_t^s(\beta_t^\ell - w_t)\right] + f'(w_t)(\delta_t + \Delta_t w_t) \right\} dt
- \left[ (1 + f'(w_t)) dc_t \right] + f'(w_t) \left[ d\beta_t^X \beta_t^s \sigma X + d\beta_t^K (\beta_t^\ell - w_t) \sigma_K \right].
\]

The first term in curly brackets equals zero because \( f(\cdot) \) solves (A3). Since \( f'(\overline{w}) = -1 \) and \( dc_t = 0 \) for all \( w_t \leq \overline{w} \), the second term in square brackets equals also zero and therefore \( \{h\} \) follows a martingale up to time \( \tau \). As a result, we have:

\[
f(w_0) = f(w) = h_0 = \mathbb{E}[h_\tau] = \mathbb{E} \left[ \int_0^\tau e^{-\int_0^s r_u du}g(w_t) dt - \int_0^\tau e^{-\int_0^s r_u du} dc_t + e^{-\int_0^\tau r_u du} R \right| w_0 = w ]
\]

The result follows. \( \square \)

B.3.2 Verification

Proof. Next, we verify the optimality of the contract \( \Pi^* \) among all contracts \( \Pi \) satisfying incentive compatibility. To do so, we show that the principal obtains under any contract \( \Pi \in \mathbb{I} \) at most (scaled) payoff \( \hat{G}(\Pi)/K \leq p(w^*) \), with equality if and only if \( \Pi = \Pi^* \). Here, \( p(\cdot) \) solves the HJB-equation (11) with corresponding payout threshold \( \overline{w} \) and \( w_0 = w^* \).

Consider any incentive-compatible contract \( \Pi \equiv (\{C\}, \{s\}, \{\ell\}, \tau) \). For any \( t \leq \tau \), define its auxiliary gain process \( G_t \) as

\[
G_t(\Pi) = \int_0^t e^{-ru} (dX_u - C(s_u, \ell_u) du) - \int_0^t e^{-ru} dC_u + e^{-rt} P(W_t, K_t),
\]

where the agent’s continuation payoff evolves according to (7). Recall that \( w_t = \frac{W_t}{K_t} \) and \( P(W_t, K_t) = \frac{W_t}{K_t} \).
\( K_t p(w_t) \). Itô’s lemma implies that for \( t \leq \tau \):

\[
e^{rt} dG_t(\Pi)_{I_t} = \frac{e^{rt} dG_t(\Pi)}{K_t} = \left[ -(r - \mu P_t)p(w_t) + \alpha s_t - C(s_t, \ell_t) + p'(w_t)w_t(\gamma - \mu \ell_t) \right. \\
+ \frac{p''(w_t)}{2} \left[ (\beta_t^s \sigma X)^2 + \sigma_K^2 (\beta_t^f - w_t)^2 + 2 \rho \sigma_X \sigma_K \gamma_s (\beta_t^f - w_t) \right] \right] dt - (1 + p'(w_t))dC_t \\
+ \sigma_K (p(w_t) + p'(w_t)(\beta_t^f - w_t)) dZ_t^K + \sigma_X (1 + \beta_t^s p'(w_t)) dZ_t^X.
\]

Under the optimal investment and incentives, the first term in square bracket stays at zero always. Other investment and incentive policies will make this term negative (owing to the concavity of \( p \)). The second term is non positive since \( p'(w_t) \geq -1 \), but equal to zero under the optimal contract. Therefore, for the auxiliary gain process, we have

\[
dG_t(\Pi) = \mu_G(t) dt + e^{-rt} K_t \left[ \sigma_K (p(w_t) + p'(w_t)(\beta_t^f - w_t)) dZ_t^K + \sigma_X (1 + \beta_t^s p'(w_t)) dZ_t^X \right],
\]

where \( \mu_G(t) \leq 0 \). Due to our assumption of bounded sensitivities \( \{\beta^s\}, \{\beta^f\} \), it follows that

\[
\mathbb{E} \left( \int_0^t e^{-ru} (p(w_u) + p'(w_u)(\beta_u^f - w_u)) dZ_u^K \right) = \mathbb{E} \left( \int_0^t e^{-ru} (1 + \beta^s u p'(w_u)) dZ_u^X \right) = 0,
\]

which implies that \( \{G_t\}_{t \geq 0} \) follows a supermartingale. Furthermore, under \( \Pi \), investors’ expected payoff is

\[
\tilde{G}(\Pi) = \mathbb{E} \left[ \int_0^\tau e^{-ru} (dX_u - C(s_u, \ell_u) du) - \int_0^\tau e^{-ru} dC_u + e^{-rt} RK_t \right].
\]

As a result, we have that

\[
\tilde{G}(\Pi) = \mathbb{E} [G_\tau(\Pi)] \\
= \mathbb{E} \left[ G_{\tau \wedge t}(\Pi) + 1_{\{t \leq \tau\}} \left( \int_t^\tau e^{-rs} (dX_s - dC_s - C(s_s, \ell_s) ds) + e^{-rt} RK_s - e^{-rt} P(W_t, K_t) \right) \right] \\
= \mathbb{E} [G_{\tau \wedge t}(\Pi)] \\
+ e^{-rt} \mathbb{E} \left[ 1_{\{t \leq \tau\}} \mathbb{E}_t \left( \int_t^\tau e^{-r(s-t)} (dX_s - dC_s - C(s_s, \ell_s) ds) + e^{-r(\tau-t)} RK_s - P(W_t, K_t) \right) \right] \\
\leq G_0 + e^{-rt} \mathbb{E} \left[ P^{FB}(K_t) - W_t - P(W_t, K_t) \right] \\
\leq G_0 + e^{-rt} \left( P^{FB} - R \right) \mathbb{E} [K_t],
\]

where \( P^{FB} \equiv \frac{P^{FB}(K_t)}{K_t} \) is the (scaled) first best value. The inequalities follow from the supermartingale property of \( G_t \), the fact that the value of the firm with agency is below first best, and the fact that \( P^{FB} - w - p(w) \leq p^{FB} - R \). Since \( \mu \ell_{\text{max}} < r \), it follows that \( \lim_{t \to \infty} e^{-rt} \mathbb{E} [K_t] = 0 \). Therefore, letting \( t \to \infty \) yields \( G(\Pi) \leq G_0 \equiv P(W_0, K_0) = p(w_0)K_0 \) for all incentive compatible contracts. For the optimal contract \( \Pi^* \), the investors’ payoff \( \tilde{G}(\Pi^*) \) achieves \( P(W_0, K_0) = p(w_0)K_0 \) since the above weak inequality holds in equality when \( t \to \infty \). This completes the argument.
Proof of Proposition 2.3
B.3.3 Auxiliary Results

In this section, we prove the following auxiliary Lemma, which is key for establishing the concavity of the value function.

Lemma 2. Let \( p(\cdot) \) the unique, twice continuously differentiable solution to the HJB-equation (11) on the interval \( [0, \overline{w}] \) subject to the boundary conditions \( p(0) = R, \ p'(\overline{w}) = -1 \) and \( p''(\overline{w}) = 0 \). Further, assume the processes \{s, \ell\} are of bounded variation. Then it follows for any \( w_1 \in (0, \overline{w}] \) with \( p''(w_1) = 0 \) that \( p'(w_1) < 0 \) and that the policy functions \( s(\cdot), \ell(\cdot) \) are continuous in a neighbourhood of \( w_1 \).

Proof. We start with an important observation. Because the processes \{s, \ell\} are by hypothesis of bounded variation, they can be written as the difference of two almost surely increasing processes, such that \( a_t = a_t^1 - a_t^2 \) for all \( t \geq 0, a \in \{s, \ell\} \) and \( a_t^1 \) increases almost surely. By Froda’s theorem, each of the processes \{a\} has no essential discontinuity and at most countably many jump-discontinuities with probability one. Since \{w\} follows a Brownian semimartingale, this implies that any point of discontinuity of \( a(\cdot) \) can neither be an essential discontinuity nor can the set of discontinuity points of \( a(\cdot) \) be dense in \([0, \overline{w}]\) for all \( a \in \{s, \ell\} \).

We first prove that \( p'(w_1) < 0 \). Let us suppose to the contrary \( p'(w_1) \geq 0 \), hence \( w_1 < \overline{w} \). Note that for any \( \delta > 0 \) exists \( z \in (w_1 - \delta, w_1 + \delta) \) such that \( s(\cdot), \ell(\cdot) \) are continuous in a neighbourhood of \( z \), because discontinuity points do not form a dense set. Since \( p'(\cdot), p''(\cdot) \) are continuous, for any \( \varepsilon > 0 \) we can choose \( \delta > 0 \) and \( z \in (w_1 - \delta, w_1 + \delta) \) such that \( \min\{p'(z), p''(z)\} \geq -\varepsilon \). The HJB-equation (11) and the fact, that \( \ell(z) = \ell^{FB} \) is not necessarily optimal, imply

\[
(r - \mu \ell^{FB})p(z) \geq \max_{s \in [0, s_{\max}]} \left\{ \alpha s + p'(z)(\gamma - \mu \ell^{FB})z - C(s, \ell^{FB}) + p''(z)\Sigma(z) \right\}
\]

\[
\geq \max_{s \in [0, s_{\max}]} \left\{ \alpha s - \varepsilon(\gamma - \mu \ell^{FB})z - C(s, \ell^{FB}) + \Sigma(z) \right\}.
\]

Sending \( \varepsilon, \delta \to 0 \) such that \( s = s(z) = s_{\max} \geq s^{FB} \) and in particular for \( z = w_1 \):

\[
\alpha s - C(s, \ell^{FB}) \geq \alpha s^{FB} - C(s^{FB}, \ell^{FB}) \geq (r - \mu \ell^{FB})p^{FB}.
\]

Hence, there exists \( z \in [0, \overline{w}] \) such that \( p(z) \geq p^{FB} \), a contradiction.

Next, let us prove that \( \ell(\cdot) \) must be continuous in a neighbourhood of \( w_1 \) and assume the contrary that there is no neighbourhood of \( w_1 \), on which \( \ell(\cdot) \) is continuous. Since the set of discontinuities of \( \ell(\cdot) \) must be discrete (not dense), it is immediate that

\[
\ell_- \equiv \lim_{w \uparrow w_1} \ell(w) \neq \lim_{w \downarrow w_1} \ell(w) \equiv \ell_+,
\]

i.e. \( \ell(\cdot) \) has a jump discontinuity at \( w_1 \) itself. Without loss of generality, we will assume that \( \ell_- < \ell_+ \) and \( w_1 < \overline{w} \).\(^{22}\)

Note that for all \( \varepsilon > 0 \) there exists \( \delta > 0 \) such that for all \( z \in (w_1, w_1 + \delta) \) it holds that \( |\ell(z) - \ell_+| < \varepsilon \). The optimality of \( \ell(z) \) requires that \( \frac{\partial p(z)}{\partial t}|_{t=\ell(z)} \geq 0 \) with equality if \( \ell(z) \) is interior.

\(^{21}\)Froda’s theorem states that each real valued, monotone function has at most countably many points of discontinuity. It is clear that such a function cannot have an essential discontinuity, i.e. a point of oscillation.

\(^{22}\)Since \( p(\cdot) \) is extended linearly to the right of \( \overline{w} \), discontinuity to the right of \( \overline{w} \) is not an issue.
Due to the continuity of \(p''(\cdot)\), the limit \(\varepsilon \to 0\) yields \(\Gamma_\ell(w_1) \geq 0\) for
\[
\Gamma_\ell(w) = p(w) - p'(w)w + C_\ell(s, \ell_+) \quad \text{with} \quad C_\ell(s, \ell_+) = \frac{\partial C(s, \ell)}{\partial \ell}|_{\ell=\ell_+}
\]
In addition, for all \(\varepsilon > 0\) it must be that there exists \(\delta > 0\) such that for all \(x \in (w_1 - \delta, w_1)\) it holds that \(|\ell(x) - \ell_-| < \varepsilon\). Hence, for \(\varepsilon > 0\) sufficiently small, \(\ell(x) < \ell_{\max}\) and therefore \(\frac{\partial p(x)}{\partial \ell}|_{\ell=\ell(x)} = 0\), which implies together with the continuity of \(p''(\cdot)\) that \(\widehat{\Gamma}_\ell(w_1) = 0\) for
\[
\widehat{\Gamma}_\ell(w) = p(w) - p'(w)w + C_\ell(s, \ell_-).
\]
Next, observe that
\[
0 \leq \Gamma_\ell(w_1) - \widehat{\Gamma}_\ell(w_1) = -\lambda_\ell(\ell_+ - \ell_-).
\]
Then, it follows that \(\ell_- \geq \ell_+\), a contradiction.

Finally, assume that there is no neighbourhood of \(w_1\), on which \(s(\cdot)\) is continuous. Since the set of discontinuity points of \(s(\cdot)\) is discrete, this is equivalent to \(s_- \equiv \lim_{w \uparrow w_1} s(w) \neq \lim_{w \downarrow w_1} s(w) \equiv s_+\). Without loss of generality, suppose \(s_- > s_+\). Then, for all \(\varepsilon > 0\) there exists \(\delta > 0\) such that for all \(z \in (w_1, w_1 + \delta)\) it holds that \(|s(z) - s_+| < \varepsilon\). Optimality requires \(\frac{\partial p(z)}{\partial s}|_{s=s(z)} \geq 0\). Taking the limit \(\varepsilon \to 0\), we obtain \(\Gamma_s(w_1) \geq 0\) for \(\Gamma_s(w) = \alpha s(w) - C_s(s_+, \ell)\). Similarly, \(\widehat{\Gamma}_s(w_1) = 0\) for \(\widehat{\Gamma}_s(w) = s(w) + p'(w)C_s(s_+, \ell)\). Hence,
\[
0 \leq \Gamma_s(w_1) - \widehat{\Gamma}_s(w_1) = -\lambda_s(s_+ - s_-).
\]
Then, it follows that \(s_- \geq s_+\), a contradiction. \(\square\)

### B.3.4 Concavity of the value function

**Proof.** Since \(p''(\cdot)\) is continuous on \([0, \overline{w}]\) and \(\{s\}, \{\ell\}\) are of bounded variation, it follows that the mappings \(s(\cdot), \ell(\cdot)\) are continuous on \([0, \overline{w}]\) up to a discrete set with (Lebesgue-) measure zero. On the set, where \(s(\cdot), \ell(\cdot)\) are continuous, the envelope theorem implies now that \(p'''(\cdot)\) exists and is given by
\[
p'''(w) = \frac{(r - \gamma)p'(w) - p''(w)(w(\gamma - \mu \ell) - \sigma_k(\beta^\ell - w) - \rho \sigma_X \sigma_K \beta^s)}{\frac{1}{2}(\beta^s \sigma_X)^2 + \sigma_k^2(\beta^\ell - w)^2 + 2\rho \sigma_X \sigma_K \beta^s(\beta^\ell - w)}.
\]
We have to show that \(p''(w) < 0\) for all \(0 \leq w < \overline{w}\).

By Lemma 2 we know that \(s(\cdot), \ell(\cdot)\) are continuous in a neighbourhood of \(\overline{w}\). Then, we observe that \(p'''(w) \propto \gamma - r > 0\) due to \(\beta^s \geq \lambda_s > 0\) and thus \(p'''(\cdot) > 0\) in a neighbourhood of \(\overline{w}\). Hence, \(p''(w) < 0\) on an interval \((\overline{w} - \varepsilon, \overline{w})\) with appropriate \(\varepsilon > 0\).

Next, suppose there exists \(w_0 \in [0, \overline{w}]\) with \(p''(w_0) > 0\) and define \(w_1 = \sup\{w \in [0, \overline{w}] : p''(w) \geq 0\}\). By the previous step and continuity it follows that \(p''(w_1) = 0\) and \(w_1 < \overline{w}\). We obtain now from Lemma 2 that \(s(\cdot), \ell(\cdot)\) are continuous in a neighbourhood of \(w_1\) and that \(p'(w_1) < 0\). However, this implies \(p'''(w_1) > 0\) and therefore \(p'''(\cdot) > 0\) in a neighbourhood of \(w_1\). Thus, there exists \(w' > w_1\) with \(p''(w') > 0\), a contradiction to the definition of \(w_1\). This completes the proof. \(\square\)
C  Proofs of Propositions 3 and 4

Proof. The expressions for \( s = s(w), \ell = \ell(w) \) follow directly from the maximization of \( p(w) \) over \( s \in [0, s_{\text{max}}] \) and \( \ell \in [0, \ell_{\text{max}}] \) for a given \( w \), as indicated by the HJB-equation (11). Interior levels \( s(w), \ell(w) \) must solve the respective first order conditions of maximization, that is \( \frac{\partial p(w)}{\partial s}|_{s=s(w)} = 0 \) and \( \frac{\partial p(w)}{\partial \ell}|_{\ell=\ell(w)} = 0 \). After rearranging the FOCs of the maximization, one arrives at the desired expressions.

Due to \( p''(w) < 0 \) for all \( w < \overline{w} \) and \( p''(\overline{w}) = 0 \), it is immediate to see that \( s(w) \leq s_{FB} \), with the inequality holding as equality if and only if \( w = \overline{w} \). When \( \gamma - r \) and \( \sigma_K \) are sufficiently small, then \( p'''(w) > 0 \) for all \( w \) and due to

\[
\text{sign}\left( \frac{\partial s(w)}{\partial w} \right) = \text{sign}(p''(w))
\]

short-run investment increases in \( w \) under these circumstances.

Evaluating the HJB-equation at the boundary under the optimal controls yields:

\[
(r - \mu \ell)p(\overline{w}) + (\gamma - \mu \ell)\overline{w} = \alpha s - C(s, \ell).
\]

Hence, owing to \( \gamma > r \) and agency-induced termination, \( P(\tau < \infty) = 1: \)

\[
p(\overline{w}) + \overline{w} < \frac{\alpha s - C(s, \ell)}{r - \mu \ell} < p_{FB}.
\]

Since \( C_{\ell}(s_{FB}, \ell_{FB}) = \mu p_{FB} \) and \( C_{\ell}(s(\overline{w}), \ell(\overline{w})) = \mu (p(\overline{w}) + \overline{w}) \), it is clear that \( \ell(\overline{w}) < \ell_{FB} \) and therefore by continuity, that \( \ell(w) < \ell_{FB} \) in a left-neighbourhood of \( \overline{w} \).

\[\square\]

D  Proof of Proposition 5

We prove part i) and ii) separately and start with an auxiliary Lemma.

D.1  Proof of Proposition 5 - Auxiliary Results

Lemma 3. Under the optimal contract for an arbitrary parameter \( \theta \notin \{r, \mu\} \):

\[
\frac{\partial p(w)}{\partial \theta} = E\left\{ \int_0^T e^{-rt+\mu \int_0^t \ell_t ds} \left[ \frac{\partial \alpha}{\partial \theta} s_t - \frac{\partial C(s_t, \ell_t)}{\partial \theta} + (p'(w_t)w_t + p(w_t)) \frac{\partial (\gamma - \mu \ell_t)}{\partial \theta} \right] \right. \\
+ \left. \frac{p''(w_t)}{2} \frac{\partial}{\partial \theta} \left[ (\beta^s \sigma_X)^2 + \sigma_K^2 (\beta^l - w_t)^2 + 2 \rho \sigma_X \sigma_K \beta^s (\beta^l - w_t) \right] \right\} dt \bigg| w_0 = w.
\]

Proof. Let \( w \in [0, \overline{w}], \theta \notin \{r, \mu\} \) and \( s = s(w), \ell = \ell(w), \beta^s = \beta^s(w), \beta^l = \beta^l(w) \) be determined by the HJB-equation (11). Then, by the envelope theorem

\[
\frac{\partial p(w)}{\partial s} \frac{\partial s(w)}{\partial \theta} = \frac{\partial p(w)}{\partial \ell} \frac{\partial \ell(w)}{\partial \theta} = 0
\]

\[\text{For convenience, we suppress the dependence of } p(\cdot), w \text{ on } \theta \text{ in the notation.}\]
and therefore
\[
(r - \mu \ell) \frac{\partial p(w)}{\partial \theta} = \frac{\partial \alpha}{\partial \theta} s - \frac{\partial C(s, \ell)}{\partial \theta} + (p(w) + p'(w)w) \frac{\partial (\gamma - \mu \ell)}{\partial \theta} + w(\gamma - \mu \ell) \frac{\partial p(w)}{\partial \theta} \\
+ \frac{p''(w)}{2} \frac{\partial}{\partial \theta} \left[ (\beta^2 \sigma_X)^2 + 2 \rho \sigma_X \beta \sigma_X (\beta^2 - w)^2 \right] \\
+ \frac{\partial^2}{\partial w^2} \frac{\partial p(w)}{\partial \theta} \left[ (\beta^2 \sigma_X)^2 + 2 \rho \sigma_X \beta \sigma_X (\beta^2 - w)^2 \right].
\]

Note that we used
\[
\frac{\partial^k \partial p(w)}{\partial w^k \partial \theta} = \frac{\partial}{\partial \theta} \frac{\partial^k p(w)}{\partial w^k}
\]
for \( k \in \{1, 2\} \), i.e. we changed the order of (partial) differentiation, which is possible since \( p \) is sufficiently smooth.

The above ODE admits a unique solution subject to the boundary conditions
\[
\frac{\partial p(w)}{\partial \theta} \Big|_{w=0} = 0 \quad \text{and} \quad \frac{\partial p'(w)}{\partial \theta} \Big|_{w=\bar{w}} = \frac{\partial}{\partial w} \frac{\partial p(w)}{\partial \theta} |_{w=\bar{w}} = 0.
\]

and we are able to invoke Lemma 1 to arrive at the desired expression. 

D.2 Proof of Proposition 5 i) - Part I

Let us assume \( \sigma_X = 0 \) and state the following Lemma:

Lemma 4. Assume \( \sigma_X = 0 \). Hence, short-run investment \( s(w) \) is contractible and constant over time. Then, it must be that \( \beta^\ell > w \).

Proof. Without loss of generality, we normalize \( s(w) = s \equiv 1 \) for all \( w \) and set \( \alpha = \lambda s = 1 \). The proof is split in several parts. Part i) shows that \( \beta^\ell(\bar{w}) \neq \bar{w} \). Part ii) shows that \( \beta^\ell(w) \neq w \) and part iii) concludes by showing \( \beta^\ell(w) > w \) for all \( w \in [0, \bar{w}] \).

i) Let us first show that \( \beta^\ell(\bar{w}) = \lambda s \ell(\bar{w}) \neq \bar{w} \). Define \( \ell(\bar{w}) \equiv \ell \) and suppose to the contrary \( \lambda s \ell = \bar{w} \). Then:
\[
p(\bar{w}) = \frac{1}{r - \mu \ell} \left( \alpha s - \frac{1}{2} (\lambda s^2 + \lambda s \lambda s \mu) - \bar{w}(\gamma - \mu \ell) \right).
\]

Let \( \varepsilon > 0 \) and consider the Taylor-expansion of \( p(\bar{w} - \varepsilon) \) around \( p(\bar{w}) \), given by \( p(\bar{w} - \varepsilon) = p(\bar{w}) + \varepsilon + o(\varepsilon^3) \). Further, define \( \ell_\varepsilon \equiv \ell(\bar{w} - \varepsilon) \) and note that in optimum \( \beta^\ell(\bar{w} - \varepsilon) = \lambda s \ell_\varepsilon + o(\varepsilon) \) by continuity. Hence:
\[
(r - \mu \ell_\varepsilon) p(\bar{w} - \varepsilon) = \alpha s - \frac{\lambda s \alpha s^2}{2} \left( - \frac{1}{2} \lambda \ell_\varepsilon \mu + p'(\bar{w} - \varepsilon) \left( \gamma - \mu \ell_\varepsilon \right) \right) \\
+ \frac{\sigma^2_K}{2} (\lambda s \ell_\varepsilon + o(\varepsilon) - \bar{w} + \varepsilon)^2 p''(\bar{w} - \varepsilon) \\
= \alpha s - \frac{\lambda s \alpha s^2}{2} \left( - \frac{1}{2} \lambda \ell_\varepsilon \mu + \left( -1 + o(\varepsilon^2) \right) \left( \gamma - \mu \ell_\varepsilon \right) \right) \\
+ \frac{\sigma^2_K}{2} (\lambda s \ell_\varepsilon - \bar{w} + o(\varepsilon))^2 p''(\bar{w} - \varepsilon),
\]
where we used that \( p'(\bar{w} - \varepsilon) = p'(\bar{w}) - \varepsilon p''(\bar{w}) + o(\varepsilon^2) \).
Combining the above and utilizing the Taylor expansion for \( p(\overline{w} - \varepsilon) \) around \( p(\overline{w}) \) yields:

\[
p(\overline{w} - \varepsilon)\mu(\ell - \ell) = \varepsilon(r - \mu\ell) + (\gamma - \mu\ell)(\overline{w} - \varepsilon) - \overline{w}(\gamma - \mu\ell) + \frac{1}{2} \mu\lambda\ell(\ell^2 - \ell'^2) - \frac{\sigma^2}{2}(\lambda\ell\varepsilon - \overline{w} + o(\varepsilon))^2 p''(\overline{w} - \varepsilon) + o(\varepsilon^2) + o(\varepsilon^3).
\]

Next, note that \( \ell = \ell + \varepsilon\ell(\overline{w} - \varepsilon) + o(\varepsilon^2) \), in case \( \ell(\cdot) \) is differentiable, which is guaranteed for \( \varepsilon > 0 \) sufficiently small. This yields

\[
\mu p(\overline{w} - \varepsilon)(-\varepsilon\ell'(\overline{w} - \varepsilon)) = \varepsilon(r - \gamma) - \overline{w}\mu\varepsilon\ell'(\overline{w} - \varepsilon) + o(\varepsilon^2)
\]

\[
\quad\iff o(\varepsilon) - \mu(p(\overline{w} - \varepsilon) + \overline{w})\ell'(\overline{w} - \varepsilon) = r - \gamma.
\]

If \( \ell(\overline{w}) = \ell_{\text{max}} \), then it must either be that \( \ell'(\overline{w} - \varepsilon) = o(\varepsilon) \) for \( \varepsilon \) sufficiently small, which leads to \( \gamma - r = o(\varepsilon) \) and thereby a contradiction, or \( \lim_{w \uparrow \overline{w}} \ell'(w) > 0 \).

If \( \ell(\overline{w}) < \ell_{\text{max}} \) or \( \lim_{w \uparrow \overline{w}} \ell'(w) > 0 \), then \( \ell(\overline{w} - \varepsilon) \) solves the following first-order condition of maximization after utilizing the boundary conditions at \( w = \overline{w} \):

\[
\mu p(\overline{w}) + \mu\overline{w} - \lambda\ell\mu\ell(\overline{w}) + o(\varepsilon^2) = 0.
\]

Invoking the implicit function theorem, we can differentiate the above identity wrt. \( w = \overline{w} \), so as to obtain \( \ell'(\overline{w}) = 0 \) as well as \( \ell''(\overline{w}) = 0 \). Then, by Taylor’s theorem, \( \ell'(\overline{w} - \varepsilon) = o(\varepsilon^2) \) and we obtain the desired contradiction. This concludes the proof.

ii) Let us assume that there exists now \( w < \overline{w} \) with \( \beta^\ell = w \), in which case the HJB-equation under the optimal control reads:

\[
(r - \mu\ell(w))p(w) = \alpha s - \frac{\lambda_s \alpha s^2}{2} - \frac{\lambda_N \ell^2 \mu}{2} + p'(w)w(\gamma - \mu\ell(w)).
\]

Due to \( p'(w) \geq -1 \) i.e., since scaled payouts at rate \( w(\gamma - \mu\ell) \) and this way keeping \( w_t = w \) constant for all future times \( t \) is always an option but not necessarily optimal – it follows that

\[
p(w) \geq \frac{1}{r - \mu\ell}(\alpha s - \frac{\lambda_s \alpha s^2}{2} - \frac{\lambda_N \ell^2 \mu}{2} - w(\gamma - \mu\ell)).
\]

Furthermore,

\[
p(w) < p(\overline{w}) - (w - \overline{w}) = \frac{1}{r - \mu\ell}(\alpha s - \frac{\lambda_s \alpha s^2}{2} - \frac{\lambda_N \ell^2 \mu}{2} - w(\gamma - r) - w(r - \mu\ell))
\]

\[
< \frac{1}{r - \mu\ell}(\alpha s - \frac{\lambda_s \alpha s^2}{2} - \frac{\lambda_N \ell^2 \mu}{2} - w(\gamma - r) - w(r - \mu\ell))
\]

\[
= \frac{1}{r - \mu\ell}(\alpha s - \frac{\lambda_s \alpha s^2}{2} - \frac{\lambda_N \ell^2 \mu}{2} - w(\gamma - \mu\ell)),
\]

where the first inequality is due to strict concavity and the second one due to \( w < \overline{w} \). This yields the desired contradiction.

iii) Eventually, let us assume that \( \beta^\ell = \ell(w)\lambda_\ell < w \) and define for this sake the function \( \chi(w) = \beta^\ell(w) - w \). At \( w = 0 \), it is evident that \( \chi(w) \geq 0 \). If it were that \( \chi(w) = 0 \) for some \( w > 0 \), then it must either be that \( \chi(\overline{w}) = 0 \), which contradicts part i), or \( \chi(w) = 0 \) for \( 0 < w < \overline{w} \),
which contradicts part ii). This proves the Lemma.

\[ \blacksquare \]

D.3 Proof of Proposition 5 i) - Part II

Proof. Here, we prove that \( \sigma_K = 0 \) and \( \sigma_X > 0 \) imply that \( \ell(w) < \ell^{FB} \), provided investment is not at the corner.

For interior levels, \( \ell = \ell(w) \) solves the First-Order condition of maximization \( \frac{\partial p(w)}{\partial \ell} = 0 \), so that

\[
\mu(p(w) - p'(w)w) - \lambda_\ell \mu \ell + p''(w)\ell(\lambda_\ell \sigma_K)^2 - p''(w)w\lambda_\ell \sigma_K^2 = 0.
\]

Because of \( p(w) - wp'(w) < p^{FB} \) and \( \lambda_\ell \ell > w \) and \( \ell^{FB} \) solves \( \mu p^{FB} - \lambda_\ell \mu \ell = 0 \), it is immediate to see that \( \ell(w) < \ell^{FB} \) for all \( w \in [0, \bar{w}] \). For corner levels, a similar argument applies, which readily yields \( \ell(w) \leq \ell^{FB} \).

\[ \blacksquare \]

Proof of Proposition 5 ii)

Proof. Let \( \theta \) an arbitrary set of model parameters and denote the family of solutions to the principal’s problem by \( \{ p_\theta, \bar{w}_\theta \} \). By Berge’s Maximum Theorem, \( \bar{w}_\theta \) is continuous wrt. (the value of) \( \theta \), in the standard Euclidean metric space on \( R \) and \( p^\theta \) is continuous in \( \theta \) on \( A^B \) with respect to the topology, induced by the norm \( ||\cdot||_\cdot, ||\cdot||_\infty \) where

\[
||f||_\infty = \sup_{x \in A} |f(x)|.
\]

Here, \( A, B \) are some compact subsets of \( R \). We choose \( A \) sufficiently large, so that \( \bar{w}_\theta \in R \) and \( 0 \in A \) for all considered \( \theta \). We may choose \( B \), so that \( p_\theta(w) \in B \) for all \( w \in [0, \bar{w}_\theta] \) for all considered \( \theta \). For brevity, we omit a formal introduction of the sets \( A, B \) and the associated notation in the following.

Let us start by considering the limit case \( \mu \to 0 \). That is, we study the family \( \{ p_\mu, \bar{w}_\mu \}_{\mu \geq 0} \) and take the limit \( \mu \to 0 \). The model in the limit case \( \mu \to 0 \) is well behaved, and features a value function \( p_0 \) with reflecting boundary \( \bar{w}_0 \geq 0 \). Due to continuity in \( \mu \), it follows that \( p_\mu \to p_0 \) and \( \bar{w}_\mu \to \bar{w}_0 \) as \( \mu \to 0 \). As a consequence, \n
\[
\ell(w) \to \frac{-wp'_0(w)\lambda_\ell \sigma_K^2}{-p''_0(w)(\lambda_\ell \sigma_K)^2} = \frac{w}{\lambda_\ell} > 0 \text{ for } \bar{w}_0 > w > 0,
\]

where we omit for simplicity indexing for the optimal controls, e.g., for \( \ell = \ell_\mu \). It can be verified that:

\[
\nabla(dw) = o(\sigma_X^2)dt,
\]

when \( \mu \to 0 \), so that the joint limit \( \sigma_X, \mu \to 0 \) would lead to a solution, where \( dw \) has no volatility and accordingly \( \bar{w}_0 = 0 \). That is, \( \lim_{\sigma_X \to 0} w_0 = 0 \). Hence, \( \sigma_X = 0 \Rightarrow w_0 = 0 \). Since the limit case \( \mu \to 0 \) corresponds to the model of DeMarzo and Sannikov (2006), we know that \( \sigma_X > 0 \Leftrightarrow w_0 > 0 \).

In order to take the limit \( \lim_{\mu \to 0} \ell^{FB} \), we have to use the rule of de L’Hopital, which yields

\[
\lim_{\mu \to 0} \frac{1}{\mu} \left[ r - \sqrt{r^2 - \frac{\mu \alpha}{(\lambda_\alpha \lambda_\ell)}} \right] = \lim_{\mu \to 0} \frac{1}{2\sqrt{r^2 - \frac{\mu \alpha}{(\lambda_\alpha \lambda_\ell)}}} \frac{\alpha}{2\lambda_\alpha \lambda_\ell r} = \frac{\alpha}{2\lambda_\alpha \lambda_\ell r}.
\]
To avoid clutter with subscripts, we omit indexing model quantities by \( \mu \), when it does not cause confusion.

We prove now the claim regarding \( \gamma \). Let us fix all parameters except \( \gamma \) and consider the (continuous) the family of solutions \( \{p_\gamma, \overline{w}_\gamma\}_{\gamma > r \geq 0} \), in the limit \( \mu \to 0 \). We obtain that

\[
\frac{\partial \overline{w}_\gamma}{\partial \gamma} = -\frac{1}{\gamma - r} \left( \overline{w}_\gamma + r \frac{\partial p_\gamma(\overline{w}_\gamma)}{\partial \gamma} \right),
\]

where by Lemma 3:

\[
\frac{\partial p_\gamma(\overline{w}_\gamma)}{\partial \gamma} = \mathbb{E} \left( \int_0^\tau e^{-rt} p'_\gamma(w_t) w_t dt \bigg| w_0 = \overline{w}_\gamma \right).
\]

Next, observe that

\[
A(\gamma) \equiv \overline{w}_\gamma + r \frac{\partial p_\gamma(\overline{w}_\gamma)}{\partial \gamma} \geq r \mathbb{E} \left( \int_0^\tau e^{-rt} (\overline{w}_\gamma - w_t) dt \bigg| w_0 = \overline{w}_\gamma \right) > 0,
\]

where it was used that \( p'_\gamma \geq -1 \) as well as \( \mathbb{P}(\tau < \infty) = 1 \). It follows that \( \overline{w}_\gamma + r \frac{\partial p_\gamma(\overline{w}_\gamma)}{\partial \gamma} > 0 \), so that \( \overline{w}_\gamma \) has – because of \( \sigma_X > 0 \) and \( \beta^s(w) = \lambda s F_B \) – strictly positive volatility at the boundary \( \overline{w}_\gamma \), the payout boundary \( \overline{w}_\gamma \) cannot constitute an absorbing state. Therefore, it cannot be that the above expectation tends to zero, as \( \gamma \to r \), so that \( A(\gamma) \not\in o(\gamma - r) \) and therefore

\[
\lim_{\gamma \downarrow r} A(\gamma) > 0.
\]

From there it follows that

\[
\frac{\partial \overline{w}_\gamma}{\partial \gamma} \leq \frac{A(\gamma)}{(\gamma - r)},
\]

and accordingly

\[
\lim_{\gamma \downarrow r} \frac{\partial \overline{w}_\gamma}{\partial \gamma} \leq \lim_{\gamma \downarrow r} \frac{A(\gamma)}{(\gamma - r)} = -\infty.
\]

Thus, the function \( \gamma \mapsto \overline{w}_\gamma \) – defined on \([r, \infty)\) – has a singularity (pole) at \( \gamma = r \), which implies \( \lim_{\gamma \downarrow r} \overline{w}_\gamma = \infty \).

By continuity, for any \( \mu > 0 \) sufficiently small there exists \( \gamma > r \) sufficiently low, so that the payout threshold \( \overline{w}_{\gamma,\mu} \) (dependent on \( \mu, \gamma \)) satisfies \( \overline{w}_{\mu,\gamma} > \frac{\alpha}{2\lambda_\tau \lambda_\ell r} \). Under these circumstances, there is \( 0 < \overline{w}_\gamma < \overline{w}_{\mu,\gamma} \) with

\[
\overline{w}_\gamma = \frac{\alpha}{2\lambda_\tau \lambda_\ell r}.
\]

Taking the limit yields:

\[
\lim_{\mu \to 0} \ell(\overline{w}_\gamma) > \lim_{\mu \to 0} \ell^{FB}.
\]

By continuity, there exist now \( \mu > 0 \) and \( \gamma > r \) sufficiently low and \( w \in (0, \overline{w}_{\gamma,\mu}) \), so that \( \ell(w) > \ell^{FB} \).

Let \( w^H \equiv \sup\{w : \ell(w) > \ell^{FB}\} \) and \( w^L \equiv \sup\{w : \ell(w) > \ell^{FB}\} \). Since \( \ell(\overline{w}_{\mu,\gamma}) < \ell^{FB} \) for any \( \mu > 0, \gamma > r \), it must be that \( w^H < \overline{w}_{\mu,\gamma} \) with \( \lim_{\mu \to \infty, \gamma \to r} w^H = \overline{w}_{\mu,\gamma} \). In addition, \( \lim_{\mu \to 0, \gamma \to r} w^L = \frac{\alpha}{2\lambda_\tau \lambda_\ell r} \), so that there exist \( \mu > 0 \) and \( \gamma > r \), ensuring the set \( \{w : \ell(w) > \ell^{FB}\} \) is convex, thereby concluding the proof.

\[\square\]
Proof of Proposition 5 iii)

Proof. We consider parameters are such that \( \sup \{ \ell(w) : w \in [0, \bar{w}] \} = \ell^{FB} \) and let \( \mu > 0 \), so that \( \ell(w) > 0 \) for any \( w \in (0, \bar{w}] \). Let us evaluate the HJB-equation at the boundary:

\[
(r - \mu \ell(\bar{w}))p(\bar{w}) = \frac{\alpha}{2\lambda_s} - (\gamma - \mu \ell(\bar{w}))\bar{w} - \frac{\lambda \mu \ell(\bar{w})^2}{2}.
\]

Differentiating this identity wrt. \( \sigma_i \) for \( i \in \{X, K\} \) leads to:

\[
\frac{\partial \bar{w}}{\partial \sigma_i} = \frac{r - \gamma}{r - \mu \ell(\bar{w})} \frac{\partial p(\bar{w})}{\partial \sigma_i}.
\]

Lemma 3 then implies:

\[
\begin{align*}
\frac{\partial p(\bar{w})}{\partial \sigma_K} & = \mathbb{E} \left( \int_0^\tau e^{-rt + \mu \int_0^t \ell_u du} p''(w_t)(\beta_t^e - w_t)^2 \sigma_K dt \middle| w_0 = \bar{w} \right) < 0 \\
\frac{\partial p(\bar{w})}{\partial \sigma_X} & = \mathbb{E} \left( \int_0^\tau e^{-rt + \mu \int_0^t \ell_u du} \left( p''(w_t)(\beta_t^s)^2 \sigma_X \right) dt \middle| w_0 = \bar{w} \right) < 0,
\end{align*}
\]

so that \( \bar{w} \) increases in \( \sigma_i \) for \( i \in \{X, K\} \). The claim follows due to continuity in parameter values \( \{\sigma_X, \sigma_K\} \).

E Proof of Proposition 6 and 7

We prove the two propositions separately. In both cases claim i) is trivial, since \( \sigma_K = 0 \) precludes risk-externalities between short- and long-run incentives. The proof of of Proposition 6 ii) is split in two parts.

E.1 Proof of Proposition 6 ii)

i) Proof. The first part of the proof aims to show that there is short-termism for \( \sigma_X \) sufficiently small. Let us assume that correlation is negative and that wlog of \( R > 0 \). Let us fix all parameters and consider the family of solution \( \{p_{\sigma_X, \bar{w}_{\sigma_X}}\} \), which is – by Berge’s Maximum Theorem – continuous in \( \sigma_X \) wrt. an appropriate topology, already discussed before. In the limit case \( \sigma_X \to 0 \), we have \( s(w) \to s^{FB} \) for all \( w \in [0, \bar{w}_0] \). Note that due to our assumption \( R > 0 \), it follows that \( \ell(0) > 0 \) and in addition \( p''(0) < 0 \), as \( \bar{w}_0 > 0 \) due to \( \sigma_K > 0 \). If we did not have \( R > 0 \), we could just consider the solution at a point nearby with \( \ell > 0 \), so that the assumption \( R > 0 \) is indeed wlog.

We can write

\[
s(w) = \frac{\alpha + p''(w) \rho \sigma_X \sigma_K \lambda_s \lambda_e \ell(w)}{\lambda_s \alpha - p''(w)(\lambda_s \sigma_X)^2}
\]

and it follows from the HJB-equation and lemma 3:

\[
p''_{\sigma_X}(w) = \frac{-p''(w)\alpha^2 \sigma_X}{[\lambda_s \alpha - p''(w)(\lambda_s \sigma_X)^2]^2} + o(w) \leq \frac{-p''(w)\alpha \sigma_X}{\lambda_s} + o(w) = o(\sigma_X) + o(w).
\]
Thus:

\[
\frac{\partial s(w)}{\partial \sigma_X} \propto \left[ \lambda_s \alpha - p''(w)(\lambda_s \sigma_X)^2 \right] p''(w) \rho \sigma_K \lambda_s \lambda_{t\ell}(w) \\
+ 2 \left[ \alpha + p''(w) \rho \sigma_X \sigma_K \lambda_s \lambda_{t\ell}(w) \right] p''(w) \lambda_s^2 \sigma_X + o(\sigma_X) + o(w) \\
= p''(w) \rho \sigma_K \lambda_s^2 \lambda_{t\ell}(w) \alpha + o(\sigma_X) + o(w).
\]

Hence, for \( \rho < 0 \), short-run investment \( s(w) \) increases in \( \sigma_X \), provided \( \sigma_X > 0 \) and \( w \) are sufficiently close to zero. This follows from \( \lim_{\sigma_X \to 0} p''(w) \neq 0 \), because \( \sigma_K > 0 \) guarantees a non-trivial boundary condition \( \overline{w} \sigma_X > 0 \) in the limit \( \sigma_X \to 0 \). Hence, there exists \( \sigma_X > 0 \) and \( w \in [0, \overline{w} \sigma_X] \), so that \( s(w) > s^{FB} \), which was to show.

**Proof.** This part of the proof establishes the convexity of the set \( \{ w : s(w) > s^{FB} \} \) under certain parameters conditions. The limit \( \mu \to 0 \) yields \( \ell(w) \to \frac{w}{\lambda_t} + o(\sigma_X)s(w) \), so that \( \ell(w) - w \to \frac{(\lambda_t - 1)w}{\lambda_t} + o(\sigma_X) \). Therefore, \( \frac{\partial \ell(w)}{\partial w} = \frac{(\lambda_t - 1)}{\lambda_t} + o(\sigma_X) \) and for \( \sigma_X \) small the sign of \( \frac{(\lambda_t - 1)}{\lambda_t} \) determines the sign of the derivative. Hence, a standard limit argument based on continuity of the solution in model parameters yields that there exist \( \mu > 0, \lambda_t, \sigma_X > 0 \), such that \( \ell(w) - w \) decreases in \( w \). Because

\[
\frac{\partial s(w)}{\partial w} \equiv s'(w) \propto p'''(w) \rho \sigma_X \sigma_K \lambda_s (\lambda_t \ell(w) - w) + p''(w) \rho \sigma_X \sigma_K \lambda_s \frac{\partial (\lambda_t \ell(w) - w)}{\partial w} + o(\sigma_X^2),
\]

it follows that \( s'(w) < 0 \) when \( \lambda_t \ell(w) \geq w \), provided that \( p'''(w) > 0 \), which is guaranteed for \( \gamma - r \) and \( \sigma_K \) sufficiently small. We used that \( \sigma_K > 0 \) is needed to guarantee a non-trivial solution and boundary in the limit \( \sigma_X \to 0 \).

Let us conclude the proof by demonstrating \( \{ w : s(w) > s^{FB} \} \) must be a convex set, containing zero, when parameters are such that \( s'(0) < 0 \) for \( w \in [0, \overline{w}] \) with \( \lambda_t \ell(w) \geq w \). Wlog, assume that \( \{ w : s(w) > s^{FB} \} \) is non-empty. If the set is not convex, it must be that there exists \( w' \in [0, \overline{w}] \) with \( s'(w') = s^{FB} \) and therefore \( s'(w') > 0 \). Because of \( s(\overline{w}) = s^{FB} \) it follows that \( w' < \overline{w} \). However, for \( s(w') \geq s^{FB} \) being optimal it is necessary that \( \lambda_t \ell(w') > w' \), which implies \( s'(w') < 0 \), a contradiction. Next, assume the set does not contain zero, that is \( s(0) < s^{FB} \). It follows that \( s'(w) > 0 \) for \( w = \inf \{ w \geq 0 : s(w) > s^{FB} \} \). By continuity \( s(w) = s^{FB} \). However, due to \( s(\overline{w}) = s^{FB} \) it must be that \( w < \overline{w} \). For \( s(\overline{w}) = s^{FB} \) being optimal it must be that \( \lambda_t \ell(w) > \overline{w} \), which implies \( s'(w) < 0 \), a contradiction. This concludes the proof.

**E.2 Proof of Proposition 7 ii)**

**Proof.** Fix \( \sigma_X > 0 \) and consider values \( \mu \) and \( \gamma - r \) sufficiently small, such that there exists \( w < \overline{w} \) with \( \ell(w) > \lambda_t \ell(w) \). This is possible \( \overline{w} \to \infty \) for \( \gamma - r \) and \( \ell(w) \to w/\lambda_t \) as \( \mu \to 0 \).

Note that this holds for any \( \sigma_X > 0 \). Therefore, we can choose \( \sigma_X \) sufficiently small and \( \gamma - r, \mu \) sufficiently small, so that there exists \( w < \overline{w} \) with \( p''(w) < 0 \) and \( s(w) > s^{FB} \), because of

\[
s(w) = \frac{\alpha + p''(w) \rho \sigma_X \sigma_K \lambda_s (\lambda_t \ell(w) - w)}{\lambda_s \alpha + o(\sigma_X)^2} > s^{FB}.
\]

That is, because the incentive cost of short-run investment is of order \( \sigma_X^2 \) while the incentive externality is of order \( \sigma_X \). Taking the limit \( \sigma_X \to 0 \) is innocuous, only because \( \sigma_K > 0 \) guarantees
a non-trivial solution in this limit.

Since in the limit \( \mu \to 0 \) for arbitrary \( \sigma_X > 0 \), long-term investment satisfies \( \ell(w) \to \frac{w}{X} \), it follows that there exist \( \mu > 0 \) and \( \lambda_\ell > 0 \) sufficiently small, such that \( \{ w \geq 0 : \ell(w) > w \} \) is convex with supremum \( \overline{w} \). Hence, for \( \sigma_X > 0 \) sufficiently small \( \{ w \geq 0 : s(w) > s^{FB} \} \) is also convex with supremum \( \overline{w} \), while it is clear that its infimum must exceed zero.

F Proof of Proposition 8

\[ \text{Proof.} \] Claim i) is trivial and directly follows from the HJB-equation and is already explained in the main text. Claim ii) is implied by the proof of Proposition 5 i), where we show that \( \lambda_\ell \ell(w) > w \) for all \( w \), when \( \sigma_X = 0 \). The proof can be easily adjusted for linear cost (compare e.g. He (2009)).

Claim iii) relies on the premise that \( \overline{w} \) increases \( 1/(\gamma - r) \) with \( \lim_{\gamma \downarrow r} \overline{w} = \infty \) and can be proven mimicking the argument of the proof of Proposition 5 ii). Moreover, the limit \( \lambda_\ell \to 0 \) leads to a well-behaved solution with strictly positive payout threshold, so that it follows by continuity of the solution \( \{ p_{\lambda_\ell}, \overline{w}_{\lambda_\ell} \}_{\lambda_\ell \geq 0} \) that \( \beta^s(w) = w > \lambda_\ell \) for \( 0 < w < \overline{w}_{\lambda_\ell} \) when \( \lambda_\ell \) is sufficiently small.

G Asymmetric Performance Pay with convex cost

In this section, we demonstrate that asymmetric performance-pay may also arise in our baseline model with strictly convex adjustment cost of investment. This is the case when the bound \( \ell_{\text{max}} \) becomes relevant for the principal’s maximization problem. In general, optimal effort levels are given by:

\[
\ell = \ell(w) = \frac{w\alpha + p''(w)\rho_\sigma X \sigma_K \lambda_s (\lambda_\ell \ell(w) - w)}{\lambda_\ell \alpha - p''(w)(\lambda_\ell \sigma_X)^2} \wedge \ell_{\text{max}}.
\]

The following Lemma demonstrates that asymmetric performance-pay arises when \( \ell = \ell_{\text{max}} \).

**Lemma 5.** Let \( w \in (0, \overline{w}] \) such that in optimum \( \ell(w) = \ell = \ell_{\text{max}} \) and \( s(w) = s \in [0, s_{\text{max}}] \). Assume that parameters satisfy \(-\rho_\sigma K \lambda_\ell \ell_{\text{max}} < \sigma_X \lambda_s s_{\text{max}} \) for \( \rho \in (-1, 1) \). Then

\[
\beta^\ell(w) = \max \{ \lambda_\ell \ell_{\text{max}}, w - \rho \frac{\sigma_X}{\sigma_K} \lambda_s s \} \quad \text{and} \quad \beta^s(w) = \lambda_s s.
\]

In particular, the short-run IC-condition is always tight under the conditions stated.

**Proof.** Given the optimal choice \( \ell(w) = \ell_{\text{max}}, s(w) = s \), the tuple \((\beta^s(w), \beta^\ell(w))\) must satisfy

\[
(\beta^s(w), \beta^\ell(w)) = \arg \min_{\beta^s, \beta^\ell} \left[ (\beta^s \sigma_X)^2 + \frac{\sigma_K^2}{\beta^\ell}(\beta^\ell - w)^2 + 2\rho \sigma_X \sigma_K \beta^s (\beta^\ell - w) \right]
\]

subject to \( \beta^\ell \geq \lambda_\ell \ell_{\text{max}} \) and \( \beta^s \geq \lambda_s s \),

where the last inequality is tight, unless \( s = s_{\text{max}} \). Using standard arguments, one obtains:

\[
\beta^\ell(w) = \max \{ \lambda_\ell \ell_{\text{max}}, w - \rho \frac{\sigma_X}{\sigma_K} \beta^s \};
\]

\[
\beta^s(w) = \max \{ \lambda_s s_{\text{max}}, \rho \frac{\sigma_K}{\sigma_X}(w - \beta^\ell) \} \quad \text{if} \quad s = s_{\text{max}} \quad \text{and} \quad \beta^s = \lambda_s s \quad \text{othersize.}
\]
The claim is trivial if \( s < s_{\text{max}} \) or \( \rho = 0 \).

Let us suppose \( s = s_{\text{max}} \), \( \rho \neq 0 \) and \( \beta^* > \lambda_s s \). Hence, \( \beta^* = \rho \frac{\sigma_K}{\sigma_X}(w - \beta^*) \). If now \( \beta^* > \lambda_s \ell \), then \( \beta^* = w - \rho \sigma_X / \sigma_K \beta^* \). This implies \( \rho \sigma_K / \sigma_X (w - \beta^*) = \rho^2 \beta^* < \beta^* \) and hence \( \beta^* = \lambda_s s_{\text{max}} \), a contradiction.

Next, suppose \( \rho < 0 \) and \( \beta^* = \lambda_s \ell_{\text{max}} \). Hence, \( w > \lambda_s \ell_{\text{max}} \). Since \( \beta^* = \lambda_s \ell_{\text{max}} \) it follows that \( \lambda_s \ell_{\text{max}} > w - \rho \sigma_X / \sigma_K \beta^* \) and - using \( \beta^* = \rho \frac{\sigma_K}{\sigma_X}(w - \beta^*) \) - one obtains \( \lambda_s \ell_{\text{max}} > w - \rho^2 (w - \lambda_s \ell_{\text{max}}) \). Hence, \( \lambda_s \ell_{\text{max}} > w \), a contradiction.

Finally, assume \( s = s_{\text{max}} \), \( \rho < 0 \) and \( \beta^* = \lambda_s \ell_{\text{max}} \). Hence, \( \lambda_s \ell_{\text{max}} > w \) and \( \rho \sigma_K / \sigma_X (w - \lambda_s s_{\text{max}}) \), which implies \( w - \lambda_s \ell_{\text{max}} < \lambda_s s_{\text{max}} \sigma_X / (\sigma_K \rho) \). Therefore, \( -\rho \sigma_K / \lambda_s \ell_{\text{max}} > \sigma_X / (\sigma_K \rho) \), which contradicts the hypothesis.

By means of the previous Lemma it is obvious, that asymmetric performance pay always arises when \( \ell_{\text{max}} \) is sufficiently low.

Next, we state Lemma 6, which shows that asymmetric performance pay occurs generally for large values of \( w \) and the set on which it occurs is convex. That is, there is asymmetric performance pay exactly above some threshold \( w' < \bar{w} \), i.e., on the set \( (w', \bar{w}) \).

**Lemma 6.** Assume \( -\rho \sigma_K \lambda_s \ell_{\text{max}} < \sigma_X \lambda_s s_{\text{max}} \). If there exists \( w' \geq \lambda_s \ell_{\text{max}} + \max \{ \rho, 0 \} \sigma_X / \sigma_K s_{\text{max}} \) with \( \ell(w') = \ell_{\text{max}} \), then \( \ell(w) = \ell_{\text{max}} \) and \( \beta^* = w - \rho \sigma_X / \sigma_K s(w) \) for all \( w \geq w' \).

**Proof.** Let us start at the point \( w' \) and plug-in optimal incentives

\[
\max \{ \lambda_s \ell_{\text{max}}, w' - \rho \frac{\sigma_X}{\sigma_K} \lambda_s s \} = w' - \rho \frac{\sigma_X}{\sigma_K} \lambda_s s
\]

into the HJB-equation, so as to obtain the squared volatility \( \Sigma(w') = (\lambda_s s(w) \sigma_X s(w))^2 (1 - \rho^2) \), which does not depend on \( \ell \) anymore. Therefore, a necessary and sufficient condition for \( \ell(w') = \ell_{\text{max}} \) being optimal reads

\[
p(w) - wp'(w) \geq \lambda_s \ell_{\text{max}}
\]

Owing to the concavity, the benefits of long-run investment, i.e., \( p(w) - wp'(w) \) increase in \( w \), while there is no agency-cost associated with long-run incentives when \( \ell = \ell_{\text{max}} \). Thus, \( \ell(w) = \ell_{\text{max}} \) is optimal for \( w \geq w' \). \( \square \)

**Proof.** Asymmetric performance-pay arises for \( \lambda_s \) sufficiently low. \( \square \)

**Proof.** Clearly, the limit \( \lambda_s \to 0 \) leads to \( \ell(w) \to \ell_{\text{max}} \) for all \( w \), while \( \lim \lambda_s \to 0 \bar{w} > 0 \) owing to \( \sigma_X, \sigma_K > 0 \). The claim follows. \( \square \)

**H Model Solution with Private Cost**

In this section, we solve the model, when the cost of investment is private. For brevity, we only discuss the solution under the assumption of interior first-best investment levels, i.e., \( k^{FB} < k_{\text{max}} \) for \( k = s, \ell, \) and zero correlation.

The agent's continuation value \( \{W\} \) reads for \( t < \tau \):

\[
W_t = \mathbb{E}_t \left[ \int_t^\tau e^{-\gamma(u-t)}(dC_u - K_u C(s_u, \ell_u) du) \right],
\]

while the principal's continuation value under the optimal contract is given by

\[
P(W, K) \equiv \mathbb{E}_t \left[ \int_t^\tau e^{-\gamma(u-t)}(dX_u - dC_u) + e^{-\gamma(t-t')}RK_t \mid W_t = W, K_t = K \right]. \quad (A4)
\]
By the martingale representation theorem, \( \{W\} \) solves the SDE:
\[
dW_t + dC_t = \gamma W_t dt + K_t C(s_t, \ell_t) dt + \beta^s_t K_t \sigma_X dZ^X_t + \beta^\ell_t K_t \sigma_K dZ^K_t
\]
for progressively measurable processes \( \{\beta^s\}, \{\beta^\ell\} \). The incentive conditions are derived as:
\[
\beta^s_t = C_s(s_t, \ell_t) \iff \beta^s_t = \lambda_s s_t
\]
\[
\beta^\ell_t = C_\ell(s_t, \ell_t) \iff \beta^\ell_t = \lambda_\ell \ell_t.
\]
The value function scales in capital, i.e., \( P(W, K) = K p(w) \) for \( w = W/K \), and \( p(w) \) solves the following HJB-equation:
\[
(r + \delta) p(w) = \max_{s,\ell,\beta^s,\beta^\ell} \left\{ \alpha s + p'(w) w (\gamma + \delta - \mu \ell) + p'(w) C(s, \ell) + \mu \ell p(w) \right. \\
\left. + \frac{p''(w)}{2} \left[ (\beta^s \sigma_X)^2 + \sigma^2_K (\beta^\ell - w)^2 + 2 \rho \sigma_X \sigma_K \beta^s (\beta^\ell - w) \right] \right\},
\]
which is solved subject to \( p(0) - R = p'(\bar{w}) - 1 = p''(\bar{w}) = 0 \) and the incentive compatibility conditions.

The optimal investment levels \( s, \ell \) follow from the FOC of maximization:
\[
s = s(w) = \frac{\alpha}{-p'(w) \lambda_s \alpha - p''(w) (\lambda_s \sigma_X)^2} \wedge s_{\text{max}} \text{ if } -p'(w) \lambda_s \alpha - p''(w) (\lambda_s \sigma_X)^2 > 0
\]
\[
\ell = \ell(w) = \frac{\mu (p(w) - p'(w) w) - p''(w) w \lambda_\ell \sigma_K^2}{-p'(w) \lambda_\ell \mu - p''(w) (\lambda_\ell \sigma_K)^2} \wedge \ell_{\text{max}} \text{ if } -p'(w) \lambda_\ell \mu - p''(w) (\lambda_\ell \sigma_K)^2 > 0,
\]
and
\[
s = s(w) = s_{\text{max}} \text{ if } -p'(w) \lambda_s \alpha - p''(w) (\lambda_s \sigma_X)^2 \leq 0
\]
\[
\ell = \ell(w) = \ell_{\text{max}} \text{ if } -p'(w) \lambda_\ell \mu - p''(w) (\lambda_\ell \sigma_K)^2 \leq 0.
\]
Note that the direct marginal cost of investment is given by \(-p'(w) \lambda_s \alpha\) (resp. \(-p'(w) \lambda_\ell \mu\)), which is unambiguously negative for \( w \in [0, w^*] \), where \( w^* \) solves \( p'(w^*) = 0 \). Hence, incentivizing investment is beneficial since it induces a positive drift component in the agent’s continuation value \( w \), which moves \( w \) on average away from the liquidation boundary (and thereby relaxes the non-negativity constraint of wages \( dC \)).

Departing from there, we can state and prove the following Proposition.

**Proposition 9** (Short- and Long-termism). The optimal investment levels \( s, \ell \) satisfy:

i) \( s(\bar{w}) = s^{FB} \) and \( \ell(w) < \ell^{FB} \) in a neighbourhood of \( \bar{w} \)

ii) If \( \sigma_X > 0 \), then there exist values \( w^L < w^H < \bar{w} \) with \( \ell(w) > \ell^{FB} \) for \( w \in (w^L, w^H) \), provided \( \sigma_K > 0 \) is sufficiently low

iii) If \( \sigma_K > 0 \), then there exist values \( w^L < w^H < \bar{w} \) with \( s(w) > s^{FB} \) for \( w \in (w^L, w^H) \), provided \( \sigma_X > 0 \) is sufficiently low.

**Proof.**

i) Utilizing the boundary conditions \( p'(\bar{w}) - 1 = p''(\bar{w}) = 0 \) yields \( s(\bar{w}) = 1/\lambda_s = s^{FB} \).

Owing to agency-induced termination, \( P(\tau < \infty) = 1 \), we have that \( p(w) - w p'(w) < p^{FB} \).
Again invoking the boundary conditions yields:

\[ \ell(\bar{w}) = \frac{p(w) - p'(w)w}{\lambda_{\ell}} < \frac{p^{FB}}{\lambda_{\ell}} = \ell^{FB} \]

and by continuity the relationship holds in an appropriate left neighbourhood of \( \bar{w} \).

ii) By Berge’s maximum theorem, the solution \( \{ p_{\sigma_K}, \bar{w}_{\sigma_K} \}_{\sigma_K} \) is continuous in \( \sigma_K > 0 \) and converges to a well behaved solution with \( \bar{w} > 0 \) when \( \sigma_K \to 0 \), because of \( \sigma_X > 0 \). Then, by continuity, there exists values \( w' \in (0, \bar{w}) \) and \( \sigma_K \) sufficiently small, so that

\[ -p'(w)\lambda_{\ell}\mu - p''(w)(\lambda_{\ell}\sigma_K)^2 = -p'(w)\lambda_{\ell}\mu + o(\sigma^2_K) < 0, \]

in which case \( \ell(w') = \ell^{\max} > \ell^{FB} \), thereby concluding the proof.

iii) By Berge’s maximum theorem, the solution \( \{ p_{\sigma_X}, \bar{w}_{\sigma_X} \}_{\sigma_X} \) is continuous in \( \sigma_X > 0 \) and converges to a well behaved solution with \( \bar{w} > 0 \) when \( \sigma_X \to 0 \), because of \( \sigma_K > 0 \). Then, by continuity, there exist values \( w' \in (0, \bar{w}) \) and \( \sigma_X \) sufficiently small, so that

\[ -p'(w)\lambda_{s}\alpha - p''(w)(\lambda_{s}\sigma_X)^2 = -p'(w)\lambda_{s}\alpha + o(\sigma^2_X) < 0, \]

in which case \( s(w') = s^{\max} > s^{FB} \), thereby concluding the proof.

The proof relied on exploiting the direct cost effect. While we are also able to prove short- and long-termism in the case of private investment cost, the key differences to our results presented in the main-text are as follows.

First, the statement is "if" and not "if and only if". While a dual moral hazard problem implies short-termism (resp. long-termism) when short-run (resp. long-run) risk is sufficiently low, it could also be that short-termism (resp. long-termism) arises in a model with \( \sigma_K = 0 \) (resp. \( \sigma_X = 0 \)). This is due to the direct cost effect, which renders it beneficial to incur investment cost when \( w \) is low.

Second, short-termism can arise even without correlation between permanent and transitory shocks.
References


