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Growth Options, Incentives, and Pay for Performance: Theory and Evidence

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Abstract. Pay–performance sensitivity is a common proxy for the strength of incentives. We show that growth options create a wedge between expected-pay–effort sensitivity, which determines actual incentives, and pay–performance sensitivity, which is the ratio of expected-pay–effort to performance–effort sensitivity. An increase in growth option intensity can increase performance–effort sensitivity more than expected-pay–effort sensitivity so that, as incentives increase, pay–performance sensitivity decreases. We document empirical evidence consistent with this finding. Pay–performance sensitivity, measured by dollar changes in manager wealth over dollar changes in firm value, decreases with proxies for growth option intensity and increases with proxies for growth option exercise.

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Keywords: dynamic contracting • real options • pay–performance sensitivity

1. Introduction

A fundamental insight of agency theory is that managers need incentives to maximize shareholder value (Jensen and Meckling 1976). At a basic level, such incentives require that a manager's expected pay be sensitive to the manager's actions. In practice, these actions are often unobservable, and as a result, compensation contracts implement incentives by making managers' pay sensitive to performance. As such, a substantial literature has developed that estimates managerial incentives by measuring pay–performance sensitivity (Murphy 1985, Jensen and Murphy 1990, Baker and Hall 2004). However, as a measure of incentives, pay–performance sensitivity is confounded by the sensitivity of performance to managers' actions. We show that growth options cause the sensitivity of performance to managers' efforts to vary both across firms and within a firm over time. This variation means that pay–performance sensitivity is not a sufficient statistic for incentives. Intuitively, growth options should increase the optimal amount of incentives receive. We show that pay–performance sensitivity can be decreasing in growth-option intensity and provide empirical evidence that supports this relation.

We first present the basic intuition behind why pay–performance sensitivity is not a sufficient statistic for incentives in the context of a simple principal–agent problem. In this problem, a manager takes a hidden action, that is, effort, that affects firm value. Shareholders provide the manager with incentives by making the manager pay a function of firm value. Three distinct quantities emerge as related to the manager's incentives: expected-pay–effort sensitivity, performance–effort sensitivity, and pay–performance sensitivity. Expected-pay–effort sensitivity is defined by how sensitive the manager's expected pay is to the manager's choice of effort and directly determines the manager's incentives. When expected-pay–effort sensitivity is higher, the manager expects to receive a greater reward for any additional effort the manager applies, and the manager will, thus, respond by applying more effort. Performance–effort sensitivity is the marginal value of managerial effort to the firm. Finally, pay–performance sensitivity is the sensitivity of the manager's pay to the value of the firm. In this simple framework, pay–performance sensitivity is the ratio of expected-pay–effort sensitivity and performance–effort sensitivity so that there is a wedge between pay–performance sensitivity and incentives. As a result, a change in an underlying characteristic of the firm that leads to changes in both incentives and performance–effort sensitivity can have an ambiguous effect on pay–performance sensitivity.

Although the arguments we make in our simple principal–agent framework apply to any firm characteristic that affects the wedge between pay–performance sensitivity and incentives, our focus is on growth options. Intuitively, an increase in growth options leads to an increase in the sensitivity of firm value to effort and, at the same time, increases the optimal amount of incentives that the shareholders choose to implement. Herein lies the difficulty of measuring incentives with pay–performance sensitivity. When the elasticity of incentives to growth options is less than that of performance–effort sensitivity, an increase in growth options increases incentives and decreases pay–performance sensitivity.

Although our simple principal–agent framework illustrates the core intuition of results, it lacks sufficient richness to address why performance–effort sensitivity might be more or less elastic than expected-pay–effort sensitivity with respect to growth options. To address this question, we present a continuous-time moral-hazard model in which the presence of a growth option interacts with the provision of incentives and characterize the circumstances under which pay–performance sensitivity differs from expected-pay–effort sensitivity.

In the model, an investor hires a manager to run a firm. The investor also possesses a growth option to increase the firm's capital base. The manager can exert unobservable effort to increase productivity growth. The investor provides the manager with incentives by exposing the manager to fluctuations in productivity. The investor is risk neutral, and the manager is risk averse, so it is costly to provide the manager with incentives. Thus, from the investor's perspective, there are two components of the total cost of effort: effort costs paid by the manager and the incentive costs of forgone risk sharing. Our main result is that expected-pay–effort sensitivity increases with the size of the growth option, whereas pay–performance sensitivity decreases if incentive costs are more convex than effort costs.

The intuition for the result follows from the relation between expected-pay–effort sensitivity and performance–effort sensitivity under the optimal contract. An increase in the size of the growth option increases the marginal benefit of effort and, thus, increases the optimal level of effort. The contract must increase expected-pay–effort sensitivity to implement such an increase in effort. The manager's incentive compatibility constraint implies that expected-pay–effort sensitivity is equal to the manager's marginal effort cost. When incentive costs are more convex than the manager's effort costs, marginal incentive costs increase more than marginal effort costs. At the optimum, the first-order condition equates the marginal benefit of effort to the sum of marginal effort and incentive costs. As performance–effort sensitivity is equal to the marginal benefit of effort, the first-order condition implies that performance–effort sensitivity increases by more than expected-pay–effort sensitivity whenever incentive costs are more convex that effort cost. As a result, pay–performance sensitivity decreases with the size of the growth option, whereas expected-pay–effort sensitivity increases.

We go on to present new evidence for the relationship between pay–performance sensitivity and growth options. Using data on pay–performance sensitivity calculated by Coles et al. (2013) as well as executive and firm characteristics from the Execucomp and Compustat databases, we find that pay–performance sensitivity is negatively related to proxies for growth options. Specifically, we regress dollar changes in manager wealth to dollar changes in firm value, a measure of pay–performance sensitivity suggested by Jensen and Murphy (1990) that we call PPS, on market-to-book ratio and other proxies. We find that, for a given firm, a one standard deviation increase in the market-to-book ratio is associated with a 5.7% decrease in PPS. As a stand-alone fact, this relationship seems inconsistent with the intuition that growth options make manager effort more valuable, which should necessitate stronger incentives when growth options are present. Viewed through the lens of our model, we find this intuition to be compatible with the empirical relationship as more growth options make manager effort more valuable to the firm. If the value of manager effort increases faster than manager incentives, we would expect PPS to decrease despite stronger managerial incentives. Thus, our model also has implications for the provision of incentives. We investigate our model's predictions regarding compensation design and find them consistent with observed compensation structures among high-growth pre-IPO firms.

Although our main result is about the wedge between expected-pay–effort sensitivity and pay–performance sensitivity in the presence of growth options, the intuition behind our results holds in a much broader setting. We illustrate the generality of our results by extending our model to consider the case of an abandonment option. Rather than an opportunity to invest in additional capital, the investor instead has the opportunity to shut down the firm and sell its assets for a fixed value. In this setting, the liquidation value of the asset is a measure of the assets' redeployability. We find that redeployability has an effect on incentives that is symmetric to the effect of growth options: an increase in redeployability decreases expected-pay–effort sensitivity but increases pay–performance sensitivity.

Our work is related to the large literature on executive compensation. Frydman and Jenter (2010) and Murphy (2013) provide comprehensive reviews of the theoretical and empirical findings in this literature. In emphasizing one important aspect of the empirical evaluation of PPS, we are indebted to the research that extensively documents the importance of managerial incentives in firm decision making. Coles et al. (2006), Hirshleifer and Suh (1992), and

Rajgopal and Shevlin (2002) are among the many papers that document the effect of managerial incentives on operational decisions. There has also been work on the effect of incentives on other financing decisions as studied by Babenko (2009) and Chava and Purnanandam (2010), among others. He et al. (2014) analyzes the impact of uncertainty on managerial incentives and finds that the desire for faster learning leads the investor to offer stronger incentives to the manager.

Theoretical studies have characterized the optimal compensation contract in a variety of settings.[1] An important observation made by Baker and Hall (2004) is that the optimal structure of compensation depends on the model's assumptions about how managerial effort affects firm value. In the models of Lambert (1983), Rogerson (1985), Edmans et al. (2012), and He et al. (2014), a feature of the optimal contract is the effect of present performance on both current and future compensation. Those models are in discrete time, whereas our work, like that of DeMarzo and Sannikov (2006) and He et al. (2017), uses a continuous-time setting. A continuous-time model is desirable because it permits characterization of the optimal contract and the firm's value function using ordinary differential equations.

In our model, real options are a source of convexity in firm value and create the wedge between incentives and pay–performance sensitivity. First introduced in Brennan and Schwartz (1985), there is substantial literature analyzing the presence and implications of investment opportunities as options. Berk et al. (1999) finds that the optimal exercise of investment opportunities can simultaneously reproduce a multitude of cross-sectional asset-pricing features. Carlson et al. (2004) builds on this analysis by introducing operating leverage and reversible investment. In a similar spirit, by analyzing real options in the context of managerial incentives, we work to understand the rich interdependence between managerial decision making and investment opportunities.

By studying the effect of real options on incentives, our paper contributes to the literature on manager incentives. The seminal paper in this area is Holmstrom and Milgrom (1987), which studies the contract between a risk-averse manager and a risk-neutral firm. Our model is similar to that of He (2011) in that it features a risk-averse manager who can exert effort to increase expected cash flows. Unlike that model, our model gives the firm a growth option. Similar to earlier models, there are two kinds of costs in implementing effort as described first in Holmstrom and Milgrom (1987): the direct monetary cost and the risk–compensation term to encourage the risk-averse agent to bear incentives.

Empirical studies on measuring PPS were pioneered by the competing measures of Jensen and Murphy (1990) and Hall and Liebman (1998). An important contribution was made by Core and Guay (2002), who provided a methodology for estimating the sensitivity of option-based compensation. Our work both relies upon and contributes to the measurement of PPS by identifying growth options as an important source of variation in PPS. In this way, our work contributes to the literature on the determinants of executive compensation.[2]

Finally, our paper is related to the literature on option exercise in the presence of agency problems and asymmetric information. Grenadier and Wang (2005) analyze how agency conflicts, such as moral hazard and hidden information, can affect the timing of real option exercise. Grenadier and Malenko (2011) study a setting in which informed agents signal their private information by exercising real options. Grenadier et al. (2016) analyze how timing decisions interact with communication. Cong (2017) studies the relation between auctions of real options and investment-timing decisions. The setup of our model follows that of Gryglewicz and Hartman-Glaser (2016), which looks at the timing of investment decisions in the presence of agency conflicts. Rather than focusing on the investment decision, we focus on how growth options can affect manager incentives.

2. Pay–Performance Sensitivity and Incentives

In this section, we present a simple principal–agent problem that illustrates our main point: pay–performance sensitivity is not a direct measure of incentives. To that end, consider an investor who hires a manager to operate a firm. The gross value of this firm, V, is an increasing function of a state $X = a + Z$, where a is the manager's hidden action a and Z is mean zero noise. The shape of V is determined by an exogenous parameter λ. For example, λ could represent the firm's size, its level of productivity, or, as we focus on in this paper, the firm's endowment of growth options.

A contract specifies a compensation rule c that determines the amount to be paid to the manager by the investor. As the investor cannot observe the actions of the manager, the investor can only condition the manager's compensation on the realization of firm value or X. For simplicity, we restrict attention to contracts that are affine in firm value:

$$c(V) = W + \phi V, \tag{1}$$

so that ϕ corresponds to the dollar increase in the manager's pay per dollar increase in firm value., that is, the standard definition of pay–performance sensitivity as in Jensen and Murphy (1990). Although this restriction is not without loss of generality, it substantially simplifies the intuition we present. One advantage of the dynamic model we present in Section 3 is that it allows a characterization of the optimal contract over an unrestricted contract space.

Taking the compensation rule c as given, the manager chooses the action a^* that maximizes the manager's expected compensation net of a convex effort cost $g(a)$. The firm chooses the optimal contract to maximize the value V net of manager compensation c, taking into account the manager's choice of action a^*. The optimal contract then solves the following problem

$$\max_c \{\mathbb{E}[V(X) - c(V(X)) \mid a^*]\} \tag{2}$$

such that

$$a^* \in \arg\max_a \{\mathbb{E}[c(V(X)) \mid a] - g(a)\}, \tag{3}$$

and

$$\mathbb{E}[c(V(X)) \mid a^*] - g(a^*) \geq u_0, \tag{4}$$

where u_0 is the value of the manager's outside option.

In this setting, the manager's incentives are determined by the manager's expected-pay–effort sensitivity, that is, how much expected compensation increases in response to an increase in effort. This quantity, denoted β, is given by

$$\beta = \frac{\mathrm{d}\mathbb{E}[c(V(X)) \mid a]}{\mathrm{d}a}. \tag{5}$$

To see why β captures the strength of the manager's incentives, examine the incentive compatibility condition in Equation (3). It implies that the manager will choose an effort level that equates the marginal cost of effort with the marginal benefit, that is, the manager's expected-pay–effort sensitivity. Because the cost of effort is convex, the higher the manager's expected-pay–effort sensitivity is, the higher the manager's optimal effort level will be.

We are interested in determining the conditions under which inferences about manager incentives, that is, expected-pay–effort sensitivity, can be drawn by observing pay–performance sensitivity. For example, suppose empirical evidence shows that pay–performance sensitivity is decreasing in some firm characteristic λ, for example, growth-option intensity. Can we conclude that incentives are also decreasing in this characteristic? To answer this question, we can examine the comparative statics of both ϕ and β with respect to λ. If these two comparative statics have the same sign, then the two measures are aligned, and we can conclude that incentives are also decreasing in λ. However, as we now show, β can be increasing in λ even though ϕ is decreasing. This relation implies that evidence that pay–performance sensitivity is decreasing in some firm characteristic is not sufficient to conclude that incentives are also decreasing.

Given our restriction to affine contracts, expected-pay–effort sensitivity is the product of pay–performance sensitivity and the marginal value of manager effort

$$\beta = \phi \frac{\mathrm{d}\mathbb{E}[V(X) \mid a]}{\mathrm{d}a} = \phi\mathbb{E}[V'(X) \mid a]. \tag{6}$$

Taking a derivative of Equation (6) with respect to λ gives

$$\frac{1}{\beta}\frac{\partial \beta}{\partial \lambda} = \frac{1}{\phi}\frac{\partial \phi}{\partial \lambda} + \left(\frac{1}{\mathbb{E}[V'(X) \mid a]}\right)\frac{\partial \mathbb{E}[V'(X) \mid a]}{\partial \lambda}. \tag{7}$$

In words, Equation (7) just states that the elasticity of β with respect to λ is the sum of the elasticities of ϕ and the marginal value of manager effort. Thus, ϕ can be decreasing in λ while β is increasing in λ if the elasticity of the marginal value of manager effort is sufficiently positive.

In the specific case in which λ represents growth opportunity intensity, an increase in λ increases $V'(X)$. An increase in λ, thus, increases the marginal value of manager effort, and the amount of incentives provided per unit of pay–performance sensitivity increases. As a result, actual incentives can increase even as pay–performance sensitivity decreases.

This analysis also has implications for the design of incentives. A typical feature of many contracting models is that executive pay that is convex in performance provides strong incentives. This feature would seem to imply that if a firm's owners seek to provide powerful incentives, then executive pay should include option-like compensation. Equation (6) shows that some convexity in incentives is present just because the firm value is itself a convex function of the underlying effort of the manager. When a firm has growth opportunities, firm value is an option-like function of productivity. As a result, paying executives with stocks or deep-in-the-money options still provides convex incentives.

Equation (6) also indicates that the problem of drawing inferences about incentives using data on pay–performance sensitivity is akin to using average q to draw inference about marginal q. As is well understood, marginal and average q are not necessarily equivalent if the marginal value of investment is not constant. In the same vein, pay–performance sensitivity is not necessarily equivalent to incentives if the marginal value of manager effort is not constant. However, just as average q is useful in the empirical investigation of real investment because it is readily observable and measurable, so is pay–performance sensitivity in the empirical investigation of incentives. Our point is that one must take care to control for the marginal value of manager effort when using pay–performance sensitivity as a proxy for incentives in the same way that one must take care to properly control for the marginal value of investment when using average q as a proxy for marginal q.

In this simple principal–agent problem, not only is pay–performance sensitivity distinct from incentives, but observed changes in the former are uninformative about the latter. In the next section, we formalize the simple intuition we have presented in the context of a fully specified model in which the relation between growth-option intensity and pay–performance sensitivity arises endogenously from a dynamic principal–agent problem.

3. A Dynamic Model of Real Options and Manager Moral Hazard

We now present a dynamic model that builds on Holmstrom and Milgrom (1987) and He (2011), which explicitly solves for the optimal contract and relates the manager's incentives to the primitives of the model. The dynamic model has the advantage of allowing us to characterize firm value and the optimal contract in closed form and analyze comparative statics of pay–performance sensitivity versus pay–effort sensitivity. Building on the intuition of the previous section, we find that the two are distinct and respond differently to changes in the value of managerial effort.

In the model, time is continuous and indexed by t. An infinitely lived firm generates a continuous cash flow given by X_tK_t, where K_t is the capital base and X_t is firm productivity. Capital K_t takes the initial value $K_0 = 1$, and the firm has a real option to pay P and increase capital to k. Let τ denote the time of investment.

A risk-neutral investor hires a risk-averse manager to run the firm. The common discount rate is denoted by r. Both X_t and K_t are observable to the investor. A moral-hazard problem arises because the manager affects the firm's productivity. Specifically, prior to investment, productivity X_t depends on that manager's effort $a_t \in [0, a_{\max}]$ and follows the process

$$dX_t = a_tX_tdt + \sigma X_tdZ_t, \tag{8}$$

where σ is a positive constant and dZ_t is a Brownian motion that is unobservable to the investor. We assume that $r > a_{\max}$ so that firm value is finite. The manager's effort is unobservable to the investor.

In our model, the value of the manager is due to the manager's ability to grow the firm's productivity X_t. This view of a manager is consistent with characterizations of CEOs as focused on growth and future performance. As our interest lies in the interaction of agency conflicts and growth opportunities, we simplify the analysis and assume that, after an investment at time τ, firm productivity stays at X_τ forever and there are no agency conflicts. Thus, the postinvestment value of the firm's cash flow is just $(X_\tau k)/r$. In what follows, we examine the optimal contracting and valuation of the firm before investment.

The investor receives the cash flows from the firm and pays the manager compensation c_t so that the manager's net cash flow D_t follows dynamics given by

$$dD_t = X_tK_tdt - c_tdt - PdJ_t, \tag{9}$$

where $J_t = \mathbb{I}(t \geq \tau)$. We note that this specification for cash flows links current cash flows and operations to the payoff to the growth option. This feature is not essential. An alternative formulation of our model is to let X_t only affect the productivity of new capital, not current cash flows, and would yield the same economic mechanism we discuss. The key ingredient for the results we present is that managerial effort affects the value of the growth option through productivity growth.

The manager has constant absolute risk aversion (CARA) preferences over consumption and effort with instantaneous utility

$$u(c_t, a_t) = -\frac{1}{\gamma}e^{-\gamma(c_t - g(a_t)X_t)}. \tag{10}$$

The manager's private cost of effort, $g(a_t)X_t$, is measured in units of consumption. We assume the cost function $g(a)$ is continuous, increasing, and convex in effort a: $g(a) \in \mathscr{C}^1([0, a_{\max}])$, $g'(a) > 0$, $g''(a) > 0$, $g(0) = g'(0) = 0$, and $g'(a_{\max}) = \infty$. This specification for effort costs ensure that any optimal contract will specify interior effort in $(0, a_{\max})$. The cost of effort increases with the firm's current level of productivity and, therefore, with firm size. This captures the intuition that it is more difficult and costly for a manager to improve the productivity of an already productive firm.

The manager has the ability to engage in unobserved savings and borrowing at the rate r. This assumption restricts the type of incentives that the investor can impose on the manager. If the manager did not have access to private savings, the investor could implement more powerful incentives by distorting the manager's intertemporal margin and ratcheting up incentives over time. When the manager has access to private savings, the investor can only expose the manager to long-term risk via deferred compensation; otherwise, the manager could use precautionary savings to undo incentives. Without loss of generality, we assume that the manager starts with zero savings. It is also important to note that the manager cannot gain exposure to the firm's equity except through the contract as this would also allow the manager to undo incentives. Furthermore, the manager has a outside option, which the manager values at w_0.

A contract consists of a compensation rule, a recommended effort level, and an investment policy, denoted $\Pi = (\{c, a\}, \tau)$, where $\{c\} = \{c_t\}_{t\geq 0}$ and $\{a\} = \{a_t\}_{t\geq 0}$ are stochastic processes adapted to the filtration of public information $\mathscr{F}_t$ and τ is an $\mathscr{F}_t$-stopping time.

Given contract Π, the manager chooses the stochastic processes $\{\tilde{c}, \tilde{a}\}$ (which can differ from those recommended by the contract, $\{c, a\}$) to maximize the manager's utility from the contract as follows:

$$W_0(\Pi) = \max_{\{\tilde{c},\tilde{a}\}} \mathbb{E}\left[\int_0^\infty -\frac{1}{\gamma} e^{-\gamma(\tilde{c}_t + g(\tilde{a}_t, X_t)) - rt}\right], \tag{11}$$

such that X_t, K_t, and S_t follow the dynamics induced by the consumption and effort plan $\{\tilde{c}, \tilde{a}\}$. The investor's value given a contract Π is

$$v_0(\Pi) = \mathbb{E}^{\{\tilde{a}\}}\left[\int_0^\infty e^{-rt} dD_t\right], \tag{12}$$

such that X_t, K_t, and S_t follow the dynamics induced by the consumption and effort plan $\{\tilde{c}, \tilde{a}\}$ and where $\{\tilde{c}, \tilde{a}\}$ solves (11). The expectation operator $\mathbb{E}^{\tilde{a}}$ denotes dependence of expectations on the dynamics under effort $\{\tilde{a}\}$. Therefore, the investor chooses the optimal contract to maximize $v(\Pi)$ subject to providing the manager at least the manager's outside option w_0.

A contract Π is termed *incentive-compatible* and *zero-savings* if the manager's choice of $\{\tilde{c}, \tilde{a}\}$ is equal to the payment rule and recommended effort plan $\{c, a\}$ given in Π. We restrict our attention to incentive-compatible and zero-savings contracts by virtue of the following version of the revelation principle.

Lemma 1. *Let $\tilde{\Pi}$ be an arbitrary contract. There exists an incentive-compatible and zero-savings contract Π that satisfies $v(\Pi) \geq v(\tilde{\Pi})$ and $W(\Pi) \geq W(\tilde{\Pi})$.*

3.1. No-Savings and Incentive-Compatibility Conditions

The manager is compensated in current pay and promised deferred pay. The zero-savings property of the optimal contract has implications for current pay. As the manager is risk averse, the manager values smooth consumption. Thus, if current compensation is high relative to the manager's wealth, the manager will only consume a part of the compensation and save the rest. Conversely, if current compensation is low relative to the manager's wealth, the manager will borrow to increase current consumption. With CARA preferences, the manager will not save or borrow if the manager's current utility from consuming exactly the manager's compensation equals the risk-free yield on the manager's continuation utility from the contract.

Lemma 2. *A contract implements zero savings if and only if the manager's instantaneous utility is equal to the yield on the manager's continuation utility:*

$$u(c_t, a_t) = rW_t. \tag{13}$$

Given the manager's continuation utility W_t and effort a_t, the no-savings property pins down an exact level of current pay. Next, we analyze deferred pay and its role in providing incentives. To do so, we characterize the dynamics of W_t under the recommended consumption and effort plan. Utility from current pay and a change of the continuation utility from deferred pay must, in expectation, equal the required return on the continuation utility; that is, it holds that

$$\mathbb{E}_t\left[u(c_t, a_t)dt + dW_t\right] = rW_t dt. \tag{14}$$

The no-savings condition (13) implies that $\mathbb{E}_t[dW_t] = 0$. Using the martingale representation theorem as in Sannikov (2008), we can write the following dynamics for the manager's continuation utility:

$$dW_t = \beta_t(-\gamma r W_t)(dX_t - a_t X_t dt) \tag{15}$$

for some progressively measurable process β_t. The term $\beta_t(-\gamma r W_t)$ is the sensitivity of the manager's continuation utility to unexpected shocks to the firms' productivity. The term $-\gamma r W_t$ is a scaling factor that equals the marginal utility of consumption. As a result, β_t measures the sensitivity of the manager's continuation value to unexpected shocks to productivity in monetary terms. If the manager deviates from the recommended effort policy, the manager expects the investor to perceive an unexpected shock to productivity and the manager's continuation value to adjust by β_t. Thus, β_t measures the manager's incentive to deviate from the contract's recommended effort policy.

We can now characterize the incentive compatibility constraint for the manager. Consider the manager's choice of effort $\tilde{a}_t$. As the manager chooses $\tilde{a}_t$ to maximize the sum of the manager's instantaneous utility $u(c_t, \tilde{a}_t)dt$ and the expected change in the manager's continuation utility W_t, the manager's expected change in continuation utility achieved by a deviation from the recommended effort level a_t to $\tilde{a}$ is

$$\mathbb{E}\left[dW_t | \tilde{a}\right] = \beta_t(-\gamma r W_t)(\tilde{a} - a_t)X_t dt. \tag{16}$$

For the recommended effort level a_t to be incentive-compatible, it must be the case that

$$a_t \in \arg\max_{\tilde{a}} \left\{u(c_t, \tilde{a}) + \beta_t(-\gamma r W_t)(\tilde{a} - a_t)X_t\right\}. \tag{17}$$

According to our assumptions about the cost function $g(a)$, the optimal choice of effort will take on an interior solution in the interval $(0, a_{\max})$. Taking the first-order condition yields

$$u_a(c_t, a_t) + \beta_t(-\gamma r W_t)X_t = 0. \tag{18}$$

Substituting $u_a(c_t, a_t) = -u_c(c_t, a_t)g'(a_t)X_t$ and the no-savings condition (13), we can rearrange the first-order condition as follows:

$$\beta_t = g'(a_t). \tag{19}$$

Intuitively, incentive compatibility requires that the sensitivity, β_t, of the manager's continuation utility to unexpected output shocks is equal to the manager's marginal cost of effort $g'(a_t)X_t$, scaled by the marginal effect of effort on output, X_t.

Lemma 3. *A contract is incentive-compatible and implements zero savings if and only if the solution W_t to the manager's problem has dynamics given by* (15), *where β_t is defined by* (19).

The agent's continuation utility W_t can be used as a state variable to solve for the optimal contract. It is useful to further transform W_t into its certainty equivalent

$$Y_t = -\frac{1}{\gamma r}\ln(-\gamma r W_t), \tag{20}$$

so that we can take Y_t to be a state variable for the investor's problem in place of W_t. Applying Ito's lemma shows that the dynamics of Y_t under an incentive-compatible, zero-savings contract are given by the following equation:

$$dY_t = \frac{1}{2}\gamma r(\sigma\beta_t X_t)^2\,dt + \sigma\beta_t X_t dZ_t^a, \tag{21}$$

where Z_t^a is a Brownian motion under the probability measure induced by effort a. Although W_t is a martingale, the difference in risk aversion between the investor and the manager implies that the certainty equivalent Y_t must have additional drift for each additional unit of volatility. This positive drift will appear in the investor's Hamilton–Jacobi–Bellman (HJB) equation as the cost of providing incentives.

3.2. Solving for the Optimal Contract

We now present a heuristic derivation of the optimal contract. First, we characterize the payment rule to the manager. Recall that the zero-savings condition links the manager's instantaneous utility $u(c_t, a_t)$ and the manager's continuation utility W_t. This link allows us to express the manager's compensation as a function of the state of the firm X_t, the recommended effort level a_t, and the certainty equivalent Y_t:

$$c_t = rY_t + g(a_t)X_t. \tag{22}$$

We see that the manager's compensation is the yield on the manager's continuation utility plus the manager's cost of effort.

Note that Equation (22) also specifies the manager's compensation after investment. As there is no more effort implemented after investment for $t \geq \tau$, the manger's continuation utility stays constant, and the manager's compensation is simply the yield on the manager's continuation utility, $c_t = rY_\tau$. The present dollar value of such compensation is Y_τ.

We take the dynamic programming approach to determine the optimal effort and the investment timing. The investor's value function $v(X, Y)$ depends on both the firm's productivity X and the certainty equivalent of the manager's continuation utility Y. Over any interval of time in which there is no investment, the investor receives the flow equal to X minus compensation c. An application of Ito's lemma to the dynamics of X and Y gives the following Hamilton–Jacobi–Bellman equation for $v(X, Y)$:

$$rv(X,Y) = \max_a \Big\{X - (rY + g(a)X) + aXv_X(X,Y) + \frac{1}{2}\sigma^2X^2v_{XX}(X,Y) + \frac{1}{2}\gamma r(\sigma g'(a)X)^2 \cdot v_Y(X,Y) + \frac{1}{2}(\sigma g'(a)X)^2 v_{YY}(X,Y)\Big\}. \tag{23}$$

As firm value is monotonically increasing in X, the optimal investment time τ follows a threshold rule given by $\tau = \inf\{t | X_t \geq \bar{X}\}$. Following standard solution methods, we find this threshold using value-matching and smooth-pasting conditions:

$$v(\overline{X}, Y) = \frac{\overline{X}k}{r} - P - Y, \tag{24}$$

$$v_X(\overline{X}, Y) = \frac{k}{r}. \tag{25}$$

We can simplify the problem by noting that, because of the absence of wealth effects implied by the manager's CARA preferences, the total firm value is independent of the manager's continuation utility. In other words, the investor's value depends on the manager's continuation utility only by the certainty equivalent cost of the future obligation to the manager. It, thus, holds that $v(X, Y) = V(X) - Y$, where $V(X)$ represents total firm value. Using this relation, we can rewrite Equation (23) as

$$rV(X) = \max_a \Big\{X - (g(a) + \rho(a))X + aXV'(X) + \frac{1}{2}\sigma^2X^2V''(X)\Big\}, \tag{26}$$

where

$$\rho(a) = \frac{1}{2}\gamma r(\sigma g'(a))^2 X \tag{27}$$

represents the incentive cost of effort. Boundary conditions (24) and (25) can be rewritten as

$$V(\overline{X}) = \frac{\overline{X}k}{r} - P, \tag{28}$$

$$V'(\overline{X}) = \frac{k}{r}. \tag{29}$$

In summary, we obtain the following result.

Proposition 1. *The optimal contract is given by the solution to* (26), (28), *and* (29).

4. Growth Options and Optimal Incentives

In this section, we consider the implications of real options for managerial incentives. Our question is how optimal incentives and common measures of pay–performance sensitivity respond to an increase in the size of the growth option as measured by k. Keeping the cost of investment P constant, increased k means that the growth option is larger and more valuable. Although there have been many empirical investigations, reviewed by Murphy (1999) and Frydman and Jenter (2010), into the relation between pay–performance sensitivity and firm size, there has been less attention paid to the relation between investment and pay–performance sensitivity. Our results guide the empirical analysis presented in the following section.

4.1. Measuring Incentives in the Presence of Growth Options

The manager's compensation and incentives depend on the level of effort stipulated by the optimal contract. Therefore, we begin our inquiry with a discussion of managerial effort. Given our assumptions on the manager's effort cost function $g(a)$, the optimal effort is interior and satisfies the first-order condition

$$V'(X) = g'(a^*(X)) + \rho'(a^*(X)). \tag{30}$$

The marginal benefit of effort is the value of increasing the growth rate of productivity or $V'(X)$. The marginal cost of effort includes two terms. The first is the marginal increase in compensation the manager requires to cover the manager's effort. The second is the marginal increase in incentive costs the investor must pay to increase incentives. In the following analysis, we restrict our attention to parameter values such that the maximum $a^*(X)$ satisfies the second-order condition.[3] Optimal effort, which varies with productivity X_t, depends on the fundamental parameters of the model and the presence of growth opportunities.

A direct measure of the manager's incentives in our model is the sensitivity of the manager's dollar (certainty-equivalent) continuation utility to productivity shocks.[4] Prior to investment, the optimal contract sets the quantity to

$$\beta^*(X) = g'(a^*(X)). \tag{31}$$

This expression follows directly from substituting the optimal effort policy $a^*(X)$ into the incentive compatibility condition given by Equation (19). Note that $\beta^*(X)$ is also the expected dollar increase in the manager's dollar wealth resulting from an additional unit of effort as an additional unit of effort is expected to raise productivity by one unit. In other words, $\beta^*(X)$ is the manager's expected-pay–effort sensitivity and is equivalent to pay–performance sensitivity as long as changes in performance are measured by changes in current productivity. Unfortunately, changes in productivity are difficult to measure empirically.

A standard approach for the measurement of incentives is to compute the sensitivity of the manager's wealth to changes in firm value, that is, the manager's value-based pay–performance sensitivity, as first proposed by Jensen and Murphy (1990).[5] This approach is particularly convenient from an empirical point of view as it is based on firm value changes, which are easy to measure. In our model, as in He (2011), the manager's dollar value–based pay–performance sensitivity is equal to the sensitivity of the manager's dollar continuation value to changes in firm value, $V(X)$. Under the optimal contract, this quantity is given by

$$\phi^*(X) = \frac{\beta^*(X)}{V'(X)} = \frac{g(a^*(X))}{V'(X)}. \tag{32}$$

Note that, although $\phi^*(X)$ is closely related to $\beta^*(X)$, it is scaled by the slope of the value function in output $V'(X)$. Thus, the presence of growth options affects $\phi^*(X)$ by changing both $\beta^*(X)$ and $V'(X)$. To relate to the simple analysis that we conduct in Section 2, the size of the growth option affects both the optimal expected-pay–effort sensitivity and the sensitivity of the performance measure, in this case, firm value, to effort. As we show in the next proposition, the wedge between β^* and ϕ^* induced by $V'(X)$ can lead the two quantities to respond in opposite ways to changes in growth option size.

Proposition 2. *As the size of the growth option increases:*

(1) *Optimal effort $a^*(X)$ and expected-pay–effort sensitivity $\beta^*(X)$ increase,*

(2) *Pay–performance sensitivity $\phi^*(X)$ decreases if and only if the incentive cost of effort is more convex than the direct cost of effort, that is, if and only if*

$$\frac{\rho''(a)}{\rho'(a)} > \frac{g''(a)}{g'(a)}. \tag{33}$$

The intuition behind Proposition 2 is as follows. A larger growth opportunity increases the benefits that the investor derives from managerial effort and, hence, increases optimal effort. To induce this increased effort, expected-pay–effort sensitivity increases. The intuition for the second part of the proposition relies on the relation between expected-pay–effort and value–effort sensitivity. First note that, as a unit of effort leads to a unit of expected increase in X, we can interpret $V'(X)$ as value–effort sensitivity. Thus, the first-order condition in Equation (30) states that value–effort sensitivity is equal to expected-pay–effort sensitivity, $\beta^*(X)$, plus the marginal incentive costs evaluated at the optimal level of effort, $\rho'(a^*)$. When the incentive cost of effort is more convex than the direct cost of effort, an increase in optimal effort results in marginal incentive costs comprising a greater proportion of the total marginal effort costs. The first-order condition then implies that expected-pay–effort sensitivity does not increase by as much as value–effort sensitivity in response to an increase in growth-option size. As a result, value-based pay–performance sensitivity decreases.

We note that a wide range of effort cost functions satisfy the condition given in Equation (33). First note that, given the definition of $\rho(a)$, an equivalent way to state the condition is that the marginal cost of effort is convex, that is,

$$g'''(a) > 0, \tag{34}$$

which is common in the contract theory literature (Cheng et al. 2015, Bolton et al. 2016). For example, the condition is satisfied if effort costs are given by a power function, $g(a) = a^\eta$, where $\eta > 2$ by a log-linear function $g(a) = (e^{\eta a} - 1)$ with $\eta > 0$ or by an increasing convex function $g(a) = \frac{a^\eta}{a_{\max} - a}$ with $\eta \geq 1$ (which ensures interior effort).

One way to interpret the shape of the marginal cost of effort is as a measure of the degree of complexity of the task. Some tasks are relatively simple no matter the scale of effort and, therefore, have an increasing but concave marginal cost of effort. Other tasks get more and more complex as the scale of effort increases and, thus, have a convex marginal cost of effort. For example, implementing process systems that increase the productivity of capital likely gets more and more complex as the scale of these systems increases. This latter case applies to our model, and we expect that the condition in Equation (33) should hold in the data.

Another implication of our model is that different definitions of pay–performance sensitivity can have different comparative statics with respect to the same underlying parameter. For example, if we measure pay–performance sensitivity using the sensitivity of the manager's dollar continuation value to percentage changes in firm value, denoted $\varphi^*(X) = V(X)\phi^*(X)$, we can write the comparative static as

$$\frac{\partial \varphi^*(X)}{\partial k} = V(X)\frac{\partial \phi^*(X)}{\partial k} + \frac{\partial V(X)}{\partial k}\phi^*(X). \tag{35}$$

Proposition 2 gives a condition for ϕ^* to be decreasing in the size of the growth option and, thus, for the first term on the right-hand side of (35) to be negative. At the same time, the second term on the right-hand side of (35) is positive as it is always the case that the value of the firm is increasing in the size of the growth option, k, and that the optimal sensitivity ϕ^* is positive. Thus, even if ϕ^* is decreasing in k, φ^* need not be decreasing. As a result, our model provides guidance as to why different conclusions regarding managerial incentives can arise when using seemingly similar measures of pay–performance sensitivity.

4.2. Implications for the Implementation of Incentives

In this section, we discuss the implications that the presence of growth opportunities have for the practical implementation of incentives. A common question in the literature on incentives, for example, as Murphy (1999) summarizes, is what is the shape of incentive structures, either under an optimal contracting model or in the data? To shed light on this question, we first consider a simple implementation of our optimal contract.

The optimal contract can be implemented using a combination of wages and a managed equity account to provide incentives. The manager's wages ensure that the manager has compensation net of effort costs equal to rY, the riskless yield on the manager's certainty equivalent. The managed equity account ensures that the manager's wealth is sensitive to changes in firm value. The share units in the equity account adjust in response to changes in firm value to maintain the managers pay–performance sensitivity ϕ. Alternatively, the equity account can implement the same pay–performance sensitivity using a managed portfolio of options with appropriate delta sensitivity Δ. Varying levels of incentives can be achieved by performance vesting of stock and option grants or by nonlinearity of option holdings.

The typical approach for the analysis of incentives in the context of an implementation such as the preceding one is to determine the convexity or concavity of the manager's managed incentive account with respect to the firm's share price. In our model, this exercise corresponds to determining the slope of pay–performance sensitivity in firm value V. For example, a pay–performance sensitivity increasing in firm value V indicates an incentive scheme convex in share price. However, it is crucial to account for the fact illustrated in Section 2 and Proposition 2 that pay–performance sensitivity is not equivalent to incentives.

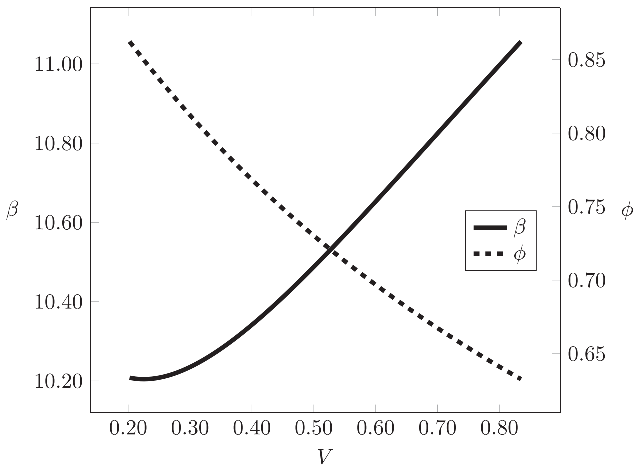
Suppose that managerial incentives measured by pay–effort sensitivity β are increasing in firm value V. Recall that pay–performance sensitivity ϕ equals β divided by $V'(X)$, value–effort sensitivity. In the presence of growth options, as productivity X increases and the firm gets closer to the investment threshold, $V'(X)$ increases. As a result, ϕ must be increasing less steeply in V than β is and, in fact, can even be decreasing in V. The intuition is that growth options increase the impact of the manager on firm value by generating convexity in firm value, $V''(X) > 0$, so that the manager's pay can be less sensitive to performance and still provide sufficient incentives. To illustrate the distinction between pay–effort sensitivity (incentives) and pay–performance sensitivity, we plot pay–effort sensitivity β and pay–performance sensitivity ϕ against firm value V in Figure 1. We see that pay–effort sensitivity is increasing in firm value, implying that optimal effort is also increasing in firm value, yet pay–performance sensitivity is decreasing in firm value.

Figure 1 illustrates that, in firms with significant growth opportunities, it is not necessary for the optimal contract to prescribe an incentive scheme that is convex in firm value because firm value itself is convex. This pattern is broadly consistent with the common practice of granting employees in-the-money stock options in technology companies.[6] In January 2014, GoPro (GPRO) issued employees stock options, which had a strike price of \$16.22 per share, as part of their compensation. This price was significantly lower than GPRO's June 2014 IPO price of \$24.00 per share. Other firms that did this include Snap (SNAP), which in 2014 offered options at a strike price of \$1.00 per share when its latest valuation put it at \$3.40, as well as Veritone (VERI), which offered options at a strike of \$8.24 per share against an IPO price of \$15.00 per share. Given the institutional constraints that necessitate the use of options in employee compensation schemes, granting in-the-money options reduces the convexity of the incentive package compared with an incentive package featuring at-the-money or out-of-the-money options and, thus, more closely matches the desired convexity of the optimal contract. By highlighting the fact that convexity of pay–performance sensitivity can come from either convexity in the compensation structure or convexity of the underlying firm value, our model helps explain the popular choice to use in-the-money options in compensation packages.

5. Empirical Findings

In this section, we provide evidence that value-based pay–performance sensitivity decreases with the size of growth opportunities.

Figure 1. The Shape of Incentives in Firm Value



Notes. Optimal pay–effort β and pay–performance sensitivity ϕ are presented over a range of firm value V. Parameters used for this plot are given by $r = 10\%$, $a_{\max} = 5\%$, $\sigma = 20\%$, $\theta = 1{,}000$, $\gamma = 1$, $k = 1.75$, and $p = 0.25$. The effort function $g(a) = \theta \frac{a^3}{a_{\max} - a}$ is chosen to satisfy the conditions laid out in Proposition 2.

5.1. Data

We merge data from three main sources. We use data on pay–performance sensitivity for the 1992–2014 period at the manager–firm level from the website of Lalitha Naveen.[7] An empirical equivalent of our model's value-based pay–performance sensitivity is Jensen and Murphy's (1990) measure of pay–performance sensitivity, that is, dollar changes in manager wealth divided by dollar changes in firm value. We call this variable Jensen and Murphy's PPS, and we use the logarithm of it as the dependent variable in the regressions in this section. We merge the PPS data with data on manager characteristics from Execucomp and data on firm characteristics from Compustat for the same period.

We use several proxies for growth opportunities. As there is no consensus in the literature on the measurement of growth opportunities, our approach is to use a broad set of several proxies suggested in previous studies and to show that our findings are robust across these proxies. Our first proxy for growth opportunities is the market-to-book ratio. Market value is defined as the market value of equity plus the book value of debt divided by total assets. A number of studies, including Gompers (1995), Collins and Kothari (1989), Korteweg and Polson (2009), and He et al. (2014), have used the market-to-book ratio as a proxy for growth options, and previous theoretical work by Berk et al. (1999) and Carlson et al. (2004) establishes the link between growth options and market-to-book ratios. The use of price data in our proxies is both a blessing and a curse. It is grounded in the assumption that the market incorporates a firm's future investment opportunities into its stock price, thus elevating the market value of a firm's assets beyond the book value of those assets. However, as discussed in Berk (1995), the potential for mispricing means that it is unsatisfactory to rely solely on this measure. Equally worrying, a relation based on price-based measures can be unrelated to the operating characteristics of the firms and can instead reflect changes in market risk premiums. Despite these well-founded concerns, previous research by Adam and Goyal (2008) and Kallapur and Trombley (1999) has found that the market-to-book ratio performs well as a proxy for growth options and investment opportunities. Nevertheless, we also include several non–price-based growth-option proxies.

Our second proxy is the value-to-book ratio as introduced in Rhodes-Kropf et al. (2005). This measure attempts to preserve the intuition behind the market-to-book ratio while correcting for potential mispricing by estimating firm value using a regression. Rhodes-Kropf et al. (2005) decomposes the market-to-book ratio into three terms: (i) firm-specific mispricing, (ii) industry mispricing, and (iii) value to book. However, we use the two-term decomposition found in Lyandres and Zhdanov (2013): (i) firm-specific, within-industry mispricing and (ii) value to book. We estimate the value of firm i in industry j at time t by performing a within-industry j regression with logarithms of market value M on book value B:

$$\log M_{ijt} = \alpha_{jt} + \beta_{jt} \log B_{ijt} + \varepsilon_{jt}. \tag{36}$$

Subtracting the log book value from the fitted value from the regression $\hat{M}_{ijt}$ yields an estimate of log value to book. As discussed in Rhodes-Kropf et al. (2005), the link between firm value, corrected for mispricings, and book value rests on two assumptions: the first links future returns on equity to future discount rates within industries, and the other assumes that book equity grows at a constant rate. To the extent that these assumptions are unsatisfactory, the value-to-book ratio we use is an imperfect proxy.

In addition to market-based proxies, we include research and development (R&D) expenditures, an investment-based measure used in Kallapur and Trombley (1999) and Lyandres and Zhdanov (2013). We scale R&D expenditures by the book value of assets. In our main analysis, we omit firms with missing R&D expenditures and, as a robustness check, repeat this analysis using all firms, setting R&D expenditures to zero if they are missing. These measures are independent of a firm's price data and are, thus, uncontaminated by mispricing. The downside is that industry-specific accounting practices restrict the classification of R&D expense, exposing this measure to concerns of a systematic bias that varies by industry. A firm's growth opportunities may include acquisition opportunities or investments in subsidiaries, which are not included in R&D expenses. Kallapur and Trombley (1999) finds that R&D spending is inconsistently correlated with realized measures of realized growth in a three- to five-year horizon, making R&D-based measures a weaker proxy for short-term investment opportunities than the market-to-book ratio, which they find to be a more relevant proxy.

Another set of investment-based measures is based on capital expenditures and following Purnanandam and Rajan (2017). This measure assumes that capital expenditures correspond to the exercise of growth options and their conversion into physical assets. As with R&D, capital expenditure–based measures are independent of a firm's stock price. To account for the fact that a firm's capital expenditure includes maintenance costs for an existing capital base, we calculate our first measure as the residual of a regression of firm CapEx scaled by assets, including a firm fixed effect to capture the predictable investment level of the firm. In terms of regression coefficients, this produces identical estimates to a regression in which capital expenditure is directly used as a regressor. The second measure is the residual from a one-lag autoregressive model of expected scaled capital expenditures and is, thus, a better measure of unanticipated capital expenditures.

These proxies are motivated by the fact that a firm's reported capital expenditures might reflect preexisting projects or other ongoing commitments, making the level of capital expenditures a noisy measurement that misrepresents a firm's growth opportunities. By taking the residual, we better capture the discretionary or uncommitted portion of a firm's capital expenditures, which better captures the exercise (and, thus, reduction) of growth options at the firm. A potential downside of capital expenditure–based measures is that the price of capital is affected by economy-wide demand, and thus, the firm's level of capital expenditures is exposed to mispricing at a market- or industry-wide level, albeit in a more indirect way than a measure based on the firm's stock price.

Standard measures of Tobin's q fail to account for intangible capital, which, per accounting rules, is usually expensed rather than capitalized and, thus, not found on a firm's balance sheet. The augmented Tobin's q measure of Peters and Taylor (2017) accounts for firms' intangible assets using an accruals-based accounting approach. In doing so, their measure better captures the market value of firms' assets and predicts investment better than standard estimates of firm-level q.

Each of our previous proxies captures the presence of growth options and also contains measurement error. We use principal component analysis to extract a statistical measure of growth options and reduce the impact of measurement error. By taking the first principal component, we extract the common variation in these proxies, which we call hybrid growth opportunities. Under the assumption that the other determinants of our proxies are uncorrelated with the true measure of growth options, hybrid growth opportunities better capture firms' underlying growth options. The drawback of this approach is that, because of sample limitations, we are limited to firm-year observations for which we have observations of all our growth proxies, thus limiting the sample and our statistical power.

Our sample then includes all firm–executive combinations from ExecuComp from 1992 to 2015. The Execucomp database focuses on the largest 1,500 publicly traded companies and has similar industry coverage to the Compustat database. We employ a broad set of standard firm- and manager-level control variables; Appendix B provides their exact definitions. Additionally, we include year and industry dummies (the latter based on the 48 Fama–French industries) to control for time and industrial fixed effects in managerial incentives. We winsorize the continuous variables at the 1st and 99th percentiles. In all the regressions presented, we lag independent variables by one year (as in, e.g., He et al. 2014). Table 1 displays summary statistics from our data set.

5.2. Results

We regress Jensen and Murphy's PPS variable on the market-to-book variable and various controls for manager and firm characteristics. The results for these regressions are presented in Table 2 alongside results for regressions using our other market-based measure of growth options, value to book. The dependent variable is the logarithm of the dollar-to-dollar pay–performance sensitivity (Jensen and Murphy's PPS). We construct the fixed effects for industry fixed effect using the Fama and French (1997) 48 sectors. The fixed effects in the model in column (3) are in firm–executive pairs. All of the standard errors are robust and clustered at the firm level. The main effect of interest can be seen in the coefficient on market to book in column (3). This coefficient states that a one standard deviation change in market to book is associated with a roughly 5.7% decrease in Jensen and Murphy's PPS. Although the magnitude of the effect on PPS is smaller than that of firm size, this effect is still economically significant.

For our value-to-book results, other than the alternative measure of growth options, all of the other controls are identical to those in columns (1)–(3). The coefficient in column (6) states that a one standard deviation increase in value to book is associated with a 1.1% decrease in Jensen and Murphy's PPS. We note that the effect of the value-to-book ratio is statistically significant and of a larger magnitude than our other specifications, and we also find that the quantitative effect associated with a one standard deviation change in the value-to-book ratio is significantly stronger when we focus on subsamples of our panel. For example, when we restrict our sample to the 2006–2014 period and still include firm–manager and year fixed effects, we find that a one standard deviation change is associated with a decline of 4.5% in PPS, which is in line with our estimates using the market-to-book ratio as a proxy.

Next, we regress Jensen and Murphy's PPS on R&D and various controls for manager and firm characteristics. The results for these regressions are given in Table 3. The dependent variable is the logarithm of the dollar-to-dollar pay–performance sensitivity. All of the other controls are identical to those in Table 2. Again, the main effect of interest is the coefficient on R&D in column (3). A one standard deviation increase in R&D expenses is associated with a 5.0% decrease in Jensen and Murphy's PPS, which is on the same order of magnitude as our previous regressions. We note that reported R&D expenses, although directly measuring growth opportunities, suffer from relatively low coverage in the Compustat database. We obtain the same results if we take an alternative approach and substitute missing R&D expenses for zero.

As another robustness check, we regress Jensen and Murphy's PPS on the capital expenditures variable along with the same set of controls for manager and firm characteristics. The results of these regressions are in Table 4. The dependent variable is again the logarithm of dollar-to-dollar pay sensitivity. The coefficient of 0.391 on capital expenditures in column (3) shows that a one standard deviation increase in capital expenditures is associated with a 2.3% increase in PPS. Significantly, because capital expenditures represent the exercise of growth options, the expected sign of our estimate is reversed. An increase in growth options leads to a decrease in PPS, and so the exercise of growth options leads to an increase in PPS. We get an estimate of similar magnitude when we replace capital expenditures with capital expenditure innovations as a dependent variable. We obtain the innovations from fitting an AR(1) model to a firm's capital expenditures and capturing the unanticipated or discretionary portion of a firm's investments. In situations in which a large portion of a firm's investments are recurring or reflect ongoing commitments, it is the incidence of new projects that is informative about the exercise of growth options.

We also regress Jensen and Murphy's PPS on augmented Tobin's q and our hybrid measure of growth opportunities. The results for these regressions are given in Table 5. All other controls are identical to those in Table 2. The main effect of interest is the coefficient on Tobin's q in column (3) and the coefficient on hybrid growth opportunities in column (6). This coefficient shows that a one standard deviation increase in Tobin's q is associated with a 2.7% decrease

Table 1. Summary Statistics

	Observations	Mean	Standard deviation	Minimum	Maximum	Median
Jensen and Murphy PPS	182,395	1.070	2.646	0.002	18.858	0.285
$ to % PPS (PPS2)	182,447	197.307	494.850	0.193	3,573.206	45.971
Wealth performance sensitivity (PPS3)	35,725	31.252	104.043	0.000	888.708	6.636
Market to book	182,391	1.917	1.293	0.771	8.529	1.473
Value to book	182,432	1.735	0.566	0.956	4.023	1.636
R&D	95,546	0.054	0.069	0.000	0.366	0.027
Total *q*	154,342	1.336	1.426	0.044	7.899	0.851
Capital expenditure	175,638	0.054	0.054	0.000	0.294	0.038
Firm size	182,432	9,897.879	27,705.211	50.598	202,475.000	1,643.600
Cash flow volatility	182,447	0.032	0.035	0.002	0.231	0.023
Firm age	182,447	21.735	13.878	0.000	56.000	19.000
Tangibility	180,163	0.270	0.237	0.003	0.880	0.197
Profitability	180,986	0.126	0.099	−0.242	0.423	0.124
Advertisement	182,447	0.011	0.029	0.000	0.176	0.000
Leverage	181,668	0.223	0.183	0.000	0.820	0.205
Dividend paying	182,097	0.556	0.497	0.000	1.000	1.000
CEO chair	115,893	0.589	0.492	0.000	1.000	1.000
Fraction of inside directors	115,893	0.284	0.163	0.000	1.000	0.250
CEO	182,447	0.186	0.389	0.000	1.000	0.000
Female	182,447	0.059	0.236	0.000	1.000	0.000

Notes. The sample covers all executives and firms in Execucomp from 1992 to 2015 and is merged with Compustat data. Jensen and Murphy PPS is dollar-to-dollar pay–performance sensitivity. Control variables are defined in Appendix B. R&D, research and development.

in PPS, and a one standard deviation increase in our hybrid measure is associated with a 4.2% decrease in PPS, both of which are consistent with our previous specifications.

Finally, we present results of regressions of hybrid growth opportunities on alternative measures of pay–performance sensitivity. These results are given in Table 6. Given the differing scales of these measures of PPS, it is more informative to consider the scaled interpretation of the coefficients in columns (3) and (6), corresponding to regressions on dollar-to-percentage PPS and wealth performance sensitivity, respectively (Edmans et al. 2008). The economic interpretation of these coefficients is that a one standard deviation increase in hybrid growth opportunities increases the PPS measures by 5.1% and 3.5%, respectively. Consistent with the predictions of our model, the effect of growth opportunities on Jensen and Murphy PPS can be negative, whereas its effect on percentage-based PPS measures is positive.

The presented regression coefficients are from ordinary least squares and fixed-effects models. Similar results are obtained from a random-effects model. In Appendix C, we present the results of an analysis in which we address potential biases introduced to the Execucomp database by the inclusion of backfilled data. We find that our results are qualitatively identical and quantitatively larger in magnitude.

6. Redeployability and Optimal Incentives

Although our main focus is on investment options, many real options within firms pertain to the optimal time to abandon an ongoing project. In this section, we investigate the implications of abandonment options for the measurement of incentives. Specifically, we consider the redeployability of capital by assuming that at any point the firm can liquidate its existing capital for a price P. For simplicity, we abstract from the growth option and assume that the firm has a fixed capital stock until liquidation. Given this assumption, the problem of providing the manager with incentives is essentially the same as the case we consider in Section 3. The optimal contract and firm value are given by the solution to the following Hamilton–Jacobi–Bellman equation for $V(X)$:

$$rV(X) = \max_{a\in[0,a_{\max}]}\Big\{X - (g(a) + \rho(a))X + aXV'(X) + \frac{1}{2}\sigma^2X^2V''(X)\Big\}, \quad (37)$$

where $\rho(a)$ is the cost of incentives as derived previously. Again, as firm value monotonically increases with manager effort a, the optimal abandonment policy will be to liquidate the firm when X crosses some lower boundary $\underline{X}$, pinned down by the following value-matching and smooth-pasting conditions:

$$V(\underline{X}) = P, \quad (38)$$

$$V'(\underline{X}) = 0. \quad (39)$$

As X tends to infinity, the probability of abandonment becomes zero. Moreover, the incentive cost of effort grows faster than the increase in cash flow because of

Table 2. Market-Based Proxies and Pay–Performance Sensitivity

	Market to book			Value to book		
	(1) log (PPS1)	(2) log (PPS1)	(3) log (PPS1)	(4) log (PPS1)	(5) log (PPS1)	(6) log (PPS1)
Market to book	−0.066***	−0.063***	−0.041***			
	(−8.75)	(−5.85)	(−6.63)			
Value to book				−0.071***	−0.068**	−0.019
				(−3.06)	(−2.41)	(−1.29)
Firm size	−0.408***	−0.378***	−0.373***	−0.404***	−0.383***	−0.361***
	(−48.50)	(−35.50)	(−18.70)	(−47.40)	(−35.75)	(−18.19)
Cash flow volatility		−1.028***	−0.858***		−1.359***	−0.966***
		(−3.50)	(−3.92)		(−4.65)	(−4.38)
Firm age		−0.087***	−0.317***		−0.077***	−0.302***
		(−4.32)	(−6.17)		(−3.84)	(−5.89)
Tangibility		−0.333***	−0.145		−0.282***	−0.124
		(−3.55)	(−1.28)		(−2.96)	(−1.09)
Profitability		−0.339**	−0.093		−0.742***	−0.257***
		(−2.46)	(−1.03)		(−5.48)	(−2.73)
Advertisement		−0.368	−0.748		−0.473	−0.803
		(−0.69)	(−1.34)		(−0.86)	(−1.43)
Advertisement missing		0.033	0.011		0.035	0.007
		(1.11)	(0.51)		(1.16)	(0.33)
Leverage		0.496***	0.393***		0.540***	0.420***
		(6.28)	(6.35)		(6.82)	(6.80)
Dividend paying		−0.170***	−0.137***		−0.169***	−0.139***
		(−5.99)	(−5.28)		(−5.90)	(−5.37)
CEO chair		0.164***	0.023*		0.165***	0.021*
		(7.95)	(1.86)		(7.93)	(1.76)
Fraction of inside directors		0.684***	−0.079		0.681***	−0.081*
		(8.63)	(−1.61)		(8.56)	(−1.66)
CEO		1.745***	0.400***		1.745***	0.400***
		(93.88)	(23.27)		(93.81)	(23.32)
Female		−0.267***			−0.264***	
		(−8.95)			(−8.85)	
Industry dummies	Yes	Yes	No	Yes	Yes	No
Firm–manager dummies	No	No	Yes	No	No	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	158,278	92,715	92,715	158,309	92,730	92,730
R^2	0.278	0.503	0.121	0.276	0.502	0.119

Notes. The sample covers all executives and firms in Execucomp from 1992 to 2015 and is merged with Compustat data. The dependent variable is the logarithm of the dollar-to-dollar pay–performance sensitivity. Market value is defined as the market value of equity plus the book value of debt divided by total assets. Value to book is calculated as the fitted value from a within-industry regression of log market value on log book value less log book value. Control variables are defined in Appendix B. *t*-statistics based on heteroskedasticity-consistent, and firm-level clustered standard errors are provided in parentheses. PPS, pay–performance sensitivity.

$^*p < 0.10$; $^{**}p < 0.05$; $^{***}p < 0.01$.

effort, and therefore, the optimal effort will tend to zero. Thus, the value function must approach a linear function consistent with zero effort and no growth as X goes to infinity:

$$\lim_{X\to\infty} V'(X) = \frac{1}{r}. \tag{40}$$

As in the growth-options case, expected-pay–effort sensitivity and pay–performance sensitivity diverge as redeployability increases so long as incentive costs are more convex than effort costs.

Proposition 3. *As redeployability increases:*

(1) *Optimal effort $a^*(X)$ and expected-pay–effort sensitivity $\beta^*(X)$ decrease.*

(2) *Pay–performance sensitivity $\phi^*(X)$ increases if the incentive cost of effort is more convex than the direct cost of effort, that is, if*

$$\frac{\rho''(a)}{\rho'(a)} > \frac{g''(a)}{g'(a)}.$$

The intuition behind this result is symmetric to that of Proposition 2. As redeployability increases, the

Table 3. R&D-Based Proxies and Pay–Performance Sensitivity

	R&D			R&D (zero if missing)		
	(1) log (PPS1)	(2) log (PPS1)	(3) log (PPS1)	(4) log (PPS1)	(5) log (PPS1)	(6) log (PPS1)
R&D	−0.592***	−0.469	−0.649**			
	(−2.63)	(−1.41)	(−2.40)			
R&D (zero if missing)				−0.643***	−0.437	−0.541*
				(−2.91)	(−1.45)	(−1.93)
Firm size	−0.430***	−0.414***	−0.361***	−0.401***	−0.380***	−0.366***
	(−42.47)	(−32.85)	(−13.82)	(−46.82)	(−35.36)	(−17.94)
Cash flow volatility		−1.483***	−0.792***		−1.297***	−0.947***
		(−4.11)	(−3.07)		(−4.37)	(−4.29)
Firm age		−0.078***	−0.338***		−0.078***	−0.298***
		(−3.44)	(−5.42)		(−3.87)	(−5.83)
Tangibility		−0.139	0.016		−0.289***	−0.106
		(−1.14)	(0.10)		(−3.03)	(−0.93)
Profitability		−0.604***	−0.310**		−0.794***	−0.278***
		(−3.77)	(−2.57)		(−5.84)	(−2.95)
Advertisement		−0.012	−0.802		−0.528	−0.791
		(−0.02)	(−1.18)		(−0.97)	(−1.41)
Advertisement missing		0.053	−0.019		0.030	0.008
		(1.47)	(−0.60)		(1.00)	(0.34)
Leverage		0.617***	0.360***		0.534***	0.421***
		(7.16)	(4.38)		(6.63)	(6.84)
Dividend paying		−0.186***	−0.176***		−0.172***	−0.138***
		(−5.13)	(−5.91)		(−6.02)	(−5.32)
CEO chair		0.165***	0.010		0.163***	0.021*
		(6.58)	(0.64)		(7.85)	(1.73)
Fraction of inside directors		0.515***	−0.099*		0.675***	−0.081*
		(5.25)	(−1.67)		(8.50)	(−1.66)
CEO		1.745***	0.402***		1.745***	0.399***
		(74.98)	(18.25)		(93.81)	(23.29)
Female		−0.256***			−0.265***	
		(−7.56)			(−8.86)	
Industry dummies	Yes	Yes	No	Yes	Yes	No
Firm–manager dummies	No	No	Yes	No	No	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	82,431	50,088	50,088	158,309	92,730	92,730
R^2	0.280	0.530	0.119	0.276	0.502	0.119

Notes. The sample covers all executives and firms in Execucomp from 1992 to 2015 and is merged with Compustat data. The dependent variable is the logarithm of the dollar-to-dollar, pay–performance sensitivity. Control variables are defined in Appendix B. *t*-statistics based on heteroskedasticity-consistent, and firm-level clustered standard errors are provided in parentheses. PPS, pay–performance sensitivity; R&D, research and development.

*$p < 0.10$; **$p < 0.05$; ***$p < 0.01$.

marginal benefit of effort decreases, and incentives optimally decrease. When incentive costs are more convex than direct-effort costs, marginal incentives costs decrease proportionally more than marginal effort costs. As the sum of marginal effort and incentive costs are equal to the marginal benefit of effort, the marginal benefit of effort decreases by less than the marginal cost of effort, which, in turn, implies that pay–performance sensitivity increases even though incentives decrease.

Although we do not test our results on redeployability and pay–performance sensitivity to the data, we note that they provide a further dimension along which to determine the empirical validity of our theory. For example, one could examine the relation between changes in industry-level redeployability and pay–performance sensitivity.

7. Conclusion

We analyze a model in which an investor needs a manager to operate a firm. In our setting, the investor would like the manager to exert costly effort and grow the firm but is unable to directly observe whether the manager exerts the recommended effort. To incentivize

Table 4. Capex-Based Proxies and Pay–Performance Sensitivity

	Capex			Capex innovations		
	(1) log (PPS1)	(2) log (PPS1)	(3) log (PPS1)	(4) log (PPS1)	(5) log (PPS1)	(6) log (PPS1)
Capital expenditure	0.361	1.659***	0.431***			
	(1.62)	(5.45)	(3.12)			
Capex innovations				0.459	1.429***	0.155
				(1.58)	(4.65)	(1.34)
Firm size	−0.397***	−0.378***	−0.360***	−0.387***	−0.371***	−0.340***
	(−46.15)	(−34.88)	(−17.61)	(−38.12)	(−30.65)	(−13.95)
Cash flow volatility		−1.524***	−1.009***		−1.225***	−1.008***
		(−5.23)	(−4.57)		(−3.73)	(−3.98)
Firm age		−0.065***	−0.295***		−0.074***	−0.337***
		(−3.23)	(−5.62)		(−3.29)	(−5.34)
Tangibility		−0.520***	−0.198*		−0.386***	0.012
		(−4.72)	(−1.66)		(−3.66)	(0.09)
Profitability		−0.912***	−0.287***		−0.821***	−0.180*
		(−6.60)	(−3.04)		(−5.53)	(−1.71)
Advertisement		−0.553	−0.859		−0.470	−0.893
		(−1.01)	(−1.51)		(−0.81)	(−1.57)
Advertisement missing		0.032	−0.000		0.036	0.005
		(1.04)	(−0.00)		(1.06)	0.16
Leverage		0.576***	0.437***		0.519***	0.449***
		(7.23)	(6.95)		(6.09)	(6.35)
Dividend paying		−0.159***	−0.140***		−0.166***	−0.139***
		(−5.54)	(−5.41)		(−5.39)	(−4.90)
CEO chair		0.163***	0.021*		0.171***	0.037**
		(7.87)	(1.67)		(7.46)	(2.47)
Fraction of inside directors		0.680***	−0.075		0.790***	−0.072
		(8.39)	(−1.50)		(8.68)	(−1.28)
CEO		1.749***	0.407***		1.670***	0.415***
		(92.82)	(23.19)		(82.87)	(19.73)
Female		−0.267***			−0.235***	
		(−9.00)			(−6.85)	
Industry dummies	Yes	Yes	No	Yes	Yes	No
Firm–manager dummies	No	No	Yes	No	No	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	151,830	89,646	89,646	92,500	64,828	64,828
R^2	0.278	0.505	0.119	0.274	0.516	0.114

Notes. The sample covers all executives and firms in Execucomp from 1992 to 2015 and is merged with Compustat data. The dependent variable is the logarithm of the dollar-to-dollar, pay–performance sensitivity. Capital expenditure innovation is calculated as the residual from a one-lag firm-specific autoregressive model of expected scaled capital expenditures. Control variables are defined in Appendix B. *t*-statistics based on heteroskedasticity-consistent, and firm-level clustered standard errors are provided in parentheses. PPS, pay–performance sensitivity.

*$p < 0.10$; **$p < 0.05$; ***$p < 0.01$.

the recommended effort level, the investor provides the manager with exposure to firm cash flows as part of the manager's compensation package. The investor also has an option to increase the firm's capital level, increasing the effect of the manager's effort on firm value. We characterize the optimal contract between the investor and the manager and analyze the manager's incentives in this setting.

An optimal contract provides the manager with sensitivity to the firm's performance through exposure to unexpected output shocks. Because of the growth option, the manager's expected-pay–effort sensitivity differs from the manager's pay–performance sensitivity. We develop conditions under which decreasing pay–performance sensitivity occurs alongside increasing expected-pay–effort sensitivity, that is, incentives. We go on to document evidence consistent with our model. Pay–performance sensitivity is strongly and negatively related to proxies for growth options.

Table 5. Additional Proxies and Pay–Performance Sensitivity

	Total q			Hybrid		
	(1) log (PPS1)	(2) log (PPS1)	(3) log (PPS1)	(4) log (PPS1)	(5) log (PPS1)	(6) log (PPS1)
Total q	−0.018**	−0.041***	−0.022***			
	(−2.53)	(−3.94)	(−3.45)			
Hybrid growth opportunities				−0.053***	−0.061***	−0.033***
				(−6.41)	(−5.55)	(−4.96)
Firm size	−0.419***	−0.390***	−0.361***	−0.428***	−0.394***	−0.371***
	(−49.07)	(−35.46)	(−17.15)	(−49.13)	(−36.10)	(−17.24)
Cash flow volatility		−1.235***	−0.921***		−1.029***	−0.909***
		(−4.04)	(−4.04)		(−3.35)	(−3.97)
Firm age		−0.075***	−0.324***		−0.073***	−0.324***
		(−3.63)	(−6.25)		(−3.57)	(−6.25)
Tangibility		−0.277***	−0.175		−0.263***	−0.163
		(−2.94)	(−1.57)		(−2.80)	(−1.46)
Profitability		−0.393***	−0.168*		−0.340**	−0.139
		(−2.78)	(−1.75)		(−2.46)	(−1.45)
Advertisement		−0.497	−1.096*		−0.328	−1.056*
		(−0.90)	(−1.81)		(−0.59)	(−1.73)
Advertisement missing		0.046	−0.013		0.043	−0.007
		(1.47)	(−0.46)		(1.37)	(−0.27)
Leverage		0.560***	0.415***		0.529***	0.406***
		(7.54)	(6.41)		(7.08)	(6.27)
Dividend paying		−0.184***	−0.154***		−0.186***	−0.154***
		(−6.31)	(−5.95)		(−6.39)	(−5.89)
CEO chair		0.149***	0.020		0.147***	0.020
		(6.88)	(1.54)		(6.78)	(1.54)
Fraction of inside directors		0.695***	−0.067		0.676***	−0.073
		(8.38)	(−1.32)		(8.10)	(−1.44)
CEO		1.745***	0.405***		1.744***	0.406***
		(89.25)	(21.93)		(89.27)	(21.85)
Female		−0.264***			−0.268***	
		(−8.51)			(−8.60)	
Industry dummies	Yes	Yes	No	Yes	Yes	No
Firm–manager dummies	No	No	Yes	No	No	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	134,062	80,482	80,482	133,092	79,985	79,985
R^2	0.287	0.511	0.123	0.289	0.512	0.124

Notes. The sample covers all executives and firms in Execucomp from 1992 to 2015 and is merged with Compustat data. The dependent variable is the logarithm of the dollar-to-dollar, pay–performance sensitivity. Tobin's q is taken from Wharton Research Data Services based on the methodology of Peters and Taylor (2017). Hybrid growth opportunities is calculated as the first principal component of market to book, value to book, scaled R&D, and scaled Capex. Control variables are defined in Appendix B. t-statistics based on heteroskedasticity-consistent, and firm-level clustered standard errors are provided in parentheses. PPS, pay–performance sensitivity; R&D, research and development.

*$p < 0.10$; **$p < 0.05$; ***$p < 0.01$.

Although our model provides clean results on managerial incentives, we acknowledge that a variety of other factors may interact with and complicate real-world manager compensation. In particular, the origin and size of growth options at a firm, which we take as exogenously given, are themselves decisions made by firms and are affected by moral hazard. Further research could explore the multifaceted role of managerial effort in simultaneously creating growth options, increasing growth-option size, and increasing firm productivity.

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Table 6. Alternative Measures of Pay–Performance Sensitivity

	Dollar-to-percentage PPS			Wealth performance sensitivity		
	(1) log (PPS2)	(2) log (PPS2)	(3) log (PPS2)	(4) log (PPS3)	(5) log (PPS3)	(6) log (PPS3)
Hybrid growth opportunities	0.369***	0.284***	0.149***	0.246***	0.180***	0.037***
	(36.16)	(22.59)	(15.45)	(15.53)	(9.56)	(2.65)
Firm size	0.513***	0.570***	0.144***	0.053***	0.078***	−0.021
	(60.03)	(53.00)	(5.14)	(3.99)	(4.60)	(−0.55)
Cash flow volatility		−1.120***	−0.641**		−1.589***	−0.192
		(−3.23)	(−1.97)		(−3.26)	(−0.36)
Firm age		−0.085***	−0.303***		−0.085***	−0.255***
		(−3.73)	(−4.61)		(−2.70)	(−2.78)
Tangibility		−0.249***	−0.260*		0.201	−0.155
		(−2.66)	(−1.70)		(1.42)	(−0.83)
Profitability		2.065***	1.006***		1.313***	0.606***
		(12.37)	(7.90)		(5.83)	(3.17)
Advertisement		0.097	−1.988***		−0.553	−2.259**
		(0.16)	(−2.59)		(−0.49)	(−2.02)
Advertisement missing		0.027	−0.014		−0.058	−0.042
		(0.79)	(−0.39)		(−0.98)	(−0.79)
Leverage		−0.535***	−0.362***		−0.607***	−0.170
		(−6.42)	(−4.50)		(−4.84)	(−1.54)
Dividend paying		−0.139***	−0.190***		0.006	−0.099**
		(−4.29)	(−5.71)		(0.13)	(−2.09)
CEO chair		0.163***	0.029*		0.458***	−0.003
		(6.92)	(1.76)		(12.39)	(−0.14)
Fraction of inside directors		0.751***	−0.079		1.702***	0.042
		(7.97)	(−1.21)		(11.37)	(0.40)
CEO		1.724***	0.390***		0.713***	0.144***
		(91.95)	(19.32)		(21.96)	(5.55)
Female		−0.288***			−0.413***	
		(−8.65)			(−3.76)	
Industry dummies	Yes	Yes	No	Yes	Yes	No
Firm–manager dummies	No	No	Yes	No	No	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	133,130	79,997	79,997	27,855	16,630	16,630
R^2	0.301	0.523	0.257	0.165	0.251	0.0781

Notes. The sample covers all executives and firms in Execucomp from 1992 to 2015 and is merged with Compustat data. The dependent variable for columns (1)–(3) is the logarithm of the dollar-to-percentage pay–performance sensitivity. The dependent variable for columns (4)–(6) is the logarithm of wealth performance sensitivity. Hybrid growth opportunities is calculated as the first principal component of market to book, value to book, scaled R&D, and scaled Capex. Control variables are defined in Appendix B. *t*-statistics based on heteroskedasticity-consistent, and firm-level clustered standard errors are provided in parentheses. PPS, pay–performance sensitivity; R&D, research and development.

*$p < 0.10$; **$p < 0.05$; ***$p < 0.01$.

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Appendix A. Proofs

Proof of Lemma 2. Suppose that $\{\tilde{c}, \tilde{a}\}$ solves the manager's problem for a given contract Π and results in zero savings. Further suppose that the manager is endowed with savings $\mathcal{S} > 0$ at time $t \geq 0$. As the manager has CARA preferences, the optimal consumption plan for $s \geq t$ is $\tilde{c}_s + r\mathcal{S}$, and the manager's effort provision $\tilde{a}_s$ is unchanged. Thus, an increase in savings from zero to $\mathcal{S}$ increases the manager's instantaneous utility by a factor of $e^{-\gamma r \mathcal{S}}$ for $s \geq t$. Therefore, we can write the manager's utility for contracts Π and savings $\mathcal{S}$ as follows:

$$W_t(\Pi;\mathcal{S}) = e^{-\gamma r\mathcal{S}} W_t(\Pi;0). \tag{A.1}$$

For the zero-savings condition to hold, it must be the case that

$$u_c(\tilde{c}_t,\tilde{a}_t) = \frac{\partial}{\partial\mathcal{S}} W_t(\Pi;0), \tag{A.2}$$

which implies that $-\gamma u(\tilde{c}_t,\tilde{a}_t) = -\gamma r W_t(\Pi;0)$ or $u(\tilde{c}_t,\tilde{a}_t) = rW_t(\Pi;0)$. □

Proof of Lemma 3 and Verification of Incentive Compatibility. We restrict the manager's consumption plan to satisfy the following integrability and transversality conditions:

$$\mathbb{E}\left[\int_0^\infty -e^{-rs}u(\tilde{c}_s,\tilde{a}_s)\,ds\right] < \infty, \tag{A.3}$$

$$\lim_{t\to\infty} S_t \overset{a.s}{=} 0. \tag{A.4}$$

Consider an arbitrary contract, comprised of the tuple (β_t, a_t, τ), and note that, if W_t solves Equation (15), then W_t is equal, by construction, to the manager's continuation utility from choosing savings $S_t = 0$ and effort a_t. Now suppose β_t and a_t satisfy Equation (17) and consider an arbitrary consumption and effort policy $(\tilde{c}_t,\tilde{a}_t)$. Let

$$G_t = \int_0^t e^{-rs}u(\tilde{c}_s,\tilde{a}_s)\,ds + e^{-rt}e^{-\gamma rS_t}W_t, \tag{A.5}$$

where $S_t = \int_0^t e^r(t-s)(c_s - \tilde{c}_s)ds$ is the manager's accumulated savings at the point the manager chooses the alternative consumption plan. An application of Ito's lemma gives

$$\begin{aligned} e^{rt+\gamma rS_t}dG_t = {} & (-\gamma rW_t(c_t - \tilde{c}_t) - \gamma rW_t\beta_t(\tilde{a}_t - a_t)X_t \\ & + e^{\gamma rS_t}u(\tilde{c}_t,\tilde{a}_t))dt - \gamma rW_t\beta_t dZ_t. \end{aligned} \tag{A.6}$$

The $\tilde{c}_t$ and $\tilde{a}_t$ that maximize the drift term must satisfy the following first-order conditions:

$$\gamma rW_t = -e^{\gamma rS_t}u_c(\tilde{c}_t,\tilde{a}_t), \text{ and} \tag{A.7}$$

$$\gamma rW_t\beta_tX_t = -X_tK_tg'(a)e^{\gamma rS_t}u_c(\tilde{c}_t,\tilde{a}_t) \tag{A.8}$$

as $u_a = -u_cX_tK_tg'(a)$. These first-order conditions are solved for $\tilde{c}_t = c_t + rS_t$ and $\tilde{a}_t = a_t$, as $rW_t = u(c_t,a_t)$. Moreover, for $\tilde{c}_t = c_t + rS_t$ and $\tilde{a}_t = a_t$, the drift term is zero. Thus, for all other choices of consumption and effort, the drift term is weakly negative and G_t is a supermartingale. □

Now consider the manager's value from choosing the policy $(\tilde{c}_t,\tilde{a}_t)$:

$$\begin{aligned} & \mathbb{E}\left[\int_0^\infty e^{-rs}u(\tilde{c}_s,\tilde{a}_s)ds\right] \\ & = \mathbb{E}[G_t] + \mathbb{E}\left[\int_t^\infty e^{-rs}u(\tilde{c}_s,\tilde{a}_s)ds - e^{-r(t+\gamma S_t)}W_t\right] \end{aligned} \tag{A.9}$$

$$\le G_0 + \mathbb{E}\left[\int_t^\infty e^{-rs}(u(\tilde{c}_s,\tilde{a}_s) - e^{\gamma rS_t}u(c_s,a_s))ds\right]. \tag{A.10}$$

Now note that $\lim_{t\to\infty} S_t \overset{a.s}{=} 0$ so that $\lim_{t\to\infty}|\tilde{c}_t - c_t| \overset{a.s}{=} 0$, which, in turn, implies that

$$\lim_{t\to\infty}\int_t^\infty e^{-rs}\big(u(\tilde{c}_s,\tilde{a}_s) - e^{\gamma rS_t}u(c_s,a_s)\big)ds \overset{a.s}{=} 0. \tag{A.11}$$

Finally, by the condition given in Equation (A.3) and Fubini's theorem, we can take the limit as $t\to\infty$ of both sides of Equation (A.10) to get

$$\begin{aligned} & \mathbb{E}\left[\int_0^\infty e^{-rs}u(\tilde{c}_s,\tilde{a}_s)ds\right] \\ & \le G_0 + \lim_{t\to\infty}\mathbb{E}\left[\int_t^\infty e^{-rs}(u(\tilde{c}_s,\tilde{a}_s) - e^{\gamma rS_t}u(c_s,a_s))\,ds\right] \quad \text{(A.12)} \\ & = G_0 = W_0. \quad \text{(A.13)} \end{aligned}$$

Therefore, all other consumption and effort plans $(\tilde{c}_t,\tilde{a}_t)$ yield no more utility than (c_t,a_t) to the manager, and the contract is an incentive-compatible, no-savings contract.

The conditions given are necessary for a contract to be no-savings by Lemma 2. To see that the conditions are also necessary for incentive compatibility, consider any contract (β_t, a_t, τ) such that β_t does not satisfy the condition given in Equation (17); then the same argument given shows that the optimal response to such a contract would be to choose $\tilde{a}_t \neq a_t$.

Proof of Proposition 1. We verify the optimality of the proposed contract with the following steps. In step 1, we show that we can replace the investor's maximization problem with one in which we maximize a function independent of Y_t. We then assume that the optimal investment policy must be a threshold rule that satisfies the boundary conditions given in Equations (28) and (29). In step 2, we consider a fixed investment threshold and verify that the solution to the HJB equations solves the investor's problem for this investment threshold. Finally, we note that we have already verified that the proposed contract is incentive compatible and satisfies the no-savings condition in the proof of Lemma 3. Although the model as presented in the paper assumes a $k=1$ pre-exercise of the option, we prove the proposition for a general k_s pre-exercise and k_b postexercise, where $k_b > k_s$. □

Before we complete these steps, we make the following technical assumption on β_t:

$$\mathbb{E}\left[\int_0^\infty \beta_t^2X_t^2dt\right] < \infty, \tag{A.14}$$

where the expectation is taken with respect to the measure induced by the incentive compatible dynamics of X_t given β_t. This restriction does not rule out contracts under which the manager has incentives to exert maximal effort forever. However, such contracts would be infinitely costly to implement, so this assumption can be made without loss of generality.

Step 1. Let $v(x,y)$ be the value to the investor under a given incentive-compatible, no-savings contract (c,a,τ) with $X_0 = X$ and $Y_0 = X$, where $Y_0 = -\frac{1}{2}\ln(-\gamma rW_0)$. Note that Lemmas 2 and 3 imply that the compensation process

c_t must be given by Equation (22). The investor's value is simply the present value of the cash flows of the firm, net of compensation to the manager, and so we have

$$v(X,Y)=\mathbb{E}\left[\int_0^\infty e^{-rt}(X_tK_t-c_t)\,dt-e^{-r\tau}P\mid X_0=X,Y_0=Y\right] \quad (A.15)$$

$$=\mathbb{E}\left[\int_0^\infty e^{-rt}(X_tK_t(1-g(a_t))-rY_t)\,dt - e^{-r\tau}P\mid X_0=X,Y_0=Y\right] \quad (A.16)]$$

$$=\mathbb{E}\left[\int_0^\infty e^{-rt}X_tK_t(1-g(a_t))dt - e^{-r\tau}P\mid X_0=X,Y_0=Y\right] \quad (A.17)]$$

$$+\mathbb{E}\left[re^{-rt}\left(Y_0+\int_0^t\frac{1}{2}\gamma r\sigma^2\beta_s^2X_s^2ds + \int_0^t\sigma X_t\beta_t dZ_t^u\right)dt\mid X_0=X,Y_0=Y\right],$$

where the last line follows from the dynamics of Y_t given in Equation (21). Evaluating separately the three terms of the last expectation, we have

$$\mathbb{E}\left[\int_0^\infty re^{-rt}Y_0dt\right]=Y_0,$$

$$\mathbb{E}\left[\int_0^\infty re^{-rt}\int_0^t\frac{1}{2}\gamma r\sigma^2\beta_s^2X_s^2dsdt\right]=\mathbb{E}\left[\int_0^\infty\int_s^\infty re^{-rt}\frac{1}{2}\gamma r\sigma^2\cdot\beta_s^2X_s^2dtds\right]$$
$$=\mathbb{E}\left[\int_0^\infty e^{-rs}\frac{1}{2}\gamma r\sigma^2\beta_s^2X_s^2ds\right],$$

$$\mathbb{E}\left[\int_0^\infty re^{-rt}\int_0^t\sigma X_t\beta_s dZ_t^u dt\right]=\int_0^\infty re^{-rt}\sigma\mathbb{E}\left[\int_0^t X_t\beta_s t dZ_t^u\right]dt = 0,$$

where we exchange the order of integration according to Fubini's theorem and the assumption given in Equation (A.14). Collecting terms gives

$$v(X,Y)=\mathbb{E}\left[\int_0^\infty e^{-rt}\left(X_t(K_t-g(a))-\frac{1}{2}\gamma r\sigma^2\beta_t^2X_t^2\right)dt - e^{-r\tau}P\mid X_0=x\right]-Y. \quad (A.18)$$

Thus, the investor's problem is equivalent to the following problem:

$$V(X_0)=\max_{\beta,a,\tau}\mathbb{E}\left[\int_0^\infty e^{-rt}\left(X_t(K_t-g(a_t))-\frac{1}{2}\gamma r\sigma^2\beta_t^2\right)dt-e^{-r\tau}P\right], \quad (A.19)$$

such that

$$dX_t=a_tX_tdt+\sigma X_tdZ_t, \quad (A.20)$$
$$K_t=k_s+(k_b-k_s)\mathbb{I}(t\geq\tau),\text{ and} \quad (A.21)$$
$$\beta_t=g'(a_t). \quad (A.22)$$

Step 2. Fix an arbitrary investment rule $\hat{\tau}$. Let $\hat{V}$ and $\hat{\beta}_t$ solve

$$r\hat{V}=\max_\beta\left\{\mathscr{L}(X,k,\hat{V};\beta,a)\right\}, \quad (A.23)$$

where

$$\mathscr{L}(X,k,V;\beta,a)=X(k-g(a))-\frac{1}{2}\gamma r\beta^2X^2+aX\frac{dV}{dX}+\frac{1}{2}\sigma^2X^2\frac{d^2V}{dX^2} \quad (A.24)$$

such that

$$\beta=g'(a), \quad (A.25)$$
$$V(X_\tau;K=k_s)\overset{a.s}{=}V(X_\tau;K=k_b)-P, \quad (A.26)$$

and let $\hat{c}_t$ be the compensation given by Equation (22) that makes $\hat{a}_t$ incentive compatible. In other words, $(\hat{\beta},\hat{a})$ is the optimal contract given investment time $\hat{\tau}$. Now, consider an arbitrary incentive-compatible, no-savings contract $(\tilde{\beta}_t,\tilde{a}_t)$ and let

$$G_t=\int_0^t e^{-rs}\left(\tilde{X}_s(\tilde{K}_s-g(\tilde{a}_s))-\frac{1}{2}\gamma r\sigma\tilde{\beta}_s^2\tilde{X}_s^2\right)ds + e^{-rt}\hat{V}(\tilde{X}_t,\tilde{K}_t)-\mathbb{I}(\hat{\tau}\leq t)e^{-r\hat{\tau}}P, \quad (A.27)$$

where G_t measures the gains in present value at time $t=0$ derived from using $(\tilde{\beta}_t,\tilde{a}_t,\tau)$ up to time t and $\tilde{X}_t$ and $\tilde{K}_t$ are the productivity and capital induced by the contract $(\{\tilde{\beta}_t,\tilde{a}_t\},\hat{\tau})$. Using Ito's lemma gives

$$e^{rt}dG_t=\left(\mathscr{L}(\tilde{X}_t,\tilde{K}_t;\tilde{\beta}_t,\tilde{a}_t)-r\hat{V}\right)dt+\sigma\tilde{X}_t\frac{d\hat{V}}{dx}dZ_t + \left(\hat{V}(X_t,k_b)-\hat{V}(X_t,k_s)-P\right)d\hat{N}_t, \quad (A.28)$$

where $d\hat{N}_t=\mathbb{I}(t=\hat{\tau})$ is a counting process that measures the arrival of the investment time $\hat{\tau}$. Note that the drift term given in (A.28) is always weakly negative by Equation (A.23) and that the last term of (A.28) is always zero. Therefore, G_t is a supermartingale.

Now, consider the value from choosing the contract $(\tilde{\beta}_t,\tilde{a}_t)$. We have

$$\mathbb{E}\left[\int_0^\infty\left(\tilde{X}_s(\tilde{K}_s-g(\tilde{a}_s))-\frac{1}{2}\gamma r\sigma^2\tilde{\beta}_s^2\tilde{X}_s^2\right)ds-e^{-r\hat{\tau}}P\right] \quad (A.29)$$

$$=\mathbb{E}[G_t]+e^{-rt}\mathbb{E}\left[\int_t^\infty e^{-r(s-t)}\left(\tilde{X}_s(\tilde{K}_s-g(\tilde{a}_s))-\frac{1}{2}\gamma r\sigma^2\tilde{\beta}_s^2\tilde{X}_s^2\right)ds-\hat{V}(\tilde{X}_t,\tilde{K}_t)\right] \quad (A.30)$$

$$\leq G_0+e^{-rt}\mathbb{E}\left[\int_t^\infty e^{-r(s-t)}\left(\tilde{X}_s(\tilde{K}_s-g(\tilde{a}_s))-\frac{1}{2}\gamma r\sigma^2\tilde{\beta}_s^2\tilde{X}_s^2\right)ds-\hat{V}(\tilde{X}_t,\tilde{K}_t)\right]. \quad (A.31)$$

Now note that, as $g(\tilde{a}_s)\geq 0$ and $\tilde{\beta}_s^2\tilde{X}_s^2>0$, we have

$$\mathbb{E}\left[\int_t^\infty e^{-r(s-t)}\left(\tilde{X}_s(\tilde{K}_s-g(\tilde{a}_s))-\frac{1}{2}\gamma r\sigma^2\tilde{\beta}_s^2\tilde{X}_s^2\right)ds\right]$$
$$\leq\mathbb{E}\left[\int_t^\infty e^{-r(s-t)}\tilde{X}_s\tilde{K}_sds\right] \quad (A.32)$$
$$\leq\mathbb{E}\left[\int_t^\infty e^{-r(s-t)}\tilde{X}_sk_bds\right] \quad (A.33)$$
$$\leq\frac{\tilde{X}_tk_b}{r-a_{\max}}, \quad (A.34)$$

where the last inequality states that the firm value is bounded above by the expected present value of the gross (of effort and incentive costs) cash flow $\tilde{X}_t\tilde{K}_t$ achieved when $\tilde{a}_t = a_{\max}$ and $K_t = k_b$ for all t. Next note that

$$\hat{V}(X,k) \geq \frac{Xk}{r} > 0 \tag{A.35}$$

by Equation (A.23). Therefore,

$$\mathbb{E}\left[\int_0^{\infty} e^{-rs}\left(\tilde{X}_s(\tilde{K}_s - g(\tilde{a}_s)) - \frac{1}{2}\gamma r\sigma^2\tilde{\beta}_s^2\tilde{X}_s^2\right)ds - e^{-r\hat{\tau}}P\right]$$
$$\leq G_0 + e^{-rt}\mathbb{E}\left[\frac{\tilde{X}_t k}{r - a_{\max}}\right] \tag{A.36}$$
$$\leq G_0 + e^{-(r-1)t}\frac{X_0 k}{r - a_{\max}}, \tag{A.37}$$

where we bound $\mathbb{E}[\tilde{X}_t]$ above by evaluating the expectation under the assumption of perpetual maximum effort so that $\tilde{X}_t$ is a geometric Brownian motion. Taking limits of both sides as $t \to \infty$ gives

$$\mathbb{E}\left[\int_0^{\infty} e^{-rs}\left(\tilde{X}_s(\tilde{K}_s - g(\tilde{a}_s)) - \frac{1}{2}\gamma r\sigma^2\tilde{\beta}_s^2\tilde{X}_s^2\right)ds - e^{-r\hat{\tau}}P\right]$$
$$\leq G_0 = \hat{V}(X_0, K_0), \tag{A.38}$$

and thus, we conclude that any contract $(\tilde{\beta}, \tilde{a}, \hat{\tau})$ yields a weakly lower value than the contract $(\hat{\beta}, \hat{a}, \hat{\tau})$.

Proof of Proposition 2. We first note that the manager's performance–effort sensitivity is measured by β:

$$\beta^*(X) = g'(a^*(X)), \tag{A.39}$$

and the manager's pay–performance sensitivity is given by

$$\phi^*(X) = \frac{\beta^*(X)}{V'(X)} = \frac{g'(a^*(X))}{V'(X)}. \tag{A.40}$$

Under the optimal contract, the optimal effort policy $a^*(X)$ is given by the first-order condition

$$-g'(a^*(X)) - \gamma r\sigma^2 g'(a^*(X))g''(a^*(X))X + V'(X) = 0. \tag{A.41}$$

Differentiating the first-order condition with respect to k and rearranging it gives the expression

$$\frac{da^*}{dk} = -\frac{V_{Xk}(X)}{-g''(a^*) - \gamma r\sigma^2 X(g''(a^*)^2 + g'(a^*)g'''(a^*))}. \tag{A.42}$$

In the following analysis, we restrict our attention to parameter values such that the optimal $a^*(X)$ satisfies the second-order condition. As the denominator of Equation (A.42) is simply the second derivative of the value function with respect to effort, we find that optimal effort is increasing with the size of the growth option k. We address each measure separately. □

Expected-Pay–Effort Sensitivity. We first show that expected-pay–effort sensitivity increases with growth options k. Differentiating the expression for output-based incentives, we have

$$\frac{d\beta^*}{dk} = \sigma X g''(a^*)\frac{da^*}{dk}, \tag{A.43}$$

where, using (A.42), we can see that

$$\text{sign}\left(\frac{d\beta^*}{dk}\right) = \text{sign}\left(\frac{da^*}{dk}\right). \tag{A.44}$$

Recall that the denominator of (A.42) is negative according to our assumption that the second-order condition for the optimality of a^* holds.

Furthermore, we demonstrate that $V_{Xk} > 0$. Beginning with the Hamilton–Jacobi–Bellman equation

$$rV = X - g(a^*(X))X - \frac{1}{2}\gamma r(\sigma g'(a^*(X))X)^2 + a^*(X)X\frac{\partial V}{\partial X} + \frac{1}{2}\sigma^2 X^2\frac{\partial^2 V}{\partial X^2}, \tag{A.45}$$

we differentiate with respect to both size, X, and growth-option intensity, k, to get

$$(r - a^*(X) - a_X^*(X)X)V_{Xk} = (a^*(X) + \sigma^2)XV_{XXk} + \frac{1}{2}\sigma^2 X^2 V_{XXXk}, \tag{A.46}$$

where the envelope theorem tells us that the effect of varying k on the optimal effort level $a^*(X)$ can be ignored when taking the derivative. This result is due to the optimality of a^* and the first-order condition of the Hamilton–Jacobi–Bellman equation.

We invoke a generalized version of the Feynman–Kac formula, provided as Lemma A.1, to write the function V_{Xk} as the following expectation:

$$V_{Xk}(X) = E\left[e^{-\int_0^{\tau}(r - a^*(X_t) - a_X^*(X_t)X_t)dt}V_{Xk}(\overline{X}) \mid X_0 = X\right]$$
$$= E\left[e^{-\int_0^{\tau}(r - a^*(X_t) - a_X^*(X_t)X_t)dt}\frac{\partial^2}{\partial X\partial k}\frac{Xk}{r}\Big|_{X=\overline{X}} \mid X_0 = X\right]$$
$$= E\left[e^{-\int_0^{\tau}(r - a^*(X_t) - a_X^*(X_t)X_t)dt}\frac{1}{r} \mid X_0 = X\right] > 0. \tag{A.47}$$

With this, we have the result that $V_{Xk} > 0$, and therefore, growth options increase expected-pay–effort sensitivity, $\frac{d\beta^*}{dk} > 0$.

Pay–Performance Sensitivity. We can write pay–performance sensitivity as

$$\phi^*(X) = 1 - \frac{\rho'(a^*)}{V'(X)}. \tag{A.48}$$

Differentiating Equation (A.48) with respect to k, we have

$$\frac{\partial\phi^*(X)}{\partial k} = -\frac{1}{V'(X)^2}\left[\rho''(a^*)\frac{\partial a^*}{\partial k}V'(X) - \rho'(a^*)\frac{\partial V'(X)}{\partial k}\right].$$

Because $V'(X)^2 > 0$, we can ignore the denominator and write

$$\text{sign}\left(\frac{\partial\phi^*}{\partial k}\right) = -\text{sign}\left(\rho''(a^*)\frac{\partial a}{\partial k}V'(X) - \rho'(a^*)\frac{\partial V'(X)}{\partial k}\right). \tag{A.49}$$

Note that differentiating the first-order condition in Equation (30) with respect to the size of the growth option k gives

$$g''(a^*)\frac{\partial a^*}{\partial k} + \rho''(a^*)\frac{\partial a^*}{\partial k} = \frac{\partial V'(X)}{\partial k}. \tag{A.50}$$

Thus,

$$\text{sign}\left(\frac{\partial \phi^*}{\partial k}\right) = -\text{sign}\left(\rho''(a^*)\frac{\partial a}{\partial k}V'(X) - \rho'(a^*) \cdot \left(g''(a)\frac{\partial a^*}{\partial k} + \rho''(a^*)\frac{\partial a^*}{\partial k}\right)\right). \quad \text{(A.51)}$$

where we have substituted (A.50) for the derivative of marginal firm value with respect to the size of the growth option. Canceling and combining like terms, we have

$$\text{sign}\left(\frac{\partial \phi^*}{\partial k}\right) = -\text{sign}\,(\rho''(a^*)(V'(X) - \rho'(a^*)) - \rho'(a^*)g''(a^*)). \quad \text{(A.52)}$$

Substituting the first-order condition (30) allows us to write this condition in terms of the ratio of marginal incentive costs $\rho'(a^*)$ to marginal effort costs $g'(a^*)$

$$\text{sign}\left(\frac{\partial \phi^*}{\partial k}\right) = -\text{sign}\,(g'(a^*)\rho''(a^*) - g''(a^*)\rho'(a^*)). \quad \text{(A.53)}$$

Thus, $\frac{\partial \phi^*}{\partial k} < 0$ if and only if

$$\frac{\rho''(a)}{\rho'(a)} > \frac{g''(a)}{g'(a)}.$$

Lemma A.1. *Suppose that X_t evolves according to $dX_t = \mu(X_t)dt + \sigma(X_t)dZ_t$. Then, for bounded functions $f : (0, Y] \to \mathbb{R}$, $r : (0, Y] \to \mathbb{R}^+$, and $\Omega : \mathbb{R} \to \mathbb{R}$, a function $F : (0, Y] \to \mathbb{R}$ solves both*

$$r(X)F(X) = f(X) + \mu(X)F_X(X) + \frac{1}{2}\sigma(X)^2 F_{XX}(X), \quad \text{(A.54)}$$

with a boundary condition $F(Y) = \Omega(Y)$ and

$$F(X) = E\left[\int_0^\tau e^{-\int_0^t r(X_s)ds} f(X_t)dt + e^{-\int_0^\tau r(X_s)ds}\Omega(Y) \mid X_0 = X\right], \quad \text{(A.55)}$$

where $\tau = \inf\{t \geq 0 \mid X_t \geq Y\}$.

Proof of Lemma A.1. The proof essentially follows the proof of lemma 4 in DeMarzo and Sannikov (2006). Suppose that V solves Equation (A.54) and define a process H_t by

$$H_t = \int_0^t e^{-\int_0^s r(X_u)du} f(X_s)ds + e^{-\int_0^t r(X_s)ds}V(X_s).$$

An application of Ito's formula gives the dynamics for H_t as

$$e^{\int_0^t r(X_s)ds}dH_t = \left(f(X_t) + \mu(X_t)V_X(X_t) + \frac{1}{2}\sigma(X_t)^2 V_{XX}(X_t) - r(X_t)V(X_t)\right)dt + \sigma(X_t)V(X_t)dZ_t.$$

By Equation (A.54), the drift of H_t is zero, and H_t is a martingale. As $V(X)$ is bounded on the interval $[0, \overline{X}]$, H_τ is a martingale and V satisfies

$$\begin{aligned} V(X_0) = H_0 &= E[X_\tau \mid X_0] \\ &= E\left[\int_0^\tau e^{-\int_0^t r(X_s)ds} f(X_t)dt + e^{-\int_0^\tau r(X_s)ds}V(X_\tau) \mid X_0\right] \\ &= E\left[\int_0^\tau e^{-\int_0^t r(X_s)ds} f(X_t)dt + e^{-\int_0^\tau r(X_s)ds}\Omega(Y) \mid X_0\right], \end{aligned}$$

where the last equality follows from the definition of τ as a stopping time, and the boundary condition $V(Y) = \Omega(Y)$. □

Proof of Proposition 3. We prove the proposition by first showing that the cross-derivative of firm value V with respect to productivity X and redeployability P is negative so that the marginal value of effort is decreasing in redeployability. From there, the proof follows the results of Proposition 2 to show that expected-pay–effort sensitivity decreases in redeployability, whereas pay–performance sensitivity increases. □

Let p_1 and p_2 denote two levels of redeployability with $p_2 > p_1$. The value of a firm with the option to sell its capital for p_2 will always exceed the value of a firm with the inferior option to sell for p_1 so that $V_2 > V_1$. From Lemma A.2, we can focus our analysis simply on the gap G between V_2 and V_1 for a fixed value of productivity X.

Lemma A.2. *If the difference in value between the high value firm and the low value firm is decreasing in X, then the marginal value of effort is decreasing in redeployability.*

The difference in firm values is given by

$$G(X) \triangleq V_2(X) - V_1(X),$$

so that $G'(X) < 0$ implies $V_1'(X) > V_2'(X)$. As p_1 and p_2 are arbitrary subject to $p_2 > p_1$, $\frac{\partial^2 V}{\partial X \partial P} < 0$.

We first establish some properties of the function G. V_i is the solution to an ordinary differential equation, so we know that $G \in \mathscr{C}(2)$. Furthermore, $G(0) = p_2 - p_1$, and $\lim_{X\to\infty} G(X) = 0$. At zero, the value of the firm is given by the redeployability of the firm's capital. As productivity increases and the probability of exercising the option decreases, effort also becomes too expensive, and firm value is simply the perpetuity value of its period cash flows $\frac{X}{r}$, which does not depend on the option to redeploy capital.

We proceed by proof by contradiction. Assume that there is some interval (x_0, x_1) on which G is weakly increasing. As $\lim_{X\to\infty} G(X) = 0$, there must then exist some $x_2 \in [x2, \infty)$ and some positive ε such that $G'(x_2) = 0$ and $G'(x) < 0$ for all $x \in (x_2, x_2 + \varepsilon)$. This means that $G''(x_2) \leq 0$. This is equivalent to $V_1''(x_2) \geq V_2''(x_2)$.

Recall that the HJB equation for firm value was

$$rV(X) = \max_{a\in[0,a_{\max}]}\left\{X - (g(a) + \rho(a))X + aXV'(X) + \frac{1}{2}\sigma^2 X^2 V''(X)\right\}.$$

The second derivative of firm value V'' does not depend upon a, and so the optimal level of effort a^* is a function of only V' and X. Therefore, if $V_1'(x_2) = V_2'(x_2)$, then $a_1^*(x_2) = a_2^*(x_2)$, and both firms will recommend the same level of effort for the manager at $X = x_2$. Given that both firms choose the same level of effort and $V_1'' > V_2''$, the HJB equation implies that $V_1(x_2) \geq V_2(x_2)$. However, this is a contradiction of the fact that firm value is increasing in redeployability $\frac{\partial V}{\partial P} > 0$, so G must be strictly decreasing.

From here, the proof is identical to the proof of Proposition 2 in that we use $\frac{\partial^2 V}{\partial X \partial P}$ to sign the derivative of optimal effort a^*

with respect to redeployability P. Using Equation (A.42), we have that effort is decreasing in redeployability. Then, by Equation (A.44), the derivative of expected-pay–effort sensitivity β^* has the same sign as $\frac{\partial a^*}{\partial P}$, $\frac{\partial \beta^*}{\partial P} < 0$ and expected-pay–effort sensitivity is decreasing in redeployability.

The sign of the derivative of pay–performance sensitivity is given by

$$\text{sign}\left(\frac{d\phi^*}{dk}\right) = \text{sign}\left(-g'''(a^*)\frac{da^*}{dk}\right).$$

When $g'''(a^*) > 0$, then $\frac{\partial \phi^*}{\partial P} > 0$. This corresponds to the case in which incentive costs are more convex than effort costs so that pay–performance sensitivity is increasing in redeployability, completing the proof.

Appendix B. Definitions of Variables

Advertisement: This variable is advertising expense/total assets = XAD/AT. *Advertisement missing* is an indicator variable for whether this measure was missing data.
Capital expenditures: This variable is capital expenditures/total assets = CAPX/AT.
CEO: This variable is an indicator variable for whether the manager in question is the CEO of the firm.
CEO chair: This variable is an indicator variable for whether the CEO is also chairman of the board.
Dividend paying: This variable is an indicator variable for whether dividends on common stock (DVC) is strictly positive.
Female: This variable is an indicator for whether the manager is female.
Firm age: This variable equals the year of the data entry less the first year the firm appeared in the Center for Research in Security Prices database.
Firm size: This variable is the natural log of total assets = log(AT).
Fraction of inside directors: This variable is the number of inside board directors divided by board size. Inside directors are those who personally or had a family member serve as a current or former firm manager.
Leverage: This variable is (long term debt + short term debt)/ total assets = (DLTT + DLC)/AT.
Market to book: This variable equals (market value of equity + book value of debt)/book value of assets = (CSHO × PRCC_F + AT - CEQ)/AT.
Profitability: This variable is operating income before D&A/ total assets = OIVDP/AT.
R&D: This variable equals R&D expense/book value of assets = XRD/AT.
Tangibility: This variable equals net PP&E/total assets = PPENT/AT.
Tobin's q: This variable is the Peters–Taylor measure of total Tobin's *q* found on WRDS = Q_TOT.
Value to book: First, we regress log(market value of equity plus book value of debt) = log(CSHO × PRCC_F + AT − CEQ) on log(book value) of assets (log(AT)), including an industry fixed effect, in which industry is determined by four-digit standard industrial classification codes. Second, we subtract log book value of assets (log(AT)) from the fitted values from the regression.

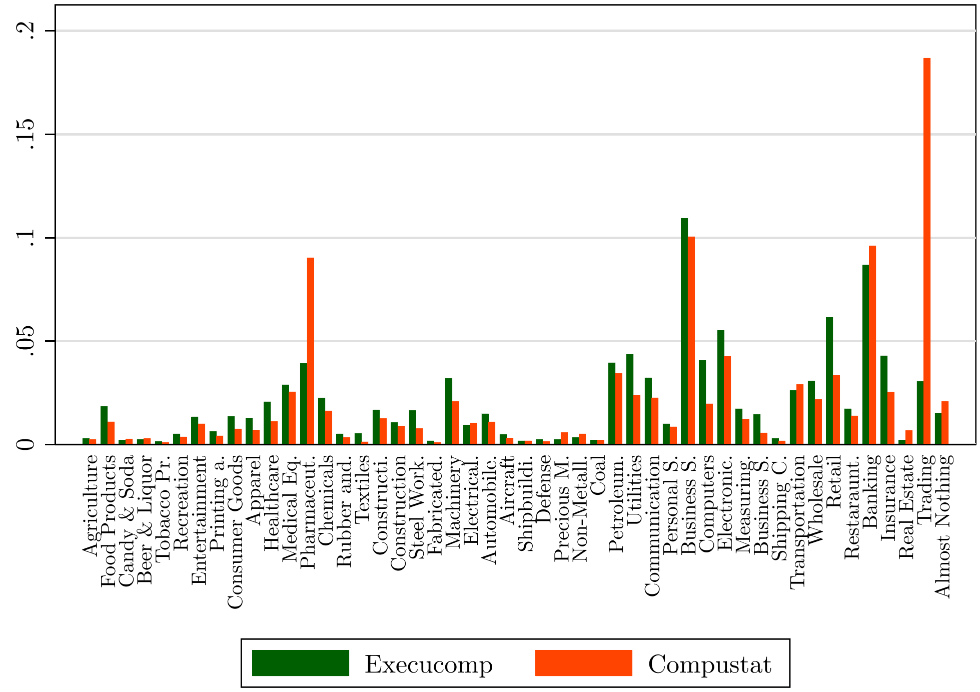
Appendix C. Accounting for Biases in the Execucomp Data Set

In this appendix, we address concerns of selection and bias in our data set. Our data set consists of a merge between Compustat, which covers all public firms, and Execucomp, which primarily covers larger public firms. In Figure C.1, we plot the distribution of Fama–French 48 industries for both Compustat as a whole and our merged data set. We see that the distribution of industry coverage does not differ significantly with the exception of pharmaceuticals and trading. These firms tend to be smaller than other public firms and, thus, are systematically underrepresented in Execucomp relative to the universe of public firms.

Another potential source of bias stems from the practice of backfilling data in Execucomp. As discussed in Gillan et al. (2017), the habit of including backfilled data means that ex post successful firms are overrepresented in the data as they are added onto indices if clients of S&P request the data be added. This practice of backfilling ceased after 2006 because of changes in the regulatory environment.

A natural test would be to perform our regressions on our entire data set, excluding those observations that were included because of backfilling. However, based on the data set provided by Gillan et al. (2017),[8] virtually all compensation data from the 1994–2005 period is backfilled. Therefore, we instead restrict our sample to the post-backfilling period from 2006 onward and find that our qualitative results are unchanged. Summary statistics for the restricted sample are reported in Table C.1. The results are reported in Tables C.2–C.6. We find that, in the latter part of the sample, a one standard deviation increase in the market-to-book ratio is associated with a 6.75% decrease in Jensen and Murphy's PPS. This is slightly larger than the 5.7% decrease we estimate over the full sample but still of a similar magnitude. Our estimates using only post-2005 data are of similar magnitude to those corresponding to the full sample. Importantly, the sign of our coefficient estimates do not change and remain consistent with the direction predicted by theory.

Figure C.1. (Color online) Fama–French 48 Industry Coverage



Notes. The representation of each of the 48 Fama–French industries is presented for both the Execucomp and Compustat databases. Although trading and pharmaceutical firms represent a larger proportion of Compustat than of Execucomp, we attribute this to Execucomp's focus on larger firms.

Table C.1. Summary Statistics

	Observations	Mean	Standard deviation	Minimum	Maximum	Median
Jensen and Murphy PPS	75,829	0.749	2.046	0.002	18.858	0.208
$ to % PPS (PPS2)	75,844	176.999	452.758	0.193	3,573.206	42.791
Wealth performance sensitivity (PPS3)	14,547	17.667	65.274	0.000	888.708	4.988
Market to book	75,826	1.810	1.125	0.771	8.529	1.443
Value to book	75,840	1.646	0.454	0.956	4.023	1.599
R&D	40,141	0.050	0.065	0.000	0.366	0.024
Total *q*	64,149	1.214	1.267	0.044	7.899	0.824
Capital expenditure	75,721	0.044	0.050	0.000	0.294	0.029
Firm size	75,840	12,141	31,095	50.598	202,475	2,306
Cash flow volatility	75,844	0.035	0.040	0.002	0.231	0.023
Firm age	75,844	24.463	14.989	0.000	56.000	21.000
Tangibility	74,844	0.239	0.233	0.003	0.880	0.155
Profitability	75,488	0.122	0.096	−0.242	0.423	0.119
Advertisement	75,844	0.011	0.029	0.000	0.176	0.000
Leverage	75,498	0.216	0.185	0.000	0.820	0.192
Dividend paying	75,724	0.543	0.498	0.000	1.000	1.000
CEO chair	56,518	0.504	0.500	0.000	1.000	1.000
Fraction of inside directors	56,518	0.215	0.114	0.000	1.000	0.200
CEO	75,844	0.192	0.394	0.000	1.000	0.000
Female	75,844	0.081	0.273	0.000	1.000	0.000

Notes. The sample covers all executives and firms in Execucomp from 2006 to 2015 and is merged with Compustat data. Jensen and Murphy PPS is the dollar-to-dollar, pay–performance sensitivity. Control variables are defined in Appendix B. R&D, research and development.

Table C.2. Market-Based Proxies and Pay–Performance Sensitivity, Backfill Bias-Free Sample

	Market to book			Value to book		
	(1) log (PPS1)	(2) log (PPS1)	(3) log (PPS1)	(4) log (PPS1)	(5) log (PPS1)	(6) log (PPS1)
Market to book	−0.103***	−0.084***	−0.059***			
	(−7.94)	(−4.53)	(−5.27)			
Value to book				−0.211***	−0.090	−0.090**
				(−3.82)	(−1.41)	(−2.48)
Firm size	−0.407***	−0.406***	−0.419***	−0.409***	−0.407***	−0.408***
	(−38.19)	(−29.86)	(−13.69)	(−37.22)	(−29.57)	(−13.43)
Cash flow volatility		−0.836**	−0.410		−1.204***	−0.535**
		(−2.00)	(−1.54)		(−2.88)	(−2.02)
Firm age		−0.046*	−0.200***		−0.037	−0.184***
		(−1.72)	(−2.84)		(−1.40)	(−2.66)
Tangibility		−0.199*	0.133		−0.136	0.156
		(−1.72)	(0.87)		(−1.16)	(1.02)
Profitability		−0.424**	−0.034		−0.977***	−0.194
		(−1.99)	(−0.29)		(−5.22)	(−1.65)
Advertisement		0.248	−0.975		0.211	−0.997
		(0.39)	(−0.94)		(0.33)	(−0.96)
Advertisement missing		0.040	0.011		0.044	0.009
		(1.03)	(0.29)		(1.15)	(0.24)
Leverage		0.565***	0.312***		0.608***	0.337***
		(5.70)	(3.67)		(6.14)	(3.98)
Dividend paying		−0.104***	−0.122***		−0.107***	−0.127***
		(−2.83)	(−3.31)		(−2.90)	(−3.45)
CEO chair		0.229***	0.028*		0.229***	0.029*
		(8.32)	(1.69)		(8.27)	(1.73)
Fraction of inside directors		0.910***	−0.081		0.901***	−0.076
		(6.78)	(−1.05)		(6.64)	(−0.97)
CEO		1.736***	0.365***		1.737***	0.365***
		(81.00)	(15.67)		(80.86)	(15.67)
Female		−0.269***			−0.263***	
		(−8.31)			(−8.09)	
Industry dummies	Yes	Yes	No	Yes	Yes	No
Firm–manager dummies	No	No	Yes	No	No	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	63,307	45,759	45,759	63,317	45,764	45,764
R^2	0.244	0.495	0.0811	0.240	0.493	0.0789

Notes. The sample covers all executives and firms in Execucomp from 2006 to 2015 and is merged with Compustat data. The dependent variable is the logarithm of the dollar-to-dollar, pay–performance sensitivity. Market value is defined as the market value of equity plus the book value of debt divided by total assets. Value to book is calculated as the fitted value from a within-industry regression of log market value on log book value less log book value. Control variables are defined in Appendix B. t-statistics based on heteroskedasticity-consistent, firm-level clustered standard errors are provided in parentheses. PPS, pay–performance sensitivity.

*$p < 0.10$; **$p < 0.05$; ***$p < 0.01$.

Table C.3. R&D-Based Proxies and Pay–Performance Sensitivity, Backfill Bias-Free Sample

	R&D			R&D (zero if missing)		
	(1) log (PPS1)	(2) log (PPS1)	(3) log (PPS1)	(4) log (PPS1)	(5) log (PPS1)	(6) log (PPS1)
R&D	−0.676*	−0.157	−0.723			
	(−1.72)	(−0.30)	(−1.62)			
R&D (zero if missing)				−0.609	−0.170	−0.495
				(−1.61)	(−0.36)	(−1.06)
Firm size	−0.418***	−0.435***	−0.405***	−0.397***	−0.403***	−0.406***
	(−29.07)	(−25.64)	(−9.47)	(−36.27)	(−29.33)	(−12.78)
Cash flow volatility		−1.379**	−0.228		−1.205***	−0.551**
		(−2.49)	(−0.71)		(−2.86)	(−2.07)
Firm age		−0.028	−0.294***		−0.038	−0.177**
		(−0.84)	(−3.15)		(−1.41)	(−2.56)
Tangibility		−0.002	0.116		−0.135	0.189
		(−0.01)	(0.53)		(−1.15)	(1.23)
Profitability		−0.884***	−0.486***		−1.015***	−0.221*
		(−3.66)	(−2.96)		(−5.41)	(−1.87)
Advertisement		0.271	−1.689		0.156	−0.907
		(0.35)	(−1.20)		(0.24)	(−0.89)
Advertisement missing		0.058	0.024		0.043	0.009
		(1.23)	(0.44)		(1.11)	(0.24)
Leverage		0.790***	0.209*		0.605***	0.338***
		(6.55)	(1.94)		(6.06)	(4.01)
Dividend paying		−0.148***	−0.194***		−0.108***	−0.125***
		(−2.95)	(−4.42)		(−2.93)	(−3.40)
CEO chair		0.235***	−0.009		0.229***	0.028*
		(6.50)	(−0.40)		(8.26)	(1.69)
Fraction of inside directors		0.652***	−0.175		0.903***	−0.073
		(3.59)	(−1.62)		(6.67)	(−0.94)
CEO		1.746***	0.400***		1.737***	0.365***
		(62.73)	(13.84)		(80.87)	(15.67)
Female		−0.220***			−0.262***	
		(−5.16)			(−8.07)	
Industry dummies	Yes	Yes	No	Yes	Yes	No
Firm–manager dummies	No	No	Yes	No	No	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	33,195	24,648	24,648	63,317	45,764	45,764
R^2	0.253	0.520	0.0962	0.240	0.493	0.0784

Notes. The sample covers all executives and firms in Execucomp from 2006 to 2015 and is merged with Compustat data. The dependent variable is the logarithm of the dollar-to-dollar, pay–performance sensitivity. Control variables are defined in Appendix B. *t*-statistics based on heteroskedasticity-consistent, firm-level clustered standard errors are provided in parentheses. PPS, pay–performance sensitivity; R&D, research and development.

*$p < 0.10$; **$p < 0.05$; ***$p < 0.01$.

Table C.4. Capex-Based Proxies and Pay–Performance Sensitivity, Backfill Bias-Free Sample

	Capex			Capex innovations		
	(1) log (PPS1)	(2) log (PPS1)	(3) log (PPS1)	(4) log (PPS1)	(5) log (PPS1)	(6) log (PPS1)
Capital expenditure	0.047	1.640***	0.262			
	(0.15)	(4.03)	(1.25)			
Capex innovations				0.213	1.665***	0.054
				(0.49)	(3.20)	(0.22)
Firm size	−0.394***	−0.400***	−0.400***	−0.407***	−0.406***	−0.482***
	(−36.69)	(−29.34)	(−13.01)	(−30.40)	(−25.06)	(−11.58)
Cash flow volatility		−1.315***	−0.538**		−0.980**	−0.136
		(−3.16)	(−2.02)		(−2.10)	(−0.37)
Firm age		−0.032	−0.174**		−0.036	−0.195**
		(−1.21)	(−2.52)		(−1.11)	(−2.01)
Tangibility		−0.384***	0.123		−0.231	−0.170
		(−2.78)	(0.74)		(−1.57)	(−0.81)
Profitability		−1.146***	−0.251**		−1.327***	−0.286**
		(−5.98)	(−2.10)		(−6.25)	(−2.00)
Advertisement		0.120	−0.942		0.434	−1.749**
		(0.19)	(−0.92)		(0.58)	(−2.50)
Advertisement missing		0.045	0.010		0.031	−0.033
		(1.17)	(0.27)		(0.70)	(−0.93)
Leverage		0.644***	0.340***		0.621***	0.475***
		(6.49)	(4.02)		(5.45)	(4.54)
Dividend paying		−0.095**	−0.127***		−0.101**	−0.154***
		(−2.57)	(−3.44)		(−2.42)	(−3.53)
CEO chair		0.229***	0.027		0.256***	0.018
		(8.33)	(1.64)		(7.74)	(0.81)
Fraction of inside directors		0.907***	−0.070		1.064***	−0.184*
		(6.74)	(−0.89)		(6.00)	(−1.65)
CEO		1.738***	0.367***		1.697***	0.305***
		(80.84)	(15.75)		(67.86)	(10.31)
Female		−0.259***			−0.239***	
		(−7.93)			(−6.00)	
Industry dummies	Yes	Yes	No	Yes	Yes	No
Firm–manager dummies	No	No	Yes	No	No	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	63,220	45,680	45,680	33,845	26,494	26,494
R^2	0.239	0.494	0.0780	0.248	0.505	0.0665

Notes. The sample covers all executives and firms in Execucomp from 2006 to 2015 and is merged with Compustat data. The dependent variable is the logarithm of the dollar-to-dollar, pay–performance sensitivity. Capital expenditure innovation is calculated as the residual from a one-lag firm-specific autoregressive model of expected scaled capital expenditures. Control variables are defined in Appendix B. *t*-statistics based on heteroskedasticity-consistent, firm-level clustered standard errors are provided in parentheses. PPS, pay–performance sensitivity.

$^{*}p < 0.10$; $^{**}p < 0.05$; $^{***}p < 0.01$.

Table C.5. Additional Proxies and Pay–Performance Sensitivity, Backfill Bias-Free Sample

	Total q			Hybrid		
	(1) log (PPS1)	(2) log (PPS1)	(3) log (PPS1)	(4) log (PPS1)	(5) log (PPS1)	(6) log (PPS1)
Total q	−0.061***	−0.065***	−0.022**			
	(−4.96)	(−3.79)	(−2.13)			
Hybrid growth opportunities				−0.102***	−0.083***	−0.045***
				(−6.98)	(−4.05)	(−3.71)
Firm size	−0.414***	−0.414***	−0.405***	−0.428***	−0.420***	−0.420***
	(−36.90)	(−28.96)	(−12.63)	(−37.57)	(−29.36)	(−13.10)
Cash flow volatility		−0.906**	−0.423		−0.700	−0.360
		(−2.08)	(−1.48)		(−1.59)	(−1.26)
Firm age		−0.040	−0.139*		−0.037	−0.139*
		(−1.45)	(−1.89)		(−1.35)	(−1.89)
Tangibility		−0.198*	0.099		−0.192*	0.086
		(−1.70)	(0.65)		(−1.65)	(0.57)
Profitability		−0.409*	−0.195		−0.377*	−0.137
		(−1.89)	(−1.52)		(−1.73)	(−1.09)
Advertisement		0.307	−1.286		0.493	−1.291
		(0.50)	(−1.15)		(0.79)	(−1.15)
Advertisement missing		0.053	−0.003		0.047	−0.002
		(1.33)	(−0.07)		(1.17)	(−0.04)
Leverage		0.627***	0.313***		0.607***	0.306***
		(6.24)	(3.56)		(6.00)	(3.48)
Dividend paying		−0.126***	−0.153***		−0.131***	−0.152***
		(−3.30)	(−4.38)		(−3.43)	(−4.35)
CEO chair		0.205***	0.026		0.201***	0.026
		(7.11)	(1.48)		(6.95)	(1.48)
Fraction of inside directors		0.847***	−0.083		0.813***	−0.086
		(5.96)	(−1.00)		(5.72)	(−1.03)
CEO		1.746***	0.364***		1.746***	0.363***
		(75.72)	(14.46)		(75.74)	(14.44)
Female		−0.264***			−0.265***	
		(−7.51)			(−7.58)	
Industry dummies	Yes	Yes	No	Yes	Yes	No
Firm–manager dummies	No	No	Yes	No	No	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	53,591	39,645	39,645	53,575	39,636	39,636
R^2	0.253	0.504	0.0801	0.255	0.504	0.0813

Notes. The sample covers all executives and firms in Execucomp from 2006 to 2015 and is merged with Compustat data. The dependent variable is the logarithm of the dollar-to-dollar, pay–performance sensitivity. Tobin's q is taken from Wharton Research Data Services based on the methodology of Peters and Taylor (2017). Hybrid growth opportunities is calculated as the first principal component of market to book, value to book, scaled R&D, and scaled Capex. Control variables are defined in Appendix B. t-statistics based on heteroskedasticity-consistent, firm-level clustered standard errors are provided in parentheses. PPS, pay–performance sensitivity; R&D, research and development.

*$p < 0.10$; **$p < 0.05$; ***$p < 0.01$.

Table C.6. Alternative Measures of Pay–Performance Sensitivity, Backfill Bias-Free Sample

	Dollar-to-percentage PPS			Wealth performance sensitivity		
	(1) log (PPS2)	(2) log (PPS2)	(3) log (PPS2)	(4) log (PPS3)	(5) log (PPS3)	(6) log (PPS3)
Hybrid growth opportunities	0.385***	0.309***	0.141***	0.282***	0.226***	0.082***
	(21.48)	(12.99)	(7.45)	(11.90)	(7.83)	(3.36)
Firm size	0.530***	0.548***	−0.017	0.066***	0.067***	−0.171***
	(44.60)	(37.28)	(−0.43)	(3.86)	(3.23)	(−2.93)
Cash flow volatility		−1.327***	−0.690		−1.669**	−0.734
		(−2.69)	(−1.49)		(−2.48)	(−0.98)
Firm age		−0.035	−0.101		−0.041	−0.187
		(−1.18)	(−1.17)		(−1.09)	(−1.35)
Tangibility		−0.202*	−0.394*		0.171	−0.683**
		(−1.70)	(−1.76)		(0.97)	(−2.25)
Profitability		1.769***	0.481***		1.249***	0.013
		(6.82)	(2.93)		(3.81)	(0.05)
Advertisement		0.690	−2.446		−1.521	−2.160
		(0.94)	(−1.61)		(−1.22)	(−0.92)
Advertisement missing		0.034	−0.032		−0.129*	−0.166*
		(0.77)	(−0.57)		(−1.89)	(−1.76)
Leverage		−0.329***	−0.206**		−0.377**	−0.160
		(−3.05)	(−1.97)		(−2.44)	(−0.99)
Dividend paying		−0.098**	−0.151***		0.036	−0.104*
		(−2.28)	(−3.51)		(0.64)	(−1.84)
CEO chair		0.221***	0.024		0.510***	−0.012
		(7.05)	(1.01)		(10.57)	(−0.31)
Fraction of inside directors		0.814***	−0.141		1.758***	0.059
		(5.20)	(−1.32)		(7.25)	(0.37)
CEO		1.735***	0.355***		0.791***	0.170***
		(77.49)	(12.43)		(16.97)	(4.30)
Female		−0.281***			−0.361***	
		(−7.42)			(−3.04)	
Industry dummies	Yes	Yes	No	Yes	Yes	No
Firm–manager dummies	No	No	Yes	No	No	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	53,583	39,640	39,640	11,604	8,524	8,524
R^2	0.293	0.510	0.242	0.113	0.220	0.105

Notes. The sample covers all executives and firms in Execucomp from 2006 to 2015 and is merged with Compustat data. The dependent variable for columns (1)–(3) is the logarithm of the dollar-to-percentage pay–performance sensitivity. The dependent variable for columns (4)–(6) is the logarithm of wealth performance sensitivity. Hybrid growth opportunities is calculated as the first principal component of market to book, value to book, scaled R&D, and scaled Capex. Control variables are defined in Appendix B. *t*-statistics based on heteroskedasticity-consistent, firm-level clustered standard errors are provided in parentheses. PPS, pay–performance sensitivity; R&D, research and development.

$^*p<0.10$; $^{**}p<0.05$; $^{***}p<0.01$.

Endnotes

[1] See, for example, Gabaix and Landier (2008), Edmans and Gabaix (2011), and Chaigneau et al. (2014).

[2] See also Baker et al. (1988), Deckop (1988), Yermack (1995), and Becker (2006).

[3] If the second-order derivative of the objective function with respect to a is zero (a knife-edge case given its dependence of X), then the implicit function theorem is not applicable.

[4] Given a performance metric, a standard way of measuring incentives is ΔManager's Wealth/ΔPerformance. When performance is a diffusion process Q, the continuous-time analog to this measure is dY/dQ because Y measures the dollar value of the manager's wealth. Because $dZ \cdot dt = 0$ and $dZ^2 = dt$, we have

$$\frac{dY}{dQ} = \frac{dY}{dQ}\frac{dZ}{dZ} = \frac{\sigma g'(a^*(X))X}{\sigma_Q},$$

where the numerator is the volatility of Y given in Equation (21) and σ_Q is the volatility of Q. Performance metric Q is X in Equation (31) and is V in Equation (32).

[5] See also Yermack (1996) and Bergstresser and Philippon (2006).

[6] Data on firm-specific employee stock options are from SEC filings around the respective firms' IPOs.

[7] Available at http://astro.temple.edu/lnaveen/data.html, accessed March 7, 2017. Core and Guay (2002) and Coles et al. (2006) are the first papers to use these data; see Coles et al. (2013) for an explanation of their construction.

[8] Available at Andrew Koch's website: Accessed March 1, 2017, http://www.pitt.edu/~awkoch/

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