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Jed DeVaro, Jin-Hyuk Kim and Nick Vikander

Øster Farimagsgade 5, Building 26, DK-1353 Copenhagen K., Denmark
Tel.: +45 35 32 30 01 – Fax: +45 35 32 30 00
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Pay-for-(Persistent)-Luck: CEO Bonuses Under Relational and Formal Contracting

Jed DeVaro* Jin-Hyuk Kim† Nick Vikander‡

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Abstract

This study investigates the structure of optimal incentives in a stochastic environment and provides evidence for the use of self-enforcing relational contracts. We show theoretically that under relational contracting, firms can credibly promise chief executive officers (CEOs) larger bonuses in good states than in bad, in a way that depends crucially on the state's persistence and the firm's discount factor. Formal contracting instead implies the same bonus in both states. Estimating an empirical model using ExecuComp data, we find that CEO annual bonuses are related to "luck" in a manner consistent with relational contracting.

JEL Classification: C73, D86, J41

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*California State University, East Bay. E-mail: jed.devaro@csueastbay.edu

†University of Colorado at Boulder. E-mail: jinhyuk.kim@colorado.edu

‡University of Copenhagen. E-mail: nick.vikander@econ.ku.dk

1 Introduction

One principle concerning CEO compensation on which most would agree is the desirability of tying part of CEO pay to firm performance. The relevance of such performance pay follows both from agency theory and common sense. Deviations from this principle, particularly during times of poor firm performance, provoke outcries from shareholders and the general public. For example, during the recent global financial crisis, some CEOs received large bonuses even though their failing firms required taxpayer-funded public bailouts. These "rewards for failure" generated public outrage and calls to tighten the link between pay and performance.

A problem with tying CEO pay to firm performance, however, is that performance can sometimes depend on factors beyond the CEO's control. In these cases, pay-for-performance amounts simply to "pay-for-luck".[1] While the adage "You make your own luck" may be partly true, it would seem unreasonable to reward CEOs for factors truly beyond their control. The Informativeness Principle from agency theory suggests that only measures which provide information about the CEO's desired action should be used in her incentive contract (Shavell, 1979; Holmström, 1979). Luck, reflecting factors beyond a CEO's control, should therefore have no impact on compensation. Bebchuk and Fried (2003, 2004) prominently argued that pay-for-luck is inconsistent with agency theory but consistent with the hypothesis of managerial power, in which excessive CEO influence and a lack of board independence lead to inefficient forms of pay.

Empirical evidence suggests that CEO cash compensation does, in fact, respond to luck (e.g., Blanchard et al., 1994; Bertrand and Mullainathan, 2001; Oyer, 2004; Garvey and Milbourn, 2006; Bizjak et al., 2008). Most studies measure luck as the portion of firm performance that can be predicted by exogenous price changes (e.g., oil prices and exchange rates) or average industry performance (see, e.g., Bertrand and Mullainathan, 2001). Such

[1] Throughout the discussion we define "luck" to mean factors beyond a CEO's control that impact firm performance. Though such factors may appear "random" from the CEO's perspective, in the broader sense they may follow from the general economic environment.

measures tend to be positively correlated over time. Our goal is to explore the implications of this simple observation that good (or bad) luck is frequently followed by more of the same. Because luck is persistent, the realization of luck today contains relevant information about the likely state of the employment relationship tomorrow, which in turn has implications for CEO effort and contract design. These implications have been neglected by the literature to date. Moreover, the greater the degree of persistence in luck, the stronger these implications should be.

Our focus is on CEO bonuses, as opposed to other components of compensation such as base pay, stock options, and restricted stock. These bonuses can be contractually specified in different ways. Firms can use formal contracts, that are directly enforceable by a third party, or alternatively they can use relational contracts that are indirectly enforceable through the threat of punishment in the context of repeated play. Both formal and relational contracting perspectives seem reasonable, *a priori*, when analysing CEO compensation. Contracts for CEOs often explicitly specify the relevant bonus structure. For example, Murphy (1999) described formula-based "80/120 plans," a commonly used piecewise-linear bonus contract. However, in a cross-sectional study, Gillan et al. (2009) found that roughly half of the S&P 500 CEOs work without any explicit employment contract at all. When a contract does exist, the board can often exercise discretion either in the performance metrics used or in judgments about whether certain performance standards have been achieved. For instance, "individual bonuses may be based in part on subjectively assessed individual performance [....] Alternatively, the boards of directors may make discretionary adjustments." (Murphy and Oyer, 2004: 2).[2]

We develop a theoretical framework for analyzing the effect of persistent luck under both formal and relational contracting. We consider an employment relationship between a principal (the shareholders) and an agent (the CEO) with a common discount factor,

[2]The scope for discretion in executive bonuses is further articulated by Murphy and Jensen (2012: 42): "sometimes these shadow plans have little or nothing to do with the performance criteria specified in the shareholder approved plans."

in a simple Markovian environment with two states of the world (high and low). The state is positively correlated over time and directly affects output in a way that is beyond the CEO's control. The CEO exerts effort to influence the probabilities of "success" or "failure" in production, expecting that "success" will result in a larger bonus. The principal is contractually obligated to pay any promised bonuses under formal contracting, whereas he can always renege on his promise under relational contracting.

We show that under formal contracting, the principal offers the same bonus for success in both states. In contrast, under relational contracting, the optimal bonus may vary across states, depending on the value of the discount factor. The principal always offers the same bonus as under formal contracting when the discount factor is sufficiently high. However, when the discount factor is low, so is the future value of the employment relationship, leaving this bonus too large to be credible. The principal then offers a smaller bonus that is conditional on the state, with a relatively larger bonus in the high state than in the low. The reason is that the principal's credibility depends on the current state. A high state today suggests a high state tomorrow, which in turn suggests higher profits from continuing the employment relationship. The principal then has much to lose by reneging on his promise of a bonus and inducing a disgruntled CEO to end the relationship. This dynamic enforcement constraint under relational contracting means that conditioning the bonus on (persistent) luck is *efficient*, in contrast to Bebchuk and Fried's "managerial power" rationale that pay-for-luck is *inefficient*.

The magnitude of the preceding result hinges on the degree of persistence of the state. If the state has a strong positive correlation over time, then bonus payments under relational contracting with a low discount factor will be highly sensitive to the state, since the current state is very informative about the future value of the employment relationship. This means that the difference between the bonus in the high state and the low state will be large. In contrast, in the extreme case where the state is independent over time, the bonus is insensitive to the state for all values of the discount factor, and exactly matches the bonus under formal contracting.[3] Thus, persistence of the state is key to differentiating formal from relational contracts, and the greater the persistence, the starker the differentiation.

These predictions derived from theory allow us to address the empirical question of whether relational contracting plays a role in executive compensation. This question is important, since there is a growing theoretical literature on relational contracts, but few empirical tests to distinguish their implications from those of formal contracts. We investigate our predictions using a merged data file drawn from ExecuComp, Compustat, and CRSP, estimating an empirical model for executive bonuses that includes a measure of persistent luck (i.e. the state) on the right-hand side. Our preferred measure of the state is an indicator for whether the part of lagged sales growth that is predicted by observable variables unrelated to CEO effort is positive. The rationale for lagging the measure and for using predicted rather than actual values is to purge the measure of any influence of current CEO effort.

We find that this measure of the state is positively autocorrelated and that it is also positively correlated with our measure of CEO performance, which is firm income. To test the main theoretical predictions, we estimate a reduced-form bonus equation that expresses the amount of the CEO annual bonus as a function of the state. Our main prediction is that the effect of the state on the bonus is positive, to the extent that relational contracting characterizes CEO bonus pay. Furthermore, since this relationship only holds for a sufficiently low discount factor, the empirical result should be stronger (and perhaps only detectable) for low values of a discount factor proxy. We identify a proxy for the discount factor by following the macroeconomics literature and assuming that the firm's default probability – and hence the probability that the employment relationship ends – is increasing in financial leverage.

[3]The reason is that one-off events over which managers have no control only affect today's surplus and have no relevance to the future value of the relationship. The only different implication of relational contracts compared to formal contracts is that the bonus would be smaller when the firm's dynamic enforcement constraint binds; however, without knowing the counterfactual for a given firm, estimating the difference is not straightforward.

The empirical results using leverage as a proxy for the (inverse) discount factor provide support for our predictions under relational contracting. That is, the marginal effect of the state on a CEO's annual bonus payment is positive, with a larger magnitude when the discount factor is low, as reflected by high values of leverage. In a sensitivity analysis, we consider an alternative measure of the (inverse) discount factor, using estimated probabilities of default, and find that our results are robust to this change. To test our prediction that the positive marginal effect of the state on the CEO's bonus is increasing in the state's persistence, we compute the first-order autocorrelation of the state for each firm and interact that variable with the measure of state in the bonus regression. The results are again consistent with our theoretical predictions under relational contracting. Overall, our empirical evidence supports the view that relational contracts play a role in the payment of executive bonuses.

The remaining discussion has the following structure. Section 2 surveys the related literature. Section 3 describes the theoretical model, and Section 4 characterizes the optimal contracts. Section 5 describes the data set, Section 6 presents estimation results, and Section 7 concludes.

2 Related Literature

The basic theory of stationary relational contracts is well known (e.g., Bull, 1987; MacLeod and Malcomson, 1989; Baker et al., 1994; Levin, 2003; Malcomson, 2012). That is, relational contracts are self-enforcing when the future value of the relationship is sufficiently large so that both parties find it profitable to adhere to their implicit obligations, rather than to engage in opportunistic behavior.[4] Whereas our study looks at stationary contracts, the recent literature has also considered relational contracts that are nonstationary. For instance, Fong and Li (2012) showed that limited liability can lead to backloading of the agent's utility.

[4]Relational contracts can be used when complete, explicit contracts are costly to design and enforce (Kvaløy and Olsen, 2009).

Chassang (2010), Board (2011), Halac (2012), Li and Matouschek (2012) and Yang (2013) showed that relational contracts can involve nonstationary phases when the principal or the agent has private information, or when there are switching costs.

Non-stationary incentives often relate to learning that occurs through the employment relationship. While learning undoubtedly matters in some cases, it does not play a role in our theoretical model, and is likely to be relatively unimportant in practice for CEOs. Unlike most workers, CEOs have already successfully reached the top of their career ladders and interact frequently with the board, and the findings of the previously mentioned studies on non-stationary relational contracts suggest both these considerations diminish the importance of learning. We further comment on the implications of uncertain information in our model at the end of Section 4.

Most existing evidence on relational contracting comes from inter-firm (supply) relationships rather than intra-firm (employment) relationships (e.g., McMillan and Woodruff, 1999; Banerjee and Duflo, 2000; Johnson et al., 2002; Lafontaine and Slade, 2012; Gil, 2013). These studies mainly focused on showing that relational contracts can substitute for formal institutions like courts and help sustain long-term relationships in developing countries. The study closest to ours in this literature is Gil and Marion (2013), which explores how relationships between contractors and subcontractors affect bidding behavior in highway procurement auctions in California. They construct an exogenous instrument to measure the future value of ongoing relationships, finding that a larger stock of relationships leads to lower bids and a greater likelihood of entry, but only when the future value is high.

Further evidence on relational employment contracts has been almost exclusively experimental (e.g., Brown et al., 2004; Fehr et al., 2009; Camerer and Linardi, 2010). We view this literature as complementary to our study, as it has focused on capturing features of competitive labor markets rather than testing the implications of principal-agent relationships. For instance, Brown et al. (2004) conducted experiments in which firms offer wages to workers, and workers can exert noncontractible effort. Relational contracting is made possible by attaching ID numbers to all firms and workers, allowing firms to make private offers to particular workers each period. They showed that repeated interactions in the absence of third-party enforcement can lead to more efficient outcomes than one-shot interactions. However, unlike in our study, there is no discretionary bonus payment at the end of the period, and the rationale for cooperation focuses on reciprocity.

Our empirical evidence supporting relational contracts contributes to the growing literature on pay-for-luck (e.g., Blanchard et al., 1994; Bertrand and Mullainathan, 2001; Oyer, 2004; Garvey and Milbourn, 2006; Bizjak et al., 2008). An explanation for pay-for-luck that has been proposed in a static framework is that CEOs' outside options are correlated with their firms' performance, so firms adjust CEO pay for retention purposes (Oyer, 2004; Bizjak et al., 2008). However, dynamics can also be an important consideration in CEO pay. For instance, Holmström (2005) argued that increased demand (or the CEO's outside option) is not likely to be the sole driver for the recent rise in CEO pay, and it is important to examine dynamic models where commitment problems and implicit incentives play a role. We argue in this spirit that relational contracting gives rise to a dynamic enforcement constraint that can help explain pay-for-luck, where firms adjust CEO pay in response to changes in the expected future value of the employment relationship.

Our empirical model for CEO bonuses includes a measure of the state of the world, which is an indicator of the sign of lagged sales growth (or, alternatively, the same measure but using predicted rather than actual sales growth, where the prediction equation nets out factors that may be related to CEO effort). The relationship between sales growth and executive compensation has been explored in prior literature. For example, Hallock and Oyer (1999) presented evidence that in addition to being rewarded for current performance, CEOs are rewarded in year t for increases in earnings in year $t + 1$. They also showed that fourth-quarter sales growth is a particularly good predictor of the following fiscal year's earnings growth. It follows that the most recent observations of sales growth should receive the most weight in an executive's compensation. Whereas Hallock and Oyer focused on whether executives have an incentive to shift sales from one fiscal quarter to another, we focus on the role of sales growth as a persistent state variable that can help empirically distinguish relational from formal contracting.

More generally, this study relates to an extensive literature on CEO compensation and firm performance (see, e.g., Hall and Liebman 1998 and the surveys by Murphy 1999 and Core et al. 2003). Whereas that literature focuses on the measurement of, and issues surrounding, the sensitivity of pay to performance, we focus on the empirical implications of relational versus formal contracting in the payment of CEO bonuses. To our knowledge, there are no prior studies that focus on empirically distinguishing between formal and relational contracting.[5]

3 The Model

Consider a repeated relationship between a principal and an agent, both of whom are risk neutral. Time has an infinite horizon with discrete periods indexed by $t = 1, 2, \ldots$. In each period t, the agent produces output, and her work either meets with success or with failure. Success or failure is a random variable equaling x_S in the case of success and x_F in the case of failure, where $x_S > x_F > 0$. Output in each period, x_t, depends on whether success or failure was achieved in that period and also on two additional stochastic components (one persistent and the other idiosyncratic). We refer to the persistent component as the state of the world and denote it by Δ_t; we refer to the idiosyncratic component as the shock and denote it by ϵ_t. Thus, $x_t \in \{x_F + \Delta_t + \epsilon_t, x_S + \Delta_t + \epsilon_t\}$.

The state can assume either of two possible values and evolves according to a Markov process: $\Delta_t = \{-\Delta, \Delta\}$, where $0 < \Delta < x_F$, and $P(\Delta_{t+1} = \Delta_t) = \theta \in (1/2, 1)$. We say that the period-t state is high if $\Delta_t = \Delta$ and that it is low if $\Delta_t = -\Delta$. Both states are *a priori*

[5] Murphy and Oyer (2004) used survey data to examine the related question of discretion in executive compensation. They found that nearly two-thirds of surveyed companies based bonuses in part on subjective assessments of individual performance. This study is complementary to Murphy and Oyer, as it tests for relational contracting by examining changes in the size of bonus payments.

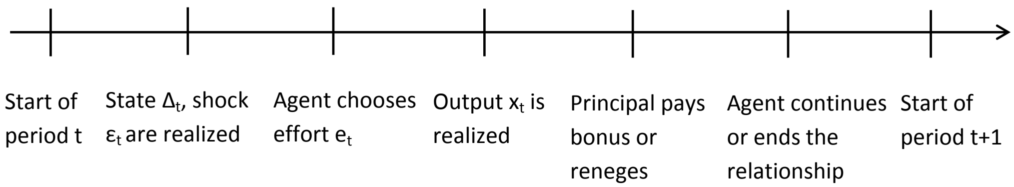
equally likely, i.e. $P(\Delta_1 = \Delta) = P(\Delta_1 = -\Delta) = 1/2$. Random shocks are independently and identically distributed with mean zero on $[-\epsilon, \epsilon]$, where $0 < \epsilon < x_F - \Delta$.

In each period t, the agent chooses effort $e_t \in [0, 1]$ at a cost of $C(e_t)$, with $C(0) = 0$, $C'(0) = 0$, $C'(e) \geq 0$, $C''(e) > 0$, $C'''(e) \geq 0$, and $\lim_{e \to 1} C'(e) = \infty$. This effort choice is not observed by the principal. The role of effort in the model is to influence the probability of success or failure. The probability of success, $p(e_t) \equiv p(x_t = x_S + \Delta_t + \epsilon_t | e_t)$, is increasing in effort, and we assume that $p(0) = 0$, $p'(e) > 0$, $p''(e) < 0$, $p'''(e) \leq 0$. The agent's incentive to increase the likelihood of success by exerting effort is driven by a desire to be paid a higher bonus, as we explain shortly.

Output x_t is observable to both the principal and the agent, but it may not be verifiable by third parties. If x_t is verifiable, then the principal can use formal contracting. If x_t is unverifiable, the principal must instead rely on relational contracting, as described below. Both the principal and agent discount future payoffs with factor $\delta \in (0, 1)$. The discount factor can be interpreted as the probability that the relationship continues to the following period.

The timing of the game is as follows. At $t = 0$, the principal offers the agent a contract, B, that specifies payment at the end of each period $t \geq 1$, conditional on the history of previous play. The principal can commit to these payments when output is verifiable (formal contracting) but not when it is unverifiable (relational contracting). At the start of any period $t \geq 1$, the state Δ_t and the shock ϵ_t are publicly revealed, and the agent chooses effort e_t. Output x_t is then realized and publicly revealed. The principal makes the payment specified under B, or possibly reneges on this payment under relational contracting, and the period ends. The agent then chooses whether or not to continue his relationship with the principal into the next period. If the agent ends the relationship, then both he and the principal earn a payoff of zero from their outside option in all later periods. If the agent continues the relationship, then play moves to period $t + 1$. The timing of play within each period $t \geq 1$ is summarized in Figure 1.

Figure 1



We focus on stationary perfect public equilibria where, on the equilibrium path, period-t payments and actions depend only on x_t, Δ_t, and ϵ_t. We can therefore write $B = (b_{SH}(\epsilon_t), b_{FH}(\epsilon_t), b_{SL}(\epsilon_t), b_{FL}(\epsilon_t))$, where b_{SH} and b_{FH} denote, respectively, the bonuses for success and failure when the state is high, and b_{SL} and b_{FL} denote the bonuses for success and failure when the state is low. The notation makes clear that these bonuses may also depend on the value of the contemporaneous shock, ϵ_t. We assume limited liability so that $B \geq 0$, and consider trigger strategies specifying the harshest credible punishment if the principal reneges on a payment specified by B: the agent then immediately ends the employment relationship (Abreu, 1988).[6] As part of the contract B, the principal could offer a base salary $w \geq 0$ paid at the start of each period, but we can restrict attention to contracts consisting entirely of bonuses, since the optimal base salary in our setting is zero.[7]

4 Theoretical Results

We begin the analysis by providing expressions for the expected payoffs of the principal and the agent. Henceforth, let e_H (e_L) denote the agent's optimal effort choice in the high (low) state. Suppose that the period-t state is high, i.e. $\Delta_t = \Delta$. Then given contract B, effort

[6]Conditional on the relationship continuing after the principal reneges, the agent exerts zero effort in all subsequent periods, and the principal offers zero bonus, so that each strategy specifies a best reply to the other.

[7]Specifically, the principal offers a base salary that provides the same payoff as the agent's outside option. Paying any higher base salary would directly reduce the principal's profits and indirectly reduce his ability to credibly offer bonuses under relational contracting.

choice e_H, and shock ϵ_t, the principal's expected period-t profits are $\pi_H(B, e_H) + \epsilon_t$, where

$$\pi_H(B, e_H) = p(e_H)(x_S + \Delta - b_{SH}(\epsilon_t)) + (1 - p(e_H))(x_F + \Delta - b_{FH}(\epsilon_t)), \tag{1}$$

and the agent's expected period-t payoff is

$$u_H(B, e_H) = p(e_H)b_{SH}(\epsilon_t) + (1 - p(e_H))b_{FH}(\epsilon_t) - C(e). \tag{2}$$

Suppose instead that the period-t state is low, i.e. $\Delta_t = -\Delta$. Then expected period-t profits are $\pi_L(B, e_L) + \epsilon_t$, where

$$\pi_L(B, e_L) = p(e_L)(x_S - \Delta - b_{SL}(\epsilon_t)) + (1 - p(e_L))(x_F - \Delta - b_{FL}(\epsilon_t)), \tag{3}$$

and the agent's expected period-t payoff is

$$u_L(B, e_L) = p(e_L)b_{SL}(\epsilon_t) + (1 - p(e_L))b_{FL}(\epsilon_t) - C(e). \tag{4}$$

For any $t' \geq t$, define $P_{t',t} \equiv P(\Delta_{t'} = \Delta_t)$, which is the probability that the state in period t' is the same as the state in period t. Given that $P(\Delta_{t+1} = \Delta_t) = \theta$, we can define $P_{t',t}$ recursively by

$$P_{t',t} = \theta P_{t'-1,t} + (1 - \theta)(1 - P_{t'-1,t}), \tag{5}$$

for $t' \geq t + 1$, with $P_{t,t} = 1$. Since $\theta > 1/2$, the correlation between states in any two periods should clearly be positive and increasing in θ. We establish these results formally in the proofs of Proposition 1 and 2.

Shocks have mean zero, so the present discounted value of expected profits as of a period t when the state is high is $\Pi_H(B, e_H, e_L) + \epsilon_t$, where

$$\Pi_H(B, e_H, e_L) = \sum_{t=1}^{\infty} \delta^{t-1} \Big(P_{t,1}\pi_H(B, e_H) + (1 - P_{t,1})\pi_L(B, e_L) \Big), \tag{6}$$

with $\pi_H(B, e_H)$ given by (1) and $\pi_L(B, e_L)$ given by (3). Similarly, the present discounted value of expected profits as of a period t when the state is low is $\Pi_L(B, e_H, e_L) + \epsilon_t$, where

$$\Pi_L(B, e_H, e_L) = \sum_{t=1}^{\infty} \delta^{t-1} \Big(P_{t,1} \pi_L(B, e_L) + (1 - P_{t,1}) \pi_H(B, e_H) \Big). \tag{7}$$

Given a stationary contract and unobservable effort, the agent's optimal effort choice in any period t depends only on the incentives offered in that period. Both states are *a priori* equally likely, and shocks have mean zero, so the principal's program under formal contracting is

$$\max \ \Pi = \frac{1}{2}\Pi_H(B, e_H, e_L) + \frac{1}{2}\Pi_L(B, e_H, e_L), \text{ subject to} \tag{8}$$

$$e_H = \arg\max_{e \in [0,1]} \ u_H(B, e), \tag{9}$$

$$e_L = \arg\max_{e \in [0,1]} \ u_L(B, e), \tag{10}$$

$$B = (b_{SH}(\epsilon_t), b_{FH}(\epsilon_t), b_{SL}(\epsilon_t), b_{FL}(\epsilon_t)) \geq 0. \tag{11}$$

Under relational contracting, the principal faces additional constraints. He must have an incentive to actually pay each bonus specified under B when called upon to do so. Given trigger strategies, the optimal way for the principal to renege on a bonus is to withhold it completely, so the benefit of reneging equals the size of the bonus. The cost of reneging is the expected future profits lost when the agent ends the productive relationship. This means that the principal's program under relational contracting includes credibility constraints

$$\max\{b_{SH}(\epsilon_t), b_{FH}(\epsilon_t)\} \leq \delta \Big(\theta \Pi_H(B, e_H, e_L) + (1 - \theta) \Pi_L(B, e_H, e_L) \Big), \tag{12}$$

$$\max\{b_{SL}(\epsilon_t), b_{FL}(\epsilon_t)\} \leq \delta \Big(\theta \Pi_L(B, e_H, e_L) + (1 - \theta) \Pi_H(B, e_H, e_L) \Big), \tag{13}$$

where both the cost and benefit from reneging may depend on the current state.

The value of the shock does not enter into the principal's objective function (8), nor does it enter into any of constraints (9), (10), (11), (12), or (13). It follows immediately that the bonuses prescribed under the optimal contract are independent of ϵ_t; that is, $B = (b_{SH}(\epsilon_t), b_{FH}(\epsilon), b_{SL}(\epsilon_t), b_{FL}(\epsilon_t)) \equiv (b_{SH}, b_{FH}, b_{SL}, b_{FL})$.

We begin with a lemma that simplifies the principal's program.

Lemma 1 *Under both formal and relational contracting, the principal never pays a positive bonus in a period where the agent fails:* $b_{FH} = b_{FL} = 0$.

The intuition for Lemma 1 is straightforward. For any given effort level, offering a positive bonus for failure increases the principal's expected payout. It also makes success relatively less attractive for the agent, which reduces his incentive to exert effort. This leads the principal to set the payment for failure as low as possible, which under limited liability is zero. The optimal contract can therefore be written as $B = (b_{SH}, 0, b_{SL}, 0)$. To ease notation, we henceforth drop the subscript S and write $b_H = b_{SH}$ and $b_L = b_{SL}$. Moreover, the optimal effort level in a given state depends only on the bonus offered for success in that state, so that $e_H = e(b_H)$ and $e_L = e(b_L)$.

Finally, Lemma 1 implies that under relational contracting, credibility constraints (12) and (13) reduce to

$$b_H \leq \delta\Big(\theta\Pi_H(b_H, b_L, e_H, e_L) + (1-\theta)\Pi_L(b_H, b_L, e_H, e_L)\Big), \tag{14}$$

$$b_L \leq \delta\Big(\theta\Pi_L(b_H, b_L, e_H, e_L) + (1-\theta)\Pi_H(b_H, b_L, e_H, e_L)\Big). \tag{15}$$

We now present a second lemma that will be useful in proving our main results. It shows that the optimal effort level is increasing in the size of the bonus but at a decreasing rate. As a result, expected profits in any given period will be a concave function of the promised bonus.

Lemma 2 *Let* $I \in \{H, L\}$, *and consider the agent's optimal effort* $e(b_I)$ *in state* I. *Then* $0 \leq e(b_I) < 1$, *where the inequality is strict for all* $b_I > 0$. *Moreover,* $e(b_I)$ *is unique, with*

$e'(b_I) > 0$ and $e''(b_I) < 0$.

We now state our first main result, where superscripts f and r denote optimal bonuses under formal and relational contracting.

Proposition 1 *If output is verifiable, then the principal will choose formal contracting and offer the same bonus in both states: $b^f \equiv b^f_H = b^f_L > 0$. If output is nonverifiable so that contracting is relational, then the principal will offer a different bonus in each state if and only if the discount factor is sufficiently low: for any $\theta \in (1/2, 1)$, there exists $\delta_0 \in (0, 1)$ such that $0 < b^r_L < b^r_H \leq b_f$ for all $\delta \in [0, \delta_0)$ and $b^r_H = b^r_L = b^f$ for all $\delta \in [\delta_0, 1]$.*

Proposition 1 has two direct empirical implications for distinguishing relational from formal contracting. First, if contracting is relational, then bonus payments should be positively correlated with the state. Second, this positive correlation should be driven by firms with low discount factors that place a relatively low weight on potential future profits.

The intuition behind the result is as follows. A large bonus will generate high effort, which increases expected output, but it will also increase the expected payment to the agent. Absent credibility concerns, the principal takes into account these two opposing effects by setting the optimal bonus that gives marginal profits of zero. Marginal profits are independent of the state, since the state does not affect the relationship between bonus and effort or the relationship between effort and success. It follows that the principal offers the same bonus b^f in both states under formal contracting.

The difference under relational contracting is that the principal faces a commitment problem. He would like to offer the same profit-maximizing bonus as under formal contracting, but he needs an incentive to actually pay this bonus when the agent succeeds. Reneging on a promised bonus increases immediate profits, but it also decreases expected future profits, as the agent reacts by ending the employment relationship. This means the bonus b^f will not be credible if it exceeds the discounted value of expected future profits, which happens if the discount factor is sufficiently low.

In this case, the principal can credibly promise a larger bonus in the high state than in the low state, because profits are higher in the high state and states are positively correlated over time. The principal then sets $b_L^r < b_H^r$ under relational contracting. Total profits are lower than under formal contracting, since marginal profits are strictly positive at the constrained optimum, but the principal cannot credibly commit to paying a larger bonus.

The driving force behind Proposition 1 is the persistence of the state over time. We now describe further how the optimal bonuses depend on the discount factor and the persistence of the state.

Proposition 2 *Consider the optimal bonuses b^f, b_H^r, and b_L^r given by Proposition 1. Then:*

(i) b^f is independent of δ, whereas b_L^r and b_H^r are increasing in δ whenever $b_L^r < b^f$, $b_H^r < b^f$.

(ii) b^f is independent of θ, whereas $b_H^r - b_L^r$ is increasing in θ whenever $b_L^r < b^f$, $b_H^r < b^f$.

A corollary to part (i) is that *ex-ante* expected per-period profits are independent of δ under formal contracting but increasing in δ under relational contracting. With relational contracting, a larger discount factor allows the principal to credibly offer bonuses closer to b^f and implement more efficient levels of effort.

Proposition 2 has a number of additional empirical implications. First, if workers are compensated through relational contracting, then firms with low discount factors should pay lower bonuses. Second, these same firms will tend to earn lower profits than those using formal contracts. Third, the sensitivity of bonus payments to the state with relational contracting should be highest for firms facing a very persistent state.

Under formal contracting, the principal chooses the optimal bonus to maximize immediate profits, which are independent of discounting or of the future state. In contrast, the credibility constraint under relational contracting depends on δ and θ through the discounted value of expected future profits. First, consider the result in part (i). When the discount factor is low, the principal always offers a relatively small bonus, since a larger bonus would not be credible. An increase in δ allows the principal to credibly increase both b_L^r and b_H^r since he then has a larger stake in continuing the employment relationship. The prospect of earning a larger bonus leads the agent to exert more effort, which in turn increases expected profits.

Now consider the result in part (ii). When persistence is low, the current state provides little information about future profits. The principal then faces similar credibility issues across states and offers similar bonuses. As the state becomes more persistent, the difference in expected future profits between the high and low states increases. This persistence differentially affects the principal's credibility across states and leads him to offer increasingly different bonuses.

We have assumed the state has a simple autocorrelation structure that is known to the principal and agent, but our main results should be robust to relaxing this assumption. For instance, suppose the persistence of the high state θ_H could differ from that of the low state θ_L, and that players were initially unaware of the true values of θ_H and θ_L, instead holding prior beliefs about each variable over $(1/2, 1)$.

In this setting, if players were to observe a recurring high state, they would infer the high state was relatively persistent and update their beliefs about θ_H towards 1. If players were to observe the state change from low to high, they would instead update their beliefs about θ_L towards $1/2$. Either way, players observing a high state would revise up their expectation of future profits, which would loosen the credibility constraint and allow for a larger bonus. Similarly, players observing the low state would revise down their expectation of future profits, which would only allow a smaller bonus to be credible. We would still expect the bonus to be larger if the state was high than if it was low, but now bonuses would change over time as players continued updating their beliefs. In the long run, beliefs would tend to the true values of θ_H and θ_L with probability one, and in the case where $\theta_H = \theta_L$, bonus payments would tend to b_H^r and b_L^r from the preceding analysis.

5 Data

The executive compensation data we use for the empirical analysis come from the Standard & Poor's Execucomp database for the period 1993–2011. Our sample comprises current constituents of all S&P 500 (large cap), S&P 400 (mid cap) and S&P 600 (small cap) companies.[8] We focus on individuals identified as CEOs for each firm. The Execucomp database contains an indicator for the executive who served as CEO for all or most of the year (i.e., CEOANN); however, this variable often has missing entries, and the CEO designation sometimes changes in a somewhat arbitrary fashion between co-CEOs and between chairman and CEO, etc. Our solution was to check for irregular data patterns, verify the executives' career profiles using online sources such as businessweek.com and forbes.com, and make necessary corrections.

The data include individual executives' age and the date they became chief executive officers (i.e., BECAMECEO), from which we calculated each CEO's tenure.[9] Compensation data are collected from each firm's annual proxy (DEF 14A) and include the CEO's salary, bonus, equity-based compensation, and other components. Consistent with our theoretical model, we focus on executive annual bonus payments. Hence, our primary dependent variable is executive i's year-t bonus, which we denote by $BONUS_{it}$. Due to the SEC rule change FAS 123(R), ExecuComp made important changes in the reporting format for some variables as of 2006. For our purposes, the most important change was that annual bonuses were mostly reported as Non-Equity Incentive Plan Compensation as of 2006, meaning that the bonus variable often equals zero in those years. We take this change into account by including non-equity incentive pay in our bonus measure from 2006 forward.[10]

[8]Compustat does not show historical constituents, so our sample includes new entries but not drop-outs.

[9]Wherever the BECAMECEO entry was missing, we searched the executive's career profile from the previously mentioned source. Importantly, the ExecuComp database resets (overwrites) the BECAMECEO variable when the same individual becomes a CEO more than once for various reasons. We did not reset the CEO tenure when we found such cases.

[10]As Florin et al. (2010) note, "[s]trictly speaking, the bonus as listed in the table is formula-based pay beyond cash salary. On the other hand, non-equity incentive compensation can be both short-term or long-term pay that is based on some pre-set criteria (based on performance) whose outcome is uncertain [...] both can be considered a type of bonus."

After eliminating firms for which only a few years' data are observed, we have an unbalanced panel of 1490 firms by 19 years. We then obtain each firm's financial information from the Compustat annual industrial file and match that information with the compensation data. All financial variables in the raw data are measured in nominal values (e.g., compensation, income, and balance sheet items), which we convert to real values in 2005 dollars using the GDP deflator. Following the literature (e.g., Bertrand and Mullanaithan, 2001), we use income before extraordinary items as our measure of executive i's year-t performance and denote it by $PERF_{it}$.

Any variable that is persistent, unaffected by CEO actions, and observed to economic actors at the time decisions are made will suffice as a measure of Δ_{it}. One variable we use to capture the period-t state is $SALESCHGPOS_{t-1}$, defined to equal 1 if $SALES_{t-1} - SALES_{t-2} > 0$ and to equal 0 otherwise, where $SALES_t$ denotes period-t sales revenue. Our use of lagged $SALESCHGPOS$ as a measure of the state requires discussion given that sales growth has also been used in the literature as a measure of executive performance. Hallock and Oyer (1999) argued that since the CEO's goal is to increase the firm's scale, sales growth can be thought of as a performance measure.

Although sales growth may often belong on the right-hand side of an executive compensation equation (e.g., Murphy, 1985; and many subsequent studies), the specific measure we consider is not particularly relevant for CEO performance.[11] For example, suppose company sales declined gradually, from 500 to 495, over a ten-year period, before plummeting abruptly to 100 and then gradually increasing to 105 over the subsequent ten years. Using the annual change in sales as the performance measure, the performance profile would look negative over the first decade and positive over the second decade, even though a more natural conclusion would be the opposite given the far greater sales revenue in the first decade.

[11] Murphy (1985: 22) explains the rationale for including sales growth (and also the level of sales) on the right-hand side of an executive compensation equation as follows: "In addition to stock performance, firm size or growth may yield information relevant for determining levels of managerial effort. Indeed, several theories of managerial production suggest that compensation should be partially determined by firm size or growth, reflecting the quantity of resources controlled by the individual executive and the scope of managerial responsibilities."

A potential concern about using $SALESCHGPOS$ as a measure of the state in our model is that sales growth could partially reflect CEO actions. We address this concern in two ways. First, in our regressions for the year-t executive bonus, we include only lagged values of $SALESCHGPOS$ on the right-hand side. The rationale is that even if sales growth from years $t-2$ to $t-1$ contains information about CEO effort, this past effort is irrelevant for period t compensation in our theoretical framework. All that we require to test our predictions is a serially correlated variable that affects CEO performance, that is observed to economic agents at the time of their decisions, and that is exogenous as of the current year t.

Second, we also consider an alternative measure of the state: the predicted values from individual regressions (one for each firm in the sample), each of the form $SALESCHG_t = \mathbf{Z}_t\gamma + \omega_t$. Here, $\mathbf{Z}_t$ is a vector of potentially time-varying covariates measuring factors that are observable to economic agents in year t, that affect sales growth, and that are unrelated to CEO effort. We then compute a binary variable equaling 1 if the lagged predicted value is positive and zero otherwise. Note that the residual, ω_t, is the unexplained part of sales that can be attributed in part to CEO effort. Measuring the state using predicted values nets out these effort-based components that are embedded in ω_t.[12] In the results we report, $\mathbf{Z}_t$ contains a constant, a linear time trend and the real GDP growth rate between years $t-2$ and $t-1$.

We measure the shock, ϵ_{it} in the notation of Section 3, using the sum of extraordinary items and discontinued operations, which we denote by $EIDO_{it}$. The factors included in $EIDO$ represent financial occurrences that are rare and unexpected. Such items would typically not factor into an evaluation of the future prospects of a company, because the shocks are seen as one-time events. These irregular items are separately reported on income statements. Examples could include natural disasters and adjustments arising from accounting

[12] A downside to this measure of the state is that ω_t likely contains more than just CEO effort. By subtracting ω_t, we are potentially netting out too much, including some information that is persistent and observed to the economic agents and that should be included in the measure of the state.

changes.[13]

Addressing our model's predictions empirically requires a measure of the discount factor, δ. In the theoretical model, there is a critical threshold for the discount factor beyond which the bonus is insensitive to the state both for formal and relational contracts. Only when the discount factor is below the threshold does a difference emerge between the two contract forms. We therefore need a proxy to identify low values of δ_{it}. We focus on the probability of default, since the greater the likelihood of default, the less weight economic agents place on future payoffs when making current decisions. Although the likelihood of default depends on a number of factors, one important factor observed in the data is leverage, where high leverage increases the risk of default (Crosbie and Bohn, 2003). We therefore use the measure $LEVERAGE_{it}$ as an empirical proxy for $(1 - \delta_{it})$.[14]

As a sensitivity check, we also use an alternative measure of the inverse discount factor: a computed measure of the probability of default. We refer to this measure as PD_{it}. Afik et al. (2012) calculated this default probability based on Merton's (1974) structural model for "distance to default" for all non-December fiscal-year-end firm-years using the merged CRSP-Compustat database covering years 1988 to 2008.[15] The distance-to-default calculation uses information on a firm's equity volatility as well as a firm's leverage, and it tends to increase with financial leverage.[16] Finally, we measure θ, the persistence of the state, by computing for each firm i the first-order autocorrelation coefficient of $SALESCHGPOS_{it}$, called $CORR_i$.

[13] In principle, $EIDO$ should be serially uncorrelated. In practice, some serial correlation might occur either because the events themselves are autocorrelated (e.g., an unexpected hurricane might be the harbinger of a broader climatic shift) or because of reporting errors (e.g., management might purposely misclassify an ordinary, recurring expense transaction as an extraordinary item or discontinued operation to make the numbers for continuing operations on the income statement look better).

[14] $LEVERAGE$ is defined to equal $(DLTT + DLC)/(DLTT + DLC + CEQ)$, where $DLTT$ and DLC are the book value of long-term debt and debt in current liabilities, respectively. CEQ is the market value of common/ordinary equity, which is calculated by multiplying the closing stock price and the number of shares outstanding.

[15] We are grateful to Zvika Afik, Ohad Arad and Koresh Galil for sharing their estimates of the probability of default.

[16] The bivariate correlation between $LEVERAGE_{it}$ and PD_{it} is 0.48, and a regression of $LEVERAGE_{it}$ on PD_{it} and firm fixed effects has a slope of 0.8.

6 Empirical Analysis

Our goal in the empirical analysis is to model the variation in executive bonuses, over time and across firms, as a function of "luck", to show evidence for or against relational contracts as opposed to formal contracts. We emphasize persistent "luck" (i.e., the state) since persistence is necessary to generate observable differences between the two contracting forms.

Table 1 presents summary statistics for the variables in our analysis. Panel A of Table 2 presents an autocorrelation matrix for $SALESCHGPOS_t$ and its first three lags. As required by our model, this proxy for the state variable is positively autocorrelated, with correlations in adjacent periods exceeding 0.21 and with correlations as far as three periods apart remaining statistically significant at the five percent level with a magnitude exceeding 0.05. Panel B of Table 2 displays the autocorrelation matrix for the alternative state variable based on the prediction equation that nets out factors that the CEO might influence. The autocorrelations are considerably higher than those in Panel A, ranging from 0.61 to 0.67 for adjacent periods and reaching 0.38 even for the correlation three periods apart. Panel C of Table 2 displays an autocorrelation matrix for $EIDO_t$ and its first three lags. These results confirm that $EIDO$ is a reasonable measure of idiosyncratic shocks; the variable is positively correlated only in adjacent years, and even those correlations are all below 0.03.

Our theoretical model posits that the shock and the state both have positive direct effects on output, or CEO performance. Therefore, we first estimate the following equation for CEO performance, $PERF_{it}$:

$$PERF_{it} = \alpha_0 + \alpha_1 EIDO_{it} + \alpha_2 SALESCHGPOS_{it-1} + \mathbf{X}_{it}\alpha + \xi_i + u_{it},$$

where $\mathbf{X}_{it}$ includes age, age squared, tenure, tenure squared, and year dummies, and where ξ_i is a firm fixed effect. As seen in column 1 of Table 3, the estimates of α_1 and α_2 are both positive and significant at the five percent level, suggesting that both the idiosyncratic shock and the persistent state are positively related to CEO performance. The same result is found in column 2 of Table 3, using the alternative measure of the state.

Turning next to the predictions on bonus compensation, we start with the following linear bonus equation:

$$BONUS_{it} = \beta_0 + \beta_1 EIDO_{it} + \beta_2 SALESCHGPOS_{it-1} + \mathbf{X}_{it}\beta + \phi_i + \varepsilon_{it},$$

where again $\mathbf{X}_{it}$ includes age, age squared, tenure, tenure squared, and year dummies, and where ϕ_i is a firm fixed effect.[17]

Our specification differs from what is typically seen in the executive compensation literature, in that the (endogenous) executive performance measure does not appear on the right-hand side of the compensation equation. A common objective in this literature is to measure pay-for-performance sensitivities, that is, the slope of a performance measure in a total compensation regression. Given our theoretical model, our objective is instead to measure the effect of stochastic "luck" on the CEO's bonus. Our bonus equation can be interpreted as a reduced form in which the performance equation substitutes for the (endogenous) CEO performance measure that would otherwise appear on the right-hand side.

First, our theoretical model predicts $\beta_1 = 0$. Second, it predicts $\beta_2 = 0$ under formal contracting, and $\beta_2 > 0$ under relational contracting if some firms in the sample have a sufficiently low discount factor δ_{it}. Results are displayed in column 1 of Table 4 and reveal $\beta_2 > 0$, consistent with relational contracting. However, $\beta_1 > 0$ is at odds with both contracting forms in our theoretical framework, and we discuss potential reasons for this at the end of the section. The results are qualitatively the same for the alternative measure of the state and are displayed in column 3 of Table 4.

The preceding results show that, on average, the size of CEO bonus payments is positively related to the state. Given our theory, if the data-generating process is indeed characterized

[17]The CEO's base salary and bonus can be expected to positively covary, but since base salary is endogenous, we exclude it from the right-hand side of the bonus equation. Including base salary in the model does not affect our results of interest.

by relational contracting, we would expect observations with a low discount factor to be driving this result. This leads us to consider the following interactive bonus specification:

$$\begin{aligned} BONUS_{it} &= \beta_0 + \beta_1 EIDO_{it} + \beta_2 SALESCHGPOS_{it-1} + \beta_3(SALESCHGPOS_{it-1} \times \\ &\quad LEVERAGE_{it}) + \beta_4 LEVERAGE_{it} + \mathbf{X}_{it}\beta + \phi_i + \varepsilon_{it}. \end{aligned}$$

High leverage implies a high default risk and therefore a low value of δ_{it}. It follows that our model predicts $\beta_2 + \beta_3 LEVERAGE_{it} = 0$ and $\beta_3 = 0$ under formal contracting, and instead $\beta_2 + \beta_3 LEVERAGE_{it} > 0$ and $\beta_3 > 0$ under relational contracting. That is, with relational contracting, the incremental effect of state should be positive and driven by firms with higher leverage.

Results from the interactive bonus model are displayed in column 2 of Table 4. The estimate of β_2 is not statistically significant, while the estimate of β_3 is positive and significant. It follows from the estimate of β_3 that the incremental effect of $SALESCHGPOS$ varies considerably with leverage. When evaluated at 0.04 (the 25^{th} percentile of the $LEVERAGE$ distribution) the incremental effect is only 33.4, whereas when evaluated at 0.52 (the 90^{th} percentile of the $LEVERAGE$ distribution) the incremental effect is about 320, showing it is indeed high-leverage firms that drive the positive and significant coefficient for $SALESCHGPOS$ in the linear model of column 1. Once again, the results are supportive of relational contracting rather than formal contracting, though again $\beta_1 > 0$ is at odds with both contract forms in our framework. As seen in column 4 of Table 4, the qualitative results remain consistent with relational contracting when using the alternative measure of the state, though now the estimated β_2 is negative and statistically significant.[18]

Furthermore, our theory predicts that both CEO performance and bonus payments should be increasing in the discount factor under relational contracting, but not under formal

[18] In the interactive specification, it is the incremental effect $\beta_2 + \beta_3 LEVERAGE_{it}$, rather than the parameter β_2, that is of interest.

contracting. Relational contracting therefore implies these variables should be decreasing in $LEVERAGE$. The data support both predictions, as seen in columns 3 and 4 of Table 3 and in columns 2 and 4 of Table 4, where in both cases $LEVERAGE$ has a negative incremental effect. The latter result is also consistent with Fahn et al.'s (2013) prediction that a firm's financial leverage may directly affect the size of bonus the firm can credibly promise. That is, our empirical specification nests this prediction, and we indeed find support for the hypothesis that debt also directly weakens the firm's incentive to honor its commitments. While leverage is an endogenous choice variable of the firm, Graham et al. (2013) show that there is little relation in the aggregate between a firm's financial leverage and its executive compensation.[19]

Yet another prediction under relational contracting is that the incremental effect of the state on the bonus is increasing in θ. In other words, we expect a stronger positive relationship between $BONUS_{it}$ and $SALESCHGPOS_{i,t-1}$ when the positive autocorrelation in $SALESCHGPOS$ is particularly strong. To address this prediction, we extend the bonus regressions from Table 4 to include $CORR_i$ along with its interactions with $SALESCHGPOS_{i,t-1}$ and $SALESCHGPOS_{i,t-1} \times LEVERAGE_{it}$. The theory predicts that the incremental effect of $SALESCHGPOS_{i,t-1}$ should be increasing in $CORR_i$. Table 5 displays the results. Estimation is by OLS, without fixed effects, given that $CORR_i$ is time invariant. Columns 1 and 2 reveal a positive and statistically significant coefficient on the two-way interaction, and the same is true in column 3. These results suggest that the positive incremental effect of the state on the bonus is increasing in the state's persistence, consistent with our prediction under relational contracting.[20]

[19]Specifically, Graham et al. (2013: 4) says that "both the level and performance sensitivity of executive compensation was largely constant from the end of World War II through the mid-1970s – precisely when leverage ratios underwent their largest change. Only after 1980 did executive pay experience a significant increase in amount and sensitivity to performance, precisely as corporate leverage stabilized and began a slight decline."

[20]While the coefficient of the two-way interaction in column 4 is statistically insignificant, the key point is that the incremental effect of $SALESCHGPOS$ on the bonus should be *increasing* in $CORR(pred)$. This is indeed the case, even setting the positive coefficient of the two-way interaction to zero (its value under the null hypothesis that we fail to reject at conventional significance levels). The incremental effect just noted is then $-175.106 + 1086.704 \times LEVERAGE \times CORR(pred)$, which is clearly increasing in $CORR(pred)$.

Financial and utilities industries are frequently excluded from estimation samples in the literature, so we excluded those observations from our sample and found our results are insensitive to this change. Our main analysis is based on the entire sample that combines S&P 500 (large cap), S&P 400 (mid cap), and S&P 600 (small cap) companies. We also repeated the analysis within each of those three subsamples. In each subsample, our main result concerning the incremental effect of $SALESCHGPOS$ on the bonus (and how it varies with $LEVERAGE$) remained qualitatively unchanged. We also tried including additional dummies for different ranges of values of sales growth, as opposed to simply a binary indicator for whether sales growth is positive. Again, our results were qualitatively unchanged, though in specifications with larger numbers of dummies not all of them were statistically significant.

Both the linear and interactive bonus models show a positive and statistically significant marginal effect of $EIDO$, even though our theory predicts a value of zero under both formal and relational contracting.[21] This result suggests that pay-for-luck in our data is partly driven by features not captured by the model. One alternative explanation could be that firms are liquidity constrained and use part of any unexpected cash flow to award CEO bonuses. Another explanation could be that CEOs have bargaining power that allows them to claim a share of any windfall profits.

Neither alternative explanation can explain both our empirical findings of a positive interaction between state and leverage, and an incremental effect of the state that is increasing in its persistence. If pay-for-luck were due only to liquidity constraints, then the impact of the state on bonus payments should not depend on the discount factor or the state's autocorrelation, since all that matters would be current cash flow. If instead pay-for-luck were due only to bargaining power, then the impact of the state on bonus payments should be largest for firms with high discount factors, who are likely to remain solvent and for whom the current state has a large impact on expected future profits. Taken together, our empirical results suggest at least part of pay-for-luck is driven by relational contracting.

[21] Note, however, that $EIDO$ does exhibit some, albeit a small degree of, positive autocorrelation, whereas its theoretical counterpart is independent over time.

As an alternative proxy for the (inverse) discount factor, we also used estimates of a firm's probability of default (PD). As seen in Table 1, the average estimated default probability in the sample is low, at only 0.03. Results using this alternative measure are broadly consistent with the results using $LEVERAGE$. Columns 5 and 6 of Table 3 (using PD) reveal the same qualitative pattern of results as columns 3 and 4 (using $LEVERAGE$). In both specifications, the incremental impact on performance is negative, and estimated with high precision.

Turning to the CEO bonus regressions, the first two columns of Table 6 replicate columns 2 and 4 of Table 4, using PD rather than $LEVERAGE$. Both columns 1 and 2 show a negative and statistically significant coefficient for PD, consistent with relational contracting. Moreover, the incremental effect of $SALESCHGPOS$ on the bonus is clearly positive, as it was using $LEVERAGE$. Columns 3 and 4 of Table 6 replicate columns 2 and 4 of Table 5 but now using PD rather than $LEVERAGE$. In both columns, the incremental effect of PD on the bonus is negative, again consistent with relational contracting. Column 3 shows that the incremental effect of $SALESCHGPOS$ evaluated at the means given in Table 1 is also positive, whether we compute it using all relevant coefficients (127.8) or only those that differ from zero at a five percent significance level (39.3). In column 4, the corresponding incremental effects of $SALESCHGPOS$ are -120.3 and 52.85, respectively. Thus, as in Table 5, the incremental effect of $SALESCHGPOS$ on bonus payments is positive, if we compute it using parameters estimated with high precision and set the others to zero (their value under the null hypothesis on a significance test at the five percent level). Following the same procedure, Table 6 also shows that the incremental effect of $SALESCHGPOS$ on the bonus is generally increasing in PD and in our proxy for θ, as predicted under relational contracting.[22]

[22] Incremental effects are calculated as in footnote 20. Following this procedure, the only incremental effect that is decreasing with respect to a variable of interest is in column 3, where $-4902.897 \times SALESCHGPOS \times PD \times CORR = -13.385 \times SALESCHGPOS$. However, this result changes if we include the positive coefficient for $SALESCHGPOS \times PD$, which is statistically significant at the 10 percent level: $925.455 \times SALESCHGPOS \times PD - 4902.897 \times SALESCHGPOS \times PD \times CORR = 14.379 \times SALESCHGPOS$.

7 Conclusion

We have presented a simple model in which formal and relational contracts have different implications for how bonus payments respond to (persistent) "luck". With those results in hand, our main focus in the empirical work was to find evidence for or against relational contracting in CEO compensation. Drawing on a large sample of publicly-traded companies, and using reasonable proxies for the state and shock variables, we found evidence consistent with relational contracting in the payment of CEO bonuses. Our findings shed new light on the debate over pay-for-luck: a reason why firms seem to reward CEOs for luck is that the expected future value of the employment relationship is larger in good states of the world than in bad, so that the firm's credibility to pay bonuses (as well as the CEO's incentive to exert effort) is higher in good states. Our approach can also be applied to establish the empirical relevance of relational contracting for other groups of workers, where management discretion over bonus payments likely plays an even bigger role.

8 Appendix

Proof of Lemma 1. By (2) and (9), the agent's optimal effort in the high state is

$$\begin{aligned} e_H &= \arg\max_{e\in[0,1]} \; p(e)b_{SH} + (1-p(e))b_{FH} - C(e), \\ &= \arg\max_{e\in[0,1]} \; p(e)(b_{SH} - b_{FH}) - C(e). \end{aligned} \tag{16}$$

By (4) and (10), the agent's optimal effort in the low state is

$$\begin{aligned} e_L &= \arg\max_{e\in[0,1]} \; p(e)b_{SL} + (1-p(e))b_{FL} - C(e), \\ &= \arg\max_{e\in[0,1]} \; p(e)(b_{SL} - b_{FL}) - C(e). \end{aligned} \tag{17}$$

Consider two contracts, $B = (b_{SH}, b_{FH}, b_{SL}, b_{FL})$ and $B' = (b'_{SH}, 0, b'_{SL}, 0)$, with $b'_{SH} = b_{SH} - b_{FH}$ and $b'_{SL} = b_{SL} - b_{FL}$. By (16) and (17), the contracts result in identical effort in both states: $e_H(B) = e_H(B')$ and $e_L(B) = e_L(B')$.

Clearly, $b_{FH} > 0$ implies $b_{SH} > b'_{SH}$. Looking at (1) then gives $\frac{\partial \pi_H(B,e_H)}{\partial b_{SH}} \leq 0$ and $\frac{\partial \pi_H(B,e_H)}{\partial b_{FH}} \leq 0$ where at least one inequality is strict. Hence, $b_{FH} > 0$ implies $\pi_H(B, e_H) < \pi_H(B', e_H)$, so that B' yields higher profits than B in the high state. Similarly, $b_{FL} > 0$ implies $b_{SL} > b'_{SL}$, and (3) shows that $\frac{\partial \pi_L(B,e_L)}{\partial b_{SL}} \leq 0$ and $\frac{\partial \pi_L(B,e_L)}{\partial b_{FL}} \leq 0$ where at least one inequality is strict. Hence, $b_{FL} > 0$ implies $\pi_L(B, e_L) < \pi_L(B', e_L)$, so that B' yields higher profits than B in the low state.

Recall from (5) and $P_{1,1} = 1$ that $P_{2,1} = \theta \in (1/2, 1)$. It then follows from (6) and (7) that both $\Pi_H(B) < \Pi_H(B')$ and $\Pi_L(B) < \Pi_L(B')$ whenever $b_{FH} > 0$ or $b_{FL} > 0$. Hence, the optimal formal contract that solves (8), subject to (9), (10) and (11), must have $b_{FH} = b_{FL} = 0$. Relational contracting differs from formal contracting through additional constraints (12) and (13). The left-hand sides of (12) and (13) are clearly larger under B with $b_{FH} > 0$ or $b_{FL} > 0$ than they are under B'. The right-hand sides of (12) and (13) are smaller under B than they are under B', since $\Pi_H(B) < \Pi_H(B')$ and $\Pi_L(B) < \Pi_L(B')$. It follows that if B satisfies (12) and (13), then B' satisfies these constraints as well. Therefore, the optimal relational contract must also have $b_{FH} = b_{FL} = 0$. ■

Proof of Lemma 2. We prove the case for $I = H$, where the proof is entirely analogous for $I = L$. By Lemma 1, (2) reduces to

$$u_H(b_H, e_H) = p(e_H)b_H - C(e_H).$$

Optimal effort $e_H = \underset{e \in [0,1]}{\arg\max}\ u_H(b_H, e)$ is therefore defined by the first-order condition

$$p'(e_H)b_H - C'(e_H) = 0, \tag{18}$$

and the second-order condition

$$p''(e_H)b_H - C''(e_H) < 0.$$

Neither condition depends on Δ, which confirms that effort only depends indirectly on the state, through the bonus offered in that state. The second-order condition always holds by $C''(e) > 0$ and $p''(e) < 0$. It follows that e_H is unique for any b_H.

If $b_H = 0$, then (18) reduces to $C'(e_H) = 0$, so that $C'(0) = 0$ implies $e(0) = 0$. If instead $b_H > 0$, then (18) will be violated at $e_H = 0$, since $p'(0) > 0$ and $C'(0) = 0$. (18) will also be violated at $e_H = 1$, since $p'(1)$ is finite and $\lim_{e\to1} C'(e) = \infty$. It follows that $e_H \in [0, 1)$ with $e_H \in (0, 1)$ for $b_H > 0$.

Differentiating both sides of (18) with respect to b_H yields

$$p''e'(b_H)b_H + p' - C''e'(b_H) = 0, \tag{19}$$

where we write $e'(b_H) = e_H$ and drop the arguments for p', p'' and C''. Rearranging gives

$$e'(b_H) = \frac{p'}{C'' - p''b_H}.$$

The second-order condition and $p' > 0$ then imply $e'(b_H) > 0$. Now differentiating (19) with respect to b_H yields

$$p'''(e'(b_H))^2b_H + p''e''(b_H)b_H + 2p''e'(b_H) - C'''(e'_H(b_H))^2 - C''e''(b_H) = 0,$$

and rearranging gives

$$e''(b_H) = \frac{(p'''b_H - C''')(e'(b_H))^2 + 2p''e'(b_H)}{C'' - p''b_H}.$$

The numerator is strictly negative by $p''' \leq 0$, $C''' \geq 0$, $p'' < 0$ and $e'(b_H) > 0$. The denominator is strictly positive by the second-order condition. It follows that $e''(b_H) < 0$. ■

Proof of Proposition 1. Relational contracting only differs from formal contracting through additional constraints (14) and (15). It follows immediately that the principal will use formal contracting whenever it is feasible, so whenever output is verifiable.

By (6) and (7), $\Pi = \frac{1}{2}\Pi_H + \frac{1}{2}\Pi_L$ is increasing in π_H and π_L, where specifically

$$\Pi_H(b_H, b_L) = \left(\sum_{t=1}^{\infty} \delta^{t-1} P_{t,1}\right) \pi_H(b_H) + \left(\sum_{t=1}^{\infty} \delta^{t-1} (1 - P_{t,1})\right) \pi_L(b_L), \tag{20}$$

and

$$\Pi_L(b_H, b_L) = \left(\sum_{t=1}^{\infty} \delta^{t-1} P_{t,1}\right) \pi_L(b_L) + \left(\sum_{t=1}^{\infty} \delta^{t-1} (1 - P_{t,1})\right) \pi_H(b_H). \tag{21}$$

Applying Lemma 1 to (1) yields

$$\pi_H(b_H) = p(e(b_H))(x_S - x_F - b_H) + x_F + \Delta, \tag{22}$$

and applying Lemma 1 to (3) yields

$$\pi_L(b) = p(e(b_L))(x_S - x_F - b_L) + x_F - \Delta. \tag{23}$$

The first-order condition $\pi'(b) = 0$ and the second-order condition $\pi''(b) < 0$ are the same in both states:

$$p'(e)e'(b)(x_S - x_F - b) - p(e) = 0, \tag{24}$$

$$\left(p''(e)e'^2 + p'(e)e''(b)\right)(x_S - x_F - b) - 2p'(e)e'(b) < 0.$$

The first-order condition is violated at $b = 0$, where $\pi'(0) > 0$, since $e(0) = 0$ and $e'(0) > 0$ by Lemma 2, and since $p(0) = 0$ and $p'(0) > 0$. It is also violated for $b \geq x_S - x_F$, where $\pi'(b) < 0$, since $e(b) > 0$ and $e'(b) > 0$ by Lemma 2, and since $p(e) > 0$ and $p'(e) > 0$.

The second-order condition is satisfied for all $b < x_S - x_F$, since $e''(b) < 0$ by Lemma 2, and since $p''(e) < 0$. It follows that $b^f \equiv b^f_H = b^f_L = \arg\max_{b \geq 0} \pi_H(b) = \arg\max_{b \geq 0} \pi_L(b) \in (0, x_S - x_F)$ is uniquely defined by (24), where $\pi'_H(b) > 0$ and $\pi'_L(b) > 0$ for $b \in [0, b_f)$, and where $\pi'_H(b) < 0$ and $\pi'_L(b) < 0$ for $b > b_f$.

We now turn to the optimal bonuses under relational contracting. Denoting $b = b_L$, and substituting (6) and (7) into (14) gives

$$b_H \leq \delta \left(\sum_{t=1}^{\infty} \delta^{t-1} \left[\theta P_{t,1} + (1-\theta)(1-P_{t,1})\right] \pi_H(b_H) + \sum_{t=1}^{\infty} \delta^{t-1} \left[(1-\theta) P_{t,1} + \theta(1-P_{t,1})\right] \pi_L(b) \right), \tag{25}$$

where $\pi_H(b_H)$ is evaluated at $e(b_H)$ and $\pi_L(b)$ is evaluated at $e(b)$. Similarly, denoting $b = b_H$, and substituting (6) and (7) into (15) gives

$$b_L \leq \delta \left(\sum_{t=1}^{\infty} \delta^{t-1} \left[\theta P_{t,1} + (1-\theta)(1-P_{t,1})\right] \pi_L(b_L) + \sum_{t=1}^{\infty} \delta^{t-1} \left[(1-\theta) P_{t,1} + \theta(1-P_{t,1})\right] \pi_H(b) \right), \tag{26}$$

where $\pi_L(b_L)$ is evaluated at $e(b_L)$ and $\pi_H(b)$ is evaluated at $e(b)$.

Under relational contracting, the optimal bonus pair (b^r_H, b^r_L) must satisfy $b^r_H \leq b^f$ and $b^r_L \leq b^f$. If either inequality were violated, then setting (b^f, b^f) instead of (b^r_H, b^r_L) would yield strictly higher profits $\Pi = \frac{1}{2}\Pi_H + \frac{1}{2}\Pi_L$, by (20) and (21). The reason is that $\pi'_H(b) < 0$ and $\pi'_L(b) < 0$ for $b > b_f$. Moreover, setting (b^f, b^f) instead of (b^r_H, b^r_L) would decrease the left-hand side and increase the right-hand side of both (25) and (26). Hence, if (25) and (26) are satisfied by (b^r_H, b^r_L), they must also be satisfied by (b^f, b^f).

The constraint (25) holds strictly at $b_H = 0$, since $\pi_H(0) = x_F + \Delta > 0$ by (22) and $\pi_L(0) = x_F - \Delta > 0$ by (23). The right-hand side of (25) is concave in b_H on $[0, b^f]$ while the left-hand side is linear. It follows that for any given b, there is at most one value of $b_H \leq b^f$ for which (25) binds, and this value (if it exists) will be strictly positive. Define the function $b_H(b)$ on domain $[0, b^f]$ as the minimum of this value and b^f. Since $\pi'_H(b_H) > 0$ for $b_H \in [0, b^f)$, the optimal bonus in the high state given $b_L = b$ is precisely $b_H(b)$.

By the same reasoning, for any b, there is at most one value of $b_L \leq b^f$ for which (26) binds, and this value (if it exists) will be strictly positive. Define the function $b_L(b)$ on domain $[0, b^f]$ as the minimum of this value and b^f. Since $\pi_L'(b_L) > 0$ for $b_L \in [0, b^f)$, the optimal bonus in the low state given $b_H = b$ is precisely $b_L(b)$.

The optimal bonus pair (b_H^r, b_L^r) must satisfy $b_H(b_L(b_H^r)) = b_H^r$, with $b_L^r = b_L(b_H^r)$. Define the correspondence $f(b)$ by $f(b_H(b)) \equiv b$, so that $f(b)$ is the inverse of $b_H(b)$. Then (b_H^r, b_L^r) must also satisfy $b_L(b_H^r) = f(b_H^r)$, again with $b_L^r = b_L(b_H^r)$. Geometrically, $f(b)$ is the reflection of $b_H(b)$ about the 45 degree line, and (b_H^r, b_L^r) lies at an intersection of $f(b)$ and $b_L(b)$.

The function $b_L(b)$ is continuous, with domain $[0, b^f]$ and range $[b_L(0), b_L(b^f)]$, where $b_L(0) > 0$ and $b_L(b^f) \leq b^f$. The function $b_H(b)$ is continuous, with domain $[0, b^f]$ and range $[b_H(0), b_H(b^f)]$, where $b_H(0) > 0$ and $b_H(b^f) \leq b^f$. It follows that its inverse $f(b)$ is also continuous, with domain $[b_H(0), b_H(b^f)]$ and range $[0, b^f]$, with $f(b_H(0)) = 0$.

We now show that $b_H'(b) > 0$ and $b_H''(b) < 0$ whenever $b_H(b) < b^f$, and that $b_L'(b) > 0$ and $b_L''(b) < 0$ whenever $b_L(b) < b^f$. This also implies $f'(b) > 0$ and $f''(b) > 0$. Suppose that $b_H(b) < b^f$, so that (25) binds at $b_H < b^f$, and fix the value of b_H. The right-hand side of (25) is increasing in b, since $\pi_L'(b) > 0$ for all $b < b^f$. It follows that (25) no longer binds after a marginal increase in b. Hence, $b_H'(b) > 0$. Similarly, suppose that $b_L(b) < b^f$, so that (26) binds at $b_L < b^f$, and fix the value of b_L. The right-hand side of (26) is increasing in b, since $\pi_H'(b) > 0$ for all $b < b^f$. It follows that (26) no longer binds after a marginal increase in b. Hence, $b_L'(b) > 0$, and $f'(b) > 0$.

Implicitly differentiating (25) with respect to b and rearranging gives

$$b_H'(b) = \frac{\delta\Big(\sum_{t=1}^{\infty} \delta^{t-1} \big[(1-\theta)P_{t,1} + \theta(1-P_{t,1})\big] \pi_L'(b) \Big)}{1 - \delta\Big(\sum_{t=1}^{\infty} \delta^{t-1} \big[\theta\ P_{t,1} + (1-\theta)(1-P_{t,1})\big] \pi_H'(b_H) \Big)}. \tag{27}$$

The numerator and the denominator of (27) are both positive by $\pi_L'(b) > 0$ and $b_H'(b) > 0$. An increase in b will decrease the numerator since $\pi_L''(b) < 0$, and increase the denominator since $b_H'(b) > 0$ and $\pi_H''(b_H) < 0$. This means that $b_H''(b) < 0$ whenever $b_H(b) < b^f$.

Implicitly differentiating (26) with respect to b and rearranging yields

$$b_L'(b) = \frac{\delta\left(\sum_{t=1}^{\infty} \delta^{t-1} \big[(1-\theta)P_{t,1} + \theta(1-P_{t,1})\big] \pi_H'(b) \right)}{1 - \delta\left(\sum_{t=1}^{\infty} \delta^{t-1} \big[\theta P_{t,1} + (1-\theta)(1-P_{t,1})\big] \pi_L'(b_L) \right)}. \tag{28}$$

The numerator and the denominator of (28) are both positive by $\pi_H'(b) > 0$ and $b_L'(b) > 0$. An increase in b will decrease the numerator since $\pi_H''(b) < 0$ and increase the denominator since $b_L'(b) > 0$ and $\pi_L''(b_L) < 0$. This means that $b_L''(b) < 0$ whenever $b_L(b) < b^f$, so that $f''(b) > 0$.

Given continuity and their respective domain and range, there exists some $b_H^r \in (0, b^f]$ for which $b_L(b_H^r) = f(b_H^r)$, so where the curves $b_L(b)$ and $f(b)$ intersect. Since $b_L(b)$ is concave while $f(b_H)$ is strictly convex, this point of intersection is unique. It defines the optimal bonus pair, $b_L^r = b_L(b_H^r) = f(b_H^r)$.

To compare the size of the two bonuses, note that $b_L^r = b_H^r$ holds if and only if $b_L(b)$ and $f(b)$ intersect on the 45 degree line. This is the case if $b_L(b) = b$ implies $f(b) = b$ or, equivalently, $b_H(b) = b$. In contrast, $b_L^r < b_H^r$ holds if and only if $b_L(b)$ intersects the 45 degree line before $f(b)$ does. This is the case if $b_L(b) = b$ implies $f(b) < b$ or, equivalently, $b_H(b) > b$.

We now prove that $b_H(b) = b^f$ whenever $b_L(b) = b^f$ and that $b_H(b) > b_L(b)$ whenever $b_L(b) < b^f$. It is sufficient to show that (25) holds strictly whenever (26) is satisfied. Substituting (22) and (23) into (25) and (26) shows the latter two constraints are symmetric with respect to b_H and b_L except for terms involving Δ. Specifically, the expression $\delta(2\theta - 1) \sum_{t=1}^{\infty} \delta^{t-1}(2P_{t,1} - 1)\Delta$ enters with a positive sign on the right-hand side of (25) and a negative sign on the right-hand side of (26). We claim that $P_{t,1} > 1/2$ for all $t \geq 1$ which, together with $\theta > 1/2$, implies this expression is itself strictly positive. Hence, (25) holds strictly whenever (26) is satisfied.

We prove the claim $P_{t,1} > 1/2$ by induction. Recall from (5) the recursive definition $P_{1,1} = 1$ and

$$P_{t,1} = \theta P_{t-1,1} + (1-\theta)(1-P_{t-1,1}),$$

for all $t \geq 2$. Clearly $P_{t,1} > 1/2$ for $t = 1$. Now fix $t' \geq 2$, and suppose that $P_{t,1} > 1/2$ for all $t = 1, \ldots t' - 1$. Write

$$P_{t',1} = \theta P_{t'-1,1} + (1-\theta)(1-P_{t'-1,1}).$$

The induction hypothesis implies $P_{t'-1,1} > 1/2$ and $(1 - P_{t'-1,1}) < 1/2$. Combined with $\theta > 1/2$, this yields $P_{t',1} > 1/2$, which establishes the claim.

To complete the proof, note that the right-hand side of (26) increases without bound as δ tends to 1. Fix $b = b^f$ and define $\delta_0 \in (0,1)$ as the value of δ for which (26) binds. Then (26) holds for all $b \in [0, b^f]$ if and only if $\delta \in [\delta_0, 1]$. Therefore, we have $b^r_L < b^r_H$ for all $\delta \in (0, \delta_0)$ and $b^r_L = b^r_H = b^f$ for all $\delta \in [\delta_0, 1]$. ■

Proof of Proposition 2. The bonus, b^f, under formal contracting is defined by the first-order condition (24), which is independent of δ and θ. It follows that b^f is independent of δ and θ as well. To complete part (i), it remains to show that bonuses b^r_L and b^r_H under relational contracting are increasing in δ whenever $b^r_L < b^f$ and $b^r_H < b^f$. Define $b_H(b)$, $b_L(b)$, and $f(b)$ as in the proof of Proposition 1. The optimal bonus pair (b^r_H, b^r_L) is defined by $b_H(b_L(b^r_H)) = b^r_H$ or, equivalently, $b_L(b^r_H) = f(b^r_H)$, with $b^r_L = b_L(b^r_H)$.

Differentiating both sides of $b_L(b^r_H) = f(b^r_H)$ with respect to δ gives

$$\frac{\partial b_L}{\partial \delta} + \frac{\partial b_L}{\partial b}\frac{db^r_H}{d\delta} = \frac{\partial f}{\partial \delta} + \frac{\partial f}{\partial b}\frac{db^r_H}{d\delta},$$

or equivalently

$$\frac{db^r_H}{d\delta} = \frac{\frac{\partial b_L}{\partial \delta} - \frac{\partial f}{\partial \delta}}{\frac{\partial f}{\partial b} - \frac{\partial b_L}{\partial b}}, \tag{29}$$

where all partial derivatives are evaluated at $b = b^r_H$. The denominator of (29) is strictly positive since $b_L(b)$ is concave, $f(b)$ is strictly convex, and (b_L^r, b_H^r) is their point of intersection: $b_L(b_H^r) = f(b_H^r)$, with $b_L^r = b_L(b_H^r)$. For the numerator of (29), suppose that (26) binds at $b_L < b^f$, and fix the value of b_L. The right-hand side of (26) is strictly increasing in δ. It follows that (26) no longer binds after a marginal increase in b, so that $\frac{\partial b_L}{\partial \delta} > 0$. Applying the same reasoning to (25) shows that $\frac{\partial b_H}{\partial \delta} > 0$. This in turn implies $\frac{\partial f}{\partial \delta} < 0$, since $f(b)$ is the inverse of $b_H(b)$. We conclude that the numerator of (29) is strictly positive and that $\frac{db_H^r}{d\delta} > 0$. Differentiating $b_L^r = b_L(b_H^r)$ with respect to δ gives $\frac{db_L^r}{d\delta} = \frac{\partial b_L}{\partial \delta} + \frac{\partial b_L}{\partial b}\frac{db_H^r}{d\delta}$. Recall that $\frac{\partial b_L}{\partial b} > 0$, so we can also conclude that $\frac{db_L^r}{d\delta} > 0$. This completes the proof of part (i).

To complete part (ii), we first show that $\frac{\partial b_H}{\partial b} < \frac{\partial b_L}{\partial b}$ for any b such that $b_L(b) < b^f$ and $b_H(b) < b^f$. Recall that $\frac{\partial b_H}{\partial b}$ and $\frac{\partial b_L}{\partial b}$ are given by expressions (27) and (28). Since $\pi_H'(b) = \pi_L'(b)$, these expression only differ by the terms $\pi_H'(b_H)$ and $\pi_L'(b_L)$ in their respective denominators. Combining $b_H(b) > b_L(b)$ from the proof of Proposition 1 with $\pi_H''(b) = \pi_L''(b) < 0$ for all $b < b^f$ gives $\pi_H'(b_H) < \pi_L'(b_L)$, so that (27) and (28) imply $\frac{\partial b_H}{\partial b} < \frac{\partial b_L}{\partial b}$.

We now show that $\frac{\partial b_H}{\partial \theta} > 0$ whenever $b < b_H(b) < b^f$ and that $\frac{\partial b_L}{\partial \theta} < 0$ whenever $b_L(b) < b < b^f$. Suppose that (25) binds at $b_H \in (b, b^f)$, and fix the value of b_H. Differentiating the right-hand side of (25) with respect to θ gives

$$\delta \sum_{t=1}^{\infty} \delta^{t-1} \left[\left(2P_{t,1} - 1 + P_{t,1}'(2\theta - 1) \right) (\pi_H(b_H) - \pi_L(b)) \right], \tag{30}$$

where $P_{t,1}'$ denotes the derivative of $P_{t,1}$. Since $\pi_H(b) > \pi_L(b)$ by (22) and (23), and since $\pi_H'(b) > 0$ for all $b < b^f$, it follows from $b < b_H$ that $\pi_H(b_H) - \pi_L(b) > 0$. We claim that $P_{t,1}' \geq 0$ for all $t \geq 1$, which we will prove below. Combined with $P_{t,1} > 1/2$ and $\theta > 1/2$, this claim implies that (30) is strictly positive, so that (25) no longer binds after a marginal increase in θ. Hence, $\frac{\partial b_H}{\partial \theta} > 0$. Since the inverse function $f(b)$ is the reflection of $b_H(b)$ about the 45-degree-line, it also follows that $\frac{\partial f}{\partial \theta} < 0$ whenever $f(b) < b < b^f$.

Similarly, suppose that (26) binds at $b_L < b$, and fix the value of b_L. Differentiating the right-hand side of (26) with respect to θ gives

$$\delta \sum_{t=1}^{\infty} \delta^{t-1} \big[\big(2P_{t,1} - 1 + P'_{t,1}(2\theta - 1) \big) (\pi_L(b_L) - \pi_H(b)) \big],$$

where $\pi_L(b_L) - \pi_H(b) < 0$ follows from $b_L < b$. Our claim that $P'_{t,1} \geq 0$ for all $t \geq 1$ therefore implies that a marginal increase in θ will violate (26). Hence, $\frac{\partial b_L}{\partial \theta} < 0$ whenever $b_L(b) < b < b^f$.

We prove our claim by induction. The cases of $t = 1$ and $t = 2$ are trivial, since $P_{1,1} = 1$ and $P_{2,1} = \theta$. Now fix $t' \geq 3$, and suppose that $P'_{t,1} > 0$ for all $t = 1, \ldots, t'-1$. Differentiating (5) with respect to θ gives

$$P'_{t',1} = 2P_{t'-1,1} - 1 + P'_{t'-1,1}(2\theta - 1).$$

$P_{t'-1,1} > 1/2$ and $\theta > 1/2$ both hold, so that $P'_{t',1} > 0$ follows from the induction hypothesis.

To complete the proof, differentiating $b^r_L = b_L(b^r_H)$ with respect to θ gives

$$\frac{db^r_L}{d\theta} = \frac{\partial b_L}{\partial \theta} + \frac{\partial b_L}{\partial b} \frac{db^r_H}{d\theta},$$

so that

$$\frac{d(b^r_H - b^r_L)}{d\theta} = \frac{db^r_H}{d\theta} \left(1 - \frac{\partial b_L}{\partial b} \right) - \frac{\partial b_L}{\partial \theta}. \tag{31}$$

Differentiating both sides of $b_L(b^r_H) = f(b^r_H)$ with respect to θ and rearranging gives

$$\frac{db^r_H}{d\theta} = \frac{\frac{\partial b_L}{\partial \theta} - \frac{\partial f}{\partial \theta}}{\frac{\partial f}{\partial b} - \frac{\partial b_L}{\partial b}}. \tag{32}$$

Using (32) to substitute for $\frac{db^r_H}{d\theta}$ in the right-hand side of (31) and simplifying then yields

$$\frac{d(b^r_H - b^r_L)}{d\theta} = \left[\frac{\partial b_L}{\partial \theta} \left(1 - \frac{\partial f}{\partial b} \right) - \frac{\partial f}{\partial \theta} \left(1 - \frac{\partial b_L}{\partial b} \right) \right] \left(\frac{1}{\frac{\partial f}{\partial b} - \frac{\partial b_L}{\partial b}} \right), \tag{33}$$

where all partial derivatives are evaluated at $b = b_H^r$.

Recall from Proposition 1 that $b_L^r < b_H^r$ whenever $b_L^r < b^f$. Geometrically, this means $b_L(b)$ and $f(b)$ intersect to the right of the 45-degree line, where $b_L^r = b_L(b_H^r) = f(b_H^r) < b_H^r$. From the result shown above, $b_L(b_H^r) = f(b_H^r) < b_H^r < b^f$ in turn implies $\frac{\partial b_L}{\partial \theta} < 0$ and $\frac{\partial f}{\partial \theta} < 0$ when evaluated at $b = b_H^r$. Furthermore, $b_L(b_H^r) < b_H^r$ also implies $\frac{\partial b_L}{\partial b} < 1$ when evaluated at $b = b_H^r$, since the function $b_L(b)$ is increasing in b at a decreasing rate and has already crossed the 45-degree-line at some $b < b_H^r$. Combining $\frac{\partial b_L}{\partial b} < 1$ with $\frac{\partial b_H}{\partial b} < \frac{\partial b_L}{\partial b}$, the fact that $f(b)$ is the inverse of $b_H(b)$, and that $f(b)$ is increasing in b at an increasing rate, a simple geometric argument shows that $\frac{\partial f}{\partial b} > 1$ when evaluated at b_H^r.

Looking at (33), we have established $\frac{\partial b_L}{\partial \theta} < 0$, $\frac{\partial f}{\partial \theta} < 0$, $\frac{\partial b_L}{\partial b} < 1$, and $\frac{\partial f}{\partial b} > 1$, when evaluated at $b = b_H^r$. This implies $\frac{d(b_H^r - b_L^r)}{d\theta} > 0$ as required.

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Table 1

DESCRIPTIVE STATISTICS

	Mean	SD
$BONUS_{it}$	1037.359	1885.46
$SALARY_{it}$	712.138	394.103
$PERF_{it}$	0.038	0.562
$EIDO_{it}$	-0.465	404.581
$SALESCHGPOS_{it-1}$	0.737	0.440
$SALESCHGPOS_{it-1}$ (predicted)	0.867	0.339
$LEVERAGE_{it}$	0.221	0.206
PD_{it}	0.030	0.094
AGE_{it}	55.924	7.620
$TENURE_{it}$	8.209	8.109
$CORR_{i}$	0.091	0.285
$CORR_{i}$ (predicted)	0.412	0.366

NOTE. – Sample size is 24,919 firm-years (though 10,240 for PD_{it}). Years cover 1993-2011. All monetary variables are measured in 2005 U.S. dollars, converted via the GDP deflator.

Table 2

PANEL A: AUTOCORRELATION MATRIX FOR *SALESCHGPOS*

	$SALESCHGPOS_{it}$	$SALESCHGPOS_{it-1}$	$SALESCHGPOS_{it-2}$	$SALESCHGPOS_{it-3}$
$SALESCHGPOS_{it}$	1.000			
$SALESCHGPOS_{it-1}$	0.217*	1.000		
$SALESCHGPOS_{it-2}$	0.070*	0.210*	1.000	
$SALESCHGPOS_{it-3}$	0.051*	0.084*	0.232*	1.000

NOTE. – * indicates correlation is statistically significantly different from zero at the 5% level.

PANEL B: AUTOCORRELATION MATRIX FOR (PREDICTED) *SALESCHGPOS*

	$SALESCHGPOS_{it}$	$SALESCHGPOS_{it-1}$	$SALESCHGPOS_{it-2}$	$SALESCHGPOS_{it-3}$
$SALESCHGPOS_{it}$	1.000			
$SALESCHGPOS_{it-1}$	0.607*	1.000		
$SALESCHGPOS_{it-2}$	0.462*	0.673*	1.000	
$SALESCHGPOS_{it-3}$	0.379*	0.463*	0.659*	1.000

NOTE. – * indicates correlation is statistically significantly different from zero at the 5% level. $SALESCHGPOS_{it}$ equals 1 if the the predicted value for year t from an individual regression for the i^{th} firm is positive, and equals 0 otherwise, where the regression for firm i takes the following form: $SALESCHG_t = \mathbf{Z}_t\boldsymbol{\gamma} + \omega_t$, where $\mathbf{Z}_t$ includes the first lag of real GDP growth, a linear time trend, and a constant.

PANEL C: AUTOCORRELATION MATRIX FOR *EIDO*

	$EIDO_{it}$	$EIDO_{it-1}$	$EIDO_{it-2}$	$EIDO_{it-3}$
$EIDO_{it}$	1.000			
$EIDO_{it-1}$	0.027*	1.000		
$EIDO_{it-2}$	0.006	0.027*	1.000	
$EIDO_{it-3}$	0.007	0.006	0.026*	1.000

NOTE. – * indicates correlation is statistically significantly different from zero at the 5% level.

Table 3

CEO PERFORMANCE REGRESSIONS (y = $PERF_{it}$)

	(1)	(2)	(3)	(4)	(5)	(6)
$EIDO_{it}$	0.006	0.006	0.005	0.005	0.006	0.006
	(0.002)***	(0.002)***	(0.002)***	(0.002)***	(0.002)***	(0.002)***
$SALESCHGPOS_{it-1}$	16.753		14.022		12.058	
	(1.903)***		(1.870)***		(2.760)***	
$SALESCHGPOS_{it-1}$ (predicted)		18.009		15.557		13.075
		(2.569)***		(2.519)***		(4.509)***
$LEVERAGE_{it}$			-205.541	-206.547		
			(7.740)***	(7.471)***		
PD_{it}					-273.371	-272.906
					(14.572)***	(14.230)***
AGE_{it}	2.154	1.971	2.660	2.480	3.541	3.285
	(1.562)	(1.492)	(1.531)*	(1.462)*	(2.656)	(2.523)
$(AGE_{it})^2$	-2.346	-2.178	-2.770	-2.597	-3.387	-3.194
	(1.382)*	(1.320)*	(1.355)**	(1.293)**	(2.338)	(2.220)
$TENURE_{it}$	0.224	0.300	0.201	0.247	-0.083	0.103
	(0.370)	(0.354)	(0.363)	(0.347)	(0.565)	(0.534)
$(TENURE_{it})^2$	0.849	0.672	1.013	0.873	1.748	1.190
	(1.128)	(1.077)	(1.106)	(1.055)	(1.828)	(1.737)
Constant	-1.675	1.902	31.627	35.008	-46.184	-40.902
	(43.943)	(41.982)	(43.108)	(41.144)	(75.034)	(71.407)
Sample Size	N = 18,511	N = 19,117	N = 18,488	N = 19,094	N = 7913	N = 8251

NOTE. – Both specifications include year dummies and firm fixed effects. Standard errors are in parentheses below each estimate. Statistical significance at the 10%, 5%, and 1% levels denoted by *, **, and ***. Dependent variable, $PERF_{it}$, is income before extraordinary items. $SALESCHGPOS_{it-1}$ (predicted), used in model (2), is computed as described in the note to Table 2, Panel B. All coefficients and standard errors are multiplied by 1000 for easier reading.

Table 4

CEO BONUS REGRESSIONS (y = $BONUS_{it}$)

	(1)	(2)	(3)	(4)
$EIDO_{it}$	0.076	0.069	0.076	0.069
	(0.024)***	(0.026)***	(0.022)***	(0.023)***
$SALESCHGPOS_{it\text{-}1}$	175.248	9.479		
	(31.207)***	(41.479)		
$SALESCHGPOS_{it\text{-}1} \times LEVERAGE_{it}$		596.845		
		(178.136)***		
$SALESCHGPOS_{it\text{-}1}$ (predicted)			94.703	-161.308
			(47.848)**	(78.790)**
$SALESCHGPOS_{it\text{-}1} \times LEVERAGE_{it}$ (pred.)				875.790
				(300.078)***
$LEVERAGE_{it}$		-1858.987		-2194.114
		(277.995)***		(381.525)***
AGE_{it}	-11.167	-7.823	10.361	11.492
	(65.996)	(67.360)	(67.593)	(69.140)
$(AGE_{it})^2$	11.282	8.208	-4.760	-5.509
	(59.934)	(61.106)	(61.206)	(62.545)
$TENURE_{it}$	30.488	30.460	25.998	25.993
	(8.358)***	(8.419)***	(8.480)***	(8.540)***
$(TENURE_{it})^2$	-62.612	-61.071	-53.536	-53.984
	(24.936)**	(25.158)**	(26.234)**	(26.510)**
Constant	1453.532	1808.982	612.872	1124.455
	(1782.245)	(1802.595)	(1825.512)	(1859.221)
Sample Size	N = 18,323	N = 18,300	N = 18,929	N = 18,906

NOTE. – All specifications include year dummies and firm fixed effects. Standard errors are in parentheses below each estimate, clustered by firm. Statistical significance at the 10%, 5%, and 1% levels denoted by *, **, and ***. Dependent variable, $BONUS_{it}$, is the year-t bonus for firm i's CEO in 2005 dollars. $SALESCHGPOS_{it\text{-}1}$ (predicted), used in models (3) and (4) is computed as described in the note to Table 2, Panel B.

Table 5

CEO BONUS REGRESSIONS ($y = BONUS_{it}$)

	(1)	(2)	(3)	(4)
$EIDO_{it}$	0.051	0.053	0.034	0.036
	(0.031)	(0.031)*	(0.031)	(0.031)
$SALESCHGPOS_{it-1}$	105.107	-17.296		
	(36.716)***	(53.244)		
$SALESCHGPOS_{it-1} \times LEVERAGE_{it}$		589.001		
		(163.666)***		
$SALESCHGPOS_{it-1} \times CORR_i$	605.131	629.232		
	(118.117)***	(138.507)***		
$SALESCHGPOS_{it-1} \times LEVERAGE_{it} \times CORR_i$		-177.639		
		(321.744)		
$SALESCHGPOS_{it-1}$ (pred.)			-131.792	-175.106
			(79.598)*	(98.397)*
$SALESCHGPOS_{it-1} \times CORR_i$ (pred.)			272.685	13.078
			(126.760)**	(140.937)
$SALESCHGPOS_{it-1} \times LEVERAGE_{it}$ (pred.)				152.741
				(227.370)
$SALESCHGPOS_{it-1} \times LEVERAGE_{it} \times CORR_i$ (pred.)				1086.704
				(274.628)***
$CORR_i$	-227.722	-344.458		
	(98.326)**	(91.098)***		
$CORR_i$ (pred.)			-162.643	-161.127
			(113.735)	(113.834)
$LEVERAGE_{it}$		33.535		-85.359
		(131.004)		(170.920)
AGE_{it}	56.658	50.503	23.650	12.811
	(20.185)***	(20.201)**	(23.427)	(23.471)
$(AGE_{it})^2$	-28.242	-24.092	1.868	10.326
	(17.870)	(17.874)	(20.756)	(20.777)
$TENURE_{it}$	-4.889	-3.598	-0.962	0.753
	(5.013)	(5.017)	(5.960)	(5.970)
$(TENURE_{it})^2$	5.393	5.22	-17.519	-20.624
	(15.262)	(15.260)	(18.346)	(18.348)
Constant	-913.106	-716.829	-142.634	213.449
	(567.417)	(568.105)	(662.971)	(665.441)
Sample Size	N = 17,058	N = 17,039	N = 12,280	N = 12,262

NOTE. – All specifications are estimated via OLS and include year dummies. Standard errors are in parentheses below each estimate. Statistical significance at the 10%, 5%, and 1% levels denoted by *, **, and ***. Dependent variable, $BONUS_{it}$, is the year-t bonus for firm i's CEO in 2005 dollars. $SALESCHGPOS_{it-1}$ (predicted), used in models (3) and (4) is computed as described in the note to Table 2, Panel B.

Table 6

CEO BONUS REGRESSIONS ($y = BONUS_{it}$)

	(1)	(2)	(3)	(4)
$EIDO_{it}$	0.077	0.081	0.048	0.030
	(0.034)**	(0.028)***	(0.033)	(0.033)
$SALESCHGPOS_{it-1}$	149.959		60.761	
	(48.876)***		(61.670)	
$SALESCHGPOS_{it-1} \times PD_{it}$	851.644		925.455	
	(776.487)		(552.399)*	
$SALESCHGPOS_{it-1} \times CORR_i$			579.206	
			(205.236)***	
$SALESCHGPOS_{it-1} \times PD_{it} \times CORR_i$			-4902.897	
			(1102.318)***	
$SALESCHGPOS_{it-1}$ (pred.)		51.695		-109.682
		(111.833)		(154.771)
$SALESCHGPOS_{it-1} \times PD_{it}$ (pred.)		2521.767		1761.622
		(1179.791)**		(776.506)**
$SALESCHGPOS_{it-1} \times CORR_i$ (pred.)				-136.761
				(258.682)
$SALESCHGPOS_{it-1} \times PD_{it} \times CORR_i$ (pred.)				-577.577
				(924.650)
$CORR_i$			-192.78	
			(175.957)	
$CORR_i$ (pred.)				341.204
				(243.434)
PD_{it}	-2222.064	-3814.658	-1204.325	-2380.854
	(487.408)***	(1036.555)***	(464.900)***	(619.842)***
AGE_{it}	-58.716	-59.511	50.085	7.635
	(146.661)	(139.371)	(35.883)	(38.819)
$(AGE_{it})^2$	57.666	57.239	-25.953	18.276
	(131.609)	(124.884)	(31.448)	(34.029)
$TENURE_{it}$	37.622	39.358	3.990	19.779
	(11.476)***	(11.641)***	(8.323)	(9.280)**
$(TENURE_{it})^2$	-95.289	-98.656	-2.507	-79.705
	(45.662)**	(46.304)**	(26.654)	(29.290)**
Constant	1761.91	1693.592	-1313.691	-460.142
	(3985.296)	(3804.394)	(1024.679)	(1121.821)
Sample Size	N = 7913	N = 8251	N = 7562	N = 5700

NOTE. – All specifications include year dummies. Specifications 1 and 2 include firm fixed effects. Standard errors are in parentheses below each estimate, clustered by firm. Statistical significance at the 10%, 5%, and 1% levels denoted by *, **, and ***. Dependent variable, $BONUS_{it}$, is the year-*t* bonus for firm *i*'s CEO in 2005 dollars. $SALESCHGPOS_{it-1}$ (predicted), is computed as described in the note to Table 2, Panel B.