Monitoring and Pay for Long-Run Performance*

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Abstract

We develop a dynamic principal-agent model in which conditioning future pay-for-performance on monitoring signals is a perfect substitute for contemporaneous pay-for-performance in providing incentives. Average pay-for-performance is higher when monitoring is less efficient, because the conditioning is a less effective substitute in that case. Monitoring efficiency has a greater effect on pay-for-performance when negative signals have accumulated. Using changes in the availability of direct flights for board directors to a firm's headquarters as an exogenous shock to monitoring, we present new empirical evidence on the monitoring-compensation linkage that supports the model's predictions.

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1 Introduction

Pay-for-performance incentives for corporate executives should be more important when monitoring is more difficult. In this paper, we present a new theoretical model to illustrate the tradeoff between providing incentives through pay-for-performance and providing incentives through conditioning future compensation on monitoring signals. We also provide novel empirical evidence of the linkage between monitoring and long-term compensation based on exogenous shocks to the quality of monitoring.

Our model is one of optimal dynamic contracting, and it resides in the literature that follows DeMarzo and Sannikov (2006) and Sannikov (2008). We model performance as a binary outcome – project success or failure – that occurs at a random time. Thus, performance is "in the long run" in our model rather than continuous, as in most models of optimal dynamic contracting. This feature of our model motivates the use of option grants, which usually vest only after a number of years, in our empirical analysis. There have been other studies of optimal contracting for long run performance, but this is the first, to our knowledge, to analyze continuous monitoring in such a setting.

In the model, even though flow compensation can be utilized, it does not feature in the optimal contract. The only transfer in the optimal contract is the lump-sum reward that the agent receives when the project succeeds. This distinguishes our results from the reflection type of flow compensation in DeMarzo and Sannikov (2006) and in many subsequent studies. We call this reward *pay for long run performance*. Conditioning the future reward on monitoring signals serves as a perfect substitute for the current reward as an incentive device. When positive signals accumulate, the current reward for success increases and conditioning declines in the sense that the agent's continuation utility becomes less sensitive to monitoring. Symmetrically, when negative signals accumulate, the current reward falls and conditioning is increased. Conditioning creates volatility in the agent's continuation utility, which the principal dislikes, but it is necessary to increase it to maintain incentives as the reward falls. The volatility arises from noise in the monitoring signals. When monitoring is less efficient, conditioning induces more volatility, so the principal optimally chooses less conditioning and substitutes a higher average reward. Consequently, the average reward is higher when monitoring is less efficient. We provide novel empirical evidence of the link between monitoring efficiency and the reward that the model predicts. We also provide empirical evidence for a second prediction of the model, which is that the sensitivity of the future reward to monitoring efficiency increases when negative signals accumulate.

Our empirical results use the availability of direct flights between board members' homes and company headquarters as a proxy for the difficulty of monitoring.[1] To measure the pay for long run performance, we use the fair value of option grants, instead of the sensitivity measure of Jensen and Murphy (1990), which incorporates the impact of short-term compensation (such as cash and bonus) on executive wealth. We find that option grants increase when direct flights are lost. This is consistent with the result that pay for long run performance should be higher when monitoring is more difficult. We find that the effect is stronger in poorly performing firms, which is also consistent with our model's second prediction. Furthermore, we find that the effect is more pronounced when the CEO is not also the chairman of the board, suggesting that board monitoring is the driving factor behind the results. Meanwhile, we do not find significant changes in other forms of compensation, including salary, bonus, and stock grants.

To address concerns regarding potential time-varying local and industry trends, we include fixed effects for industry-year and state-year. We confirm that our key findings are not driven by local or industry trends over time. We investigate the possibility of director selection effects in several exercises. First, we do not find evidence of elevated option compensation prior to the change in direct flight availability. Second, we conduct a placebo test where we replace the dependent variable in our regressions with firm characteristics and find no statistical evidence that our key dependent variable has predictive power for these firm characteristics. These findings, along with two additional robustness checks based on Bertrand and Mullainathan (2003), suggest that director selection effects do not drive our results.

We also consider alternative measures of option compensation. First, we divide option awards by salary, either contemporaneous annual salary or a long-term average. This should, to some extent, reduce issues with a varying scale of total compensation based on firm and position and allow us to interpret the coefficient as a change in option awards as

[1] This follows Bernstein, Giroud and Townsend (2016) and Bernile, Bhagwat and Yonker (2018), who use changes to airline routes as exogenous shocks to the ease of VC monitoring and to board diversity, respectively.

a percent of salary. We find consistent empirical results using this alternative dependent variable. Additionally, we examine the binary outcome of whether or not an executive receives any option compensation in a given year using a conditional logit model. We find that when a board member loses access to a direct flight to the firm's headquarters, the likelihood of executives receiving some option compensation increases.

Related Literature. Our paper adds to a large literature on monitoring and executive compensation. Notable contributions include Yermack (1995), who shows that firms that are more difficult to monitor, in the sense of having noisier accounting data, use greater pay-for-performance incentives. Hartzell and Starks (2003) show that firms with greater institutional ownership provide lower executive compensation (but compensation that is more sensitive to performance). Bebchuk and Fried (2003) survey the managerial power explanation of the monitoring-compensation linkage, which is an alternative to the contracting theory explanation, as in this paper.

An important early work on monitoring in the presence of moral hazard is Dye (1986). He shows in a single-period model that monitoring should take place following negative outcomes. In our model, monitoring occurs continuously, but our results have a similar flavor in that the sensitivity of the agent's continuation utility to monitoring increases following negative signals. Noe and Rebello (2012) study a dynamic model without moral hazard but with private managerial information about firm characteristics and conclude like us that monitoring should increase and compensation should be reduced following negative results.

Our model is in a sense the dual of the model of Piskorski and Westerfield (2016), which also examines monitoring and pay-for-performance. Performance in their model is defined by a continuously observed cash flow process, and monitoring outcomes occur at discrete random times. In contrast, performance in our model is based on an event occurring at a discrete random time, and monitoring is based on a continuously observed process. We show that three results of Piskorski and Westerfield (2016) hold also in our model of long-run performance: (1) pay-for-performance increases when monitoring is more costly or less effective, (2) the effect is stronger when negative evidence has accumulated, and (3) pay-for-performance is not necessarily monotonically related to evidence of effort. Piskorski and Westerfield discuss the empirical support for point (3).

There is various evidence in the literature for (1), including Yermack (1995). We provide novel evidence in support of (1) and (2).

Varas, Marinovic and Skrzypacz (2020) study sequential monitoring that has a direct effect on cash flows (it reveals product quality publicly) as well as providing a signal about the agent's effort. They show that, depending on whether the cash-flow effect or the signaling effect is more important, optimal monitoring can occur at deterministic times or at random times. Chen, Sun and Xiao (2020) study monitoring when adverse events arrive at random times. Their principal cannot employ negative rewards when adverse events occur, so the tradeoff between the current reward and conditioning future rewards that we study is not present in their model. The signal structure in our model is similar to that considered by Georgiadis and Szentes (2020); however, the agent's effort choice is fixed at date 0 in their model, whereas the agent in our model can dynamically change his effort. Dai, Wang and Yang (2022) study a principal who has two Poisson monitoring technologies (and an unobserved cash flow process). The focus of their paper is the principal's division of limited monitoring capacity between the two technologies. Orlov (2022) studies a model with monitoring, but the monitoring does not reveal information about the agent's effort—instead, it allows the principal to intervene to improve cash flows.

There are also papers in the dynamic contracting literature that assume a Poisson outcome, like we do, but without monitoring. Biais, Mariotti, Rochet and Villeneuve (2010) study an agent whose effort can reduce the likelihood of disasters. Varas (2018) studies a manager who can expedite project completion at the expense of quality and shows that managerial short-termism can be combated by deferring compensation. Green and Taylor (2016) analyze a project that requires two breakthroughs and the first is privately observed by the manager. They study incentives for self-reporting. Mayer (2022) studies incentives for self-reporting project failure when it is privately observed. Pagès and Possamaï (2014) model a bank that can reduce the loan default rate by exerting effort.

The rest of the paper is organized as follows. Section 2 introduces the model and presents the optimal contract. Section 3 examines the impact of monitoring efficiency on the optimal contract and develops two empirical hypotheses. Section 4 describes our data and presents the empirical results. Section 5 concludes. There are two appendices and three online appendices. Appendix A develops an extension of our base model in which monitoring is costly and the principal can choose the precision of monitoring. This model shows that pay for long-run performance is not necessarily monotonically related to evidence of effort. Appendix B contains all of the proofs. Online Appendix OA.A contains additional comparative statics from the model. Online Appendix OA.B develops an extension of our base model in which there is an unanticipated shock to the monitoring precision. Online Appendix OA.C describes details of our data construction and presents some robustness checks for our empirical results.

2 Model and Optimal Contract

An agent is employed to work on a project. The project reaches completion at a random time, if it ever reaches completion. The probability of completion is higher at each date if the agent exerts more effort. The completed project can be either a success or a failure, and the probability of success is higher if the agent exerts more effort. Project completion, and whether the project is a success or failure, is publicly observed. The principal continuously monitors the agent, viewing a noisy signal of the agent's effort. The principal provides incentives to the agent by paying a lump sum upon project completion and by terminating the project in chosen circumstances. We also allow the principal to make interim payments contingent on the monitoring history, but this turns out to be inefficient.

Both the agent and the principal are risk neutral. The principal discounts the future at rate $r > 0$, and the agent discounts at rate $\rho > r$. The agent's effort a_t must be in an interval $[0, \bar{a}]$. The agent enjoys a shirking benefit $\lambda(\bar{a} - a_t)$ when he exerts effort a_t less than $\bar{a}$. The parameter λ measures the magnitude of the agency friction. At each time t prior to project completion, the probability of completion in the next instant $\mathrm{d}t$ is $a_t\,\mathrm{d}t$. Conditional on completion, the probability of success is πa_t, where $\pi > 0$ is such that $\pi\bar{a} < 1$. Let ν denote the random project completion date. It is possibly infinite-valued. The project pays Δ upon successful completion and pays nothing otherwise. If the project is terminated, the agent receives the value $\underline{U}$ of his outside option, and the principal receives a scrap value L. Let τ denote the termination date, which is also possibly infinite-valued. We assume that the termination values are small enough relative to the project payoff that termination is inefficient; specifically,

$$(r+\bar{a})L+(\rho+\bar{a})\underline{U}<\pi\bar{a}^2\Delta. \tag{1}$$

We also assume $\underline{U}<\lambda\bar{a}/\rho$, which means that the agent would prefer to shirk forever than to take his outside option. The principal continuously observes a signal process Y that evolves as

$$\mathrm{d}Y_t=a_t\,\mathrm{d}t+\sigma\,\mathrm{d}B_t, \tag{2}$$

where σ is a constant and B is a standard Brownian motion that is independent of project completion and independent of success or failure. The Brownian motion B is observed by the agent, but the principal only observes Y.

The principal chooses a reward process R adapted to Y, and the agent receives a payment R_ν if the project is successful at the completion date ν. The principal could also pay the agent when the project completes and is a failure, but we will show in Appendix B that for each contract with payment at failure, there is an equivalent contract with zero payment at failure. Therefore we assume the payment at failure is zero in the text. The principal can also compensate the agent with a nondecreasing cumulative payment process C adapted to Y prior to project completion, though we will see later that it is optimal to take $C=0$. In sum, the agent chooses a adapted to B, and the principal chooses C, R, and τ adapted to Y. The agent's expected utility is

$$\mathbb{E}\left[\int_0^{\nu\wedge\tau}\mathrm{e}^{-\rho t}\{\mathrm{d}C_t+\lambda(\bar{a}-a_t)\,\mathrm{d}t\}+\mathbb{I}_{\{\nu\le\tau\}}\mathrm{e}^{-\rho\nu}\pi a_\nu R_\nu+\mathbb{I}_{\{\tau<\nu\}}\mathrm{e}^{-\rho\tau}\underline{U}\right], \tag{3}$$

where $\pi a_\nu R_\nu$ is the expected reward at the project completion. The principal's expected utility is

$$\mathbb{E}\left[\int_0^{\nu\wedge\tau}\mathrm{e}^{-rt}\{-\mathrm{d}C_t\}+\mathbb{I}_{\{\nu\le\tau\}}\mathrm{e}^{-r\nu}\pi a_\nu(\Delta-R_\nu)+\mathbb{I}_{\{\tau<\nu\}}\mathrm{e}^{-r\tau}L\right], \tag{4}$$

where $\pi a_\nu(\Delta-R_\nu)$ is the expected payoff net of the reward to the agent.

As in DeMarzo and Sannikov (2006) and Sannikov (2008) and subsequent work on optimal dynamic contracting, contracts can be described in terms of the agent's continuation utility. The continuation utility is observable by both the principal and the agent and can be regarded as a performance index for the contract implementation. As we will show, it increases when there are positive monitoring signals and decreases when there are negative signals. The reward paid to the agent when the project succeeds is tied to the index in the optimal contract; it increases when the index increases and decreases when it falls.

Conditional on the project not having reached completion before t, i.e., $\nu > t$, the agent's continuation utility at time t is defined as

$$U_t = \sup_{a \in [0,\bar{a}]} \mathbb{E}_t \Big[\int_t^{\tau \wedge \nu} \mathrm{e}^{-\rho(s-t)} \big(\mathrm{d}C_s + \lambda(\bar{a} - a_s)\,\mathrm{d}s \big) \\ + \mathbb{I}_{\{\nu \le \tau\}} \mathrm{e}^{-\rho(\nu - t)} \pi a_\nu R_\nu + \mathbb{I}_{\{\tau < \nu\}} e^{-\rho(\tau - t)} \underline{U} \Big]. \quad (5)$$

The following result presents the dynamics of the agent's continuation utility and the agent's optimal effort choice. The sensitivity of the agent's continuation utility to the monitoring signal Y is represented by a process φ determined by martingale representation. We will show subsequently that φ is positive at the optimal contract, so the continuation utility rises when there are positive signals and falls when there are negative signals.

Proposition 1. *Given any contract for which the agent's utility is finite, the continuation utility U follows the dynamics*

$$\mathrm{d}U_t = \rho U_t\,\mathrm{d}t - \sup_{a \in [0,\bar{a}]} \Big\{ -a_t U_t + \lambda(\bar{a} - a_t) + \varphi_t a_t + \pi a_t^2 R_t \Big\}\,\mathrm{d}t + \varphi_t\,\mathrm{d}Y_t - \mathrm{d}C_t, \quad (6)$$

for some process φ. The agent's optimal effort is given by

$$a_t^* = \begin{cases} \bar{a} & \textit{if } \pi \bar{a} R_t + \varphi_t \ge \lambda + U_t\,, \\ 0 & \textit{otherwise}\,. \end{cases} \quad (7)$$

The formula (7) is the key feature of our model. It shows that incentives can be provided either by current pay-for-performance or by conditioning future pay-for-performance on monitoring signals. The term $\pi \bar{a} R_t$ is the expected payment if the project completes at t and the agent is exerting maximum effort. As remarked before, the term

φ_t measures how the continuation utility (or the performance index) changes in response to signals. We will show that, at the optimal contract, the payment R_t for success is tied to the continuation utility, so φ_t determines how the future payment is conditioned on monitoring signals. The project is terminated when the agent's continuation utility reaches the reservation value. Therefore, φ also links the monitoring signals and the threat of termination. Condition (7) shows that incentives can be provided either through the current reward (pay-for-performance) or through conditioning the future reward (and termination) on the monitoring signals. In fact, condition (7) shows that, in our simple model, these two mechanisms are perfectly substitutable.

Henceforth, we only consider contracts that always incentivize some effort from the agent. In light of (7), this means that we only consider contracts that incentivize the maximum effort from the agent; that is, they satisfy the inequality in the first line of (7). When $a_t^* = \bar{a}$, the agent's continuation utility satisfies

$$\mathrm{d}U_t = \big((\rho + \bar{a})U_t - \pi\bar{a}^2 R_t\big)\,\mathrm{d}t + \varphi_t(\mathrm{d}Y_t - \bar{a}\,\mathrm{d}t) - \mathrm{d}C_t\,. \tag{8}$$

Also, the principal's value is

$$V_t = \sup_{R,\varphi,C} \mathbb{E}_t\Big[\int_t^{\tau\wedge\nu} e^{-r(s-t)}\,\{-\mathrm{d}C_s\} + \mathbb{I}_{\{\nu\le\tau\}} e^{-r(\nu-t)}\pi\bar{a}\big(\Delta - R_\nu\big) + \mathbb{I}_{\{\tau<\nu\}} e^{-r(\tau-t)}L\Big], \tag{9}$$

with the maximization being subject to the constraint $\pi\bar{a}R_t + \varphi_t \ \ge\ \lambda + U_t$ and the nonnegativity constraint $R \ge 0$. The dynamic programming principle yields the following differential equation for (9):

$$0 = \min\Big\{1 + V',\\ (r+\bar{a})V - \sup_{R,\varphi}\Big\{\pi\bar{a}^2(\Delta - R) + \big((\rho+\bar{a})U - \pi\bar{a}^2 R\big)V' + \frac{1}{2}\sigma^2\varphi^2 V''\Big\}\Big\} \tag{10}$$

and the boundary condition $V(\underline{U}) = L$, with the maximization in (10) again being subject to $\pi\bar{a}R + \varphi \ge \lambda + U$ and $R \ge 0$. We now describe the optimal contract.

Proposition 2. *Suppose that (10) admits a solution V and*

$$\overline{U} := \inf\{U \geq \underline{U} : V' \leq -1\}. \tag{11}$$

is finite. Suppose that V is smooth and satisfies a transversality condition, as described in Appendix B. Then the following results hold:

(i) The principal's value is $V(U_t)$ and the function V is concave.

(ii) The optimal reward for success is

$$R^* = \frac{1}{\pi\bar{a}} \max\left\{\lambda + U + \frac{\bar{a}}{\sigma^2} \cdot \frac{1+V'}{V''}, 0\right\}. \tag{12}$$

(iii) The optimal sensitivity to monitoring is $\varphi^* = \lambda + U - \pi\bar{a}R^*$, and it is always strictly positive when $U < \overline{U}$.

(iv) The optimal flow compensation is $C^* \equiv 0$.

(v)
   (a) In a neighborhood of $\overline{U}$, R^* increases in U and converges to $(\lambda + \overline{U})/(\pi\bar{a})$ as U approaches $\overline{U}$.

   (b) The optimal contract sensitivity to monitoring φ^* converges to zero as U approaches $\overline{U}$, i.e., $\lim_{U\to\overline{U}} \varphi^* = 0$,

   (c) If $\rho - r < (\rho\overline{U} - \bar{a}\lambda)V''(\overline{U})$, then $(R^*)'(\overline{U}) = \infty$ and $(\varphi^*)'(\overline{U}) = -\infty$.

Figure 1 illustrates some features of Proposition 2. As shown in the proposition, the sensitivity to monitoring φ^* is positive except at $\overline{U}$. Thus, the low continuation utility in the figure corresponds to an accumulation of negative signals, and the high continuation utility corresponds to an accumulation of positive signals. The left-hand side of each panel is the utility $\underline{U}$ of the agent's outside option. The right-hand side is the endogenous maximum utility $\overline{U}$.

Panel (a) of Figure 1 shows the optimal φ^* and the expected reward $\pi\bar{a}R^*$ contingent on completion. The inequality $\varphi^* + \pi\bar{a}R^* \geq \lambda + U$ that ensures maximum effort from the agent is binding at the optimum, as shown in part (iii) of Proposition 2. Thus, the sum of the two incentives φ^* and $\pi\bar{a}R^*$ always equals $\lambda + U$, which is the green line in Panel

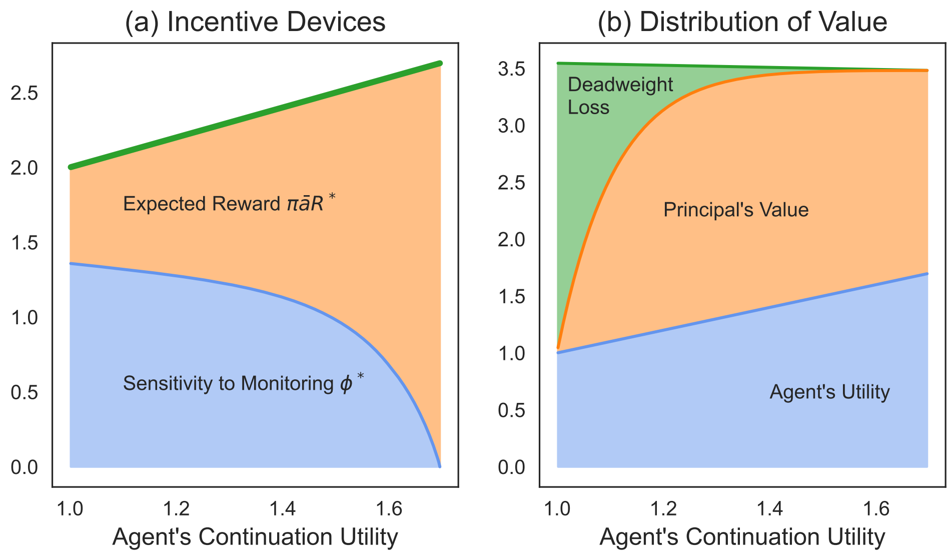


Figure 1. **The Optimal Contract**

Some features of the optimal contract are shown when $\rho = 0.1$, $r = 0.05$, $\sigma = 0.2$, $\bar{a} = 0.5$, $\lambda = 1$, $\Delta = 8$, $\pi = 1$, $\underline{U} = 1$, and $L = 0$.

(a). The decreasing nature of φ^* and increasing nature of R^* reflect the substitutability of the two incentive mechanisms discussed earlier. In response to positive signals, the promised reward increases and provides greater incentives for effort, so the monitoring sensitivity can be reduced. In fact, as shown in Proposition 2, the monitoring sensitivity converges to zero as the continuation utility approaches its maximum $\overline{U}$. Because all of the incentives are provided by the expected reward at $\overline{U}$, the expected reward $\pi\bar{a}R^*$ at $\overline{U}$ equals $\lambda + \overline{U}$, as shown in the proposition.

Even though the principal is risk-neutral about monetary payments, the nonlinearities in the model cause the principal to be risk-averse regarding variations in U, as Proposition 2 shows. The volatility of the agent's continuation utility is $\sigma\varphi^*$. The principal dislikes volatility and would therefore prefer to reduce φ^*. However, when there have been negative signals, the reward is lower and has less incentive effect, so φ must be maintained at a fairly high level in order to provide sufficient incentives to the agent, as shown in the figure.

Panel (b) of Figure 1 shows the division of value between the agent, the principal, and the deadweight cost of liquidation. At the first-best, the principal could provide utility U to the agent by promising payment of $(\rho + \bar{a})U/(\pi\bar{a}^2)$ upon successful completion, with the agent never shirking and never terminating. The remaining value for the principal would be $[\pi\bar{a}^2\Delta - (\rho + \bar{a})U]/(r + \bar{a})$. The expected deadweight cost of termination equals the difference between the first-best and second-best values for the principal. It falls in response to positive monitoring signals because such signals make it less likely that the project will eventually be terminated.

In the proof of Proposition 2, we show that $V''(\overline{U})$ must be strictly negative. This is in contrast to the situation of DeMarzo and Sannikov (2006) where the super-contact condition $V''(\overline{U}) = 0$ holds. The super-contact condition fails in our model because the coefficient of V'' in (10), i.e., $\frac{1}{2}\sigma^2(\varphi^*)^2$, vanishes at $\overline{U}$: $\varphi^*(\overline{U}) = 0$; see Proposition 2 (vb). This is different from DeMarzo and Sannikov (2006) where the coefficient of V'' is always positive. Thus, rather than reflecting at $\overline{U}$, the continuation utility in our model never crosses $\overline{U}$ due to a vanishing volatility at $\overline{U}$ (just as the interest rate in the CIR square-root model never crosses zero) and a negative drift at $\overline{U}$. Nevertheless, because $\varphi^*(\overline{U}) = 0$, the second order term $\frac{1}{2}\sigma^2(\varphi^*)^2 V''$ in (10) still vanishes at $\overline{U}$, resulting in

$$(r + \bar{a})V(\overline{U}) + (\rho + \bar{a})\overline{U} = \pi\bar{a}^2\Delta\,. \tag{13}$$

Thus, expected deadweight costs at $\overline{U}$ are zero, as shown in Figure 1, analogous to equation (13) in DeMarzo and Sannikov (2006).

The initial continuation utility U_0 for the agent is set by the contract to maximize the principal's value. As Panel (b) shows, this is interior to the region $(\underline{U}, \overline{U})$. At $\underline{U}$, the project is terminated, leaving only the value L for the principal. At $\overline{U}$, too much of the project value is promised to the agent, from the principal's point of view. Hence, the optimum is interior.

Figure 2 shows the same features of the optimal contract when the agent's outside option is less valuable. In this case, there is a possibility that the agent will receive a zero reward upon successful completion. This occurs when there has been an accumulation of negative monitoring signals. The agent will continue to exert maximum effort in the hope that positive signals will occur, leading to an eventual positive reward. However, if negative signals continue to accumulate, then the principal will terminate the project.

Figure 3 depicts the drift of the agent's continuation utility (8) and the ratio of the drift to the volatility at the optimal contract. From (8), the drift is $(\rho + \bar{a})U_t - \pi\bar{a}^2R_t^*$. Panel

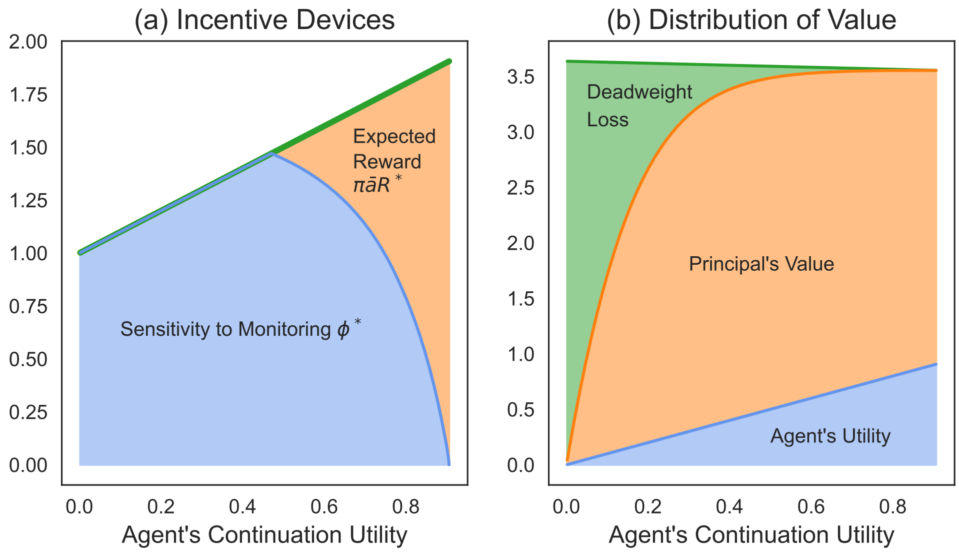


Figure 2. **Optimal Contract with Lower Reservation Utility**

Some features of the optimal contract are shown when $\rho = 0.1$, $r = 0.05$, $\sigma = 0.2$, $\bar{a} = 0.5$, $\lambda = 1$, $\Delta = 8$, $\pi = 1$, $\underline{U} = 0$, and $L = 0$.

(a) shows that the continuation utility is mean reverting, having a positive drift to the left of a critical value at which the drift is zero and having a negative drift to the right of that value. The concavity of the drift in Figure 3 reflects the convexity of R^* in Figure 1. Panel (b) shows the ratio of the drift to the volatility. Because there is mean reversion and vanishing volatility at $\overline{U}$, the drift-to-volatility ratio converges to $-\infty$ at $\overline{U}$. This pulls U back from $\overline{U}$. As shown in Proposition 2, U never exceeds $\overline{U}$. On the other hand, the drift-to-volatility ratio has a finite limit in Figure 3 as $U \to \underline{U}$. The lower barrier $\underline{U}$ is hit with positive probability, which produces the deadweight costs of termination.

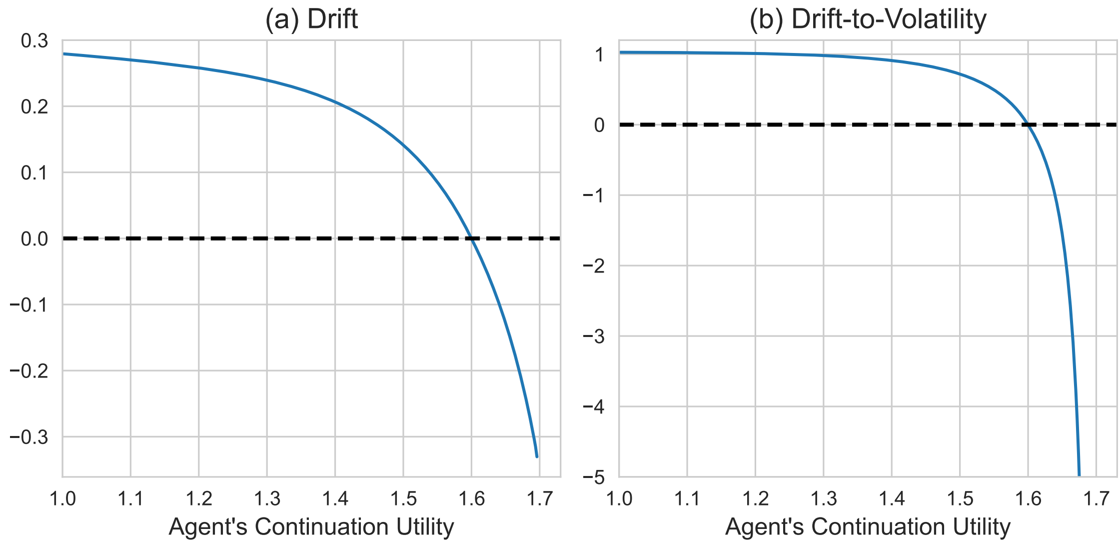


Figure 3. **Optimal Dynamics of the Continuation Utility**

Panel (a) depicts $(\rho + \bar{a})U - \pi\bar{a}^2 R^*$, which is the drift of the continuation utility. Panel (b) depicts the ratio of the drift to the volatility $\sigma\phi^*$. The parameter values are $\rho = 0.1$, $r = 0.05$, $\sigma = 0.2$, $\bar{a} = 0.5$, $\lambda = 1$, $\Delta = 8$, $\pi = 1$, $\underline{U} = 1$, and $L = 0$.

3 Monitoring Efficiency

A change in monitoring efficiency—that is, a change in σ—has several effects on the optimal contract. For a given φ, higher σ implies more volatility in U, which the principal dislikes. Consequently, the principal optimally substitutes the expected reward $\pi\bar{a}R$ for the conditioning φ when σ rises. This acts to the benefit of the agent but to the detriment of the principal. We will present several results regarding this phenomenon.

We first consider what happens when $\sigma = \infty$, meaning that there is no monitoring at all. In this case, the following proposition shows that the reward R^* and continuation utility U both fall deterministically until the project is completed or terminated. The proposition is essentially a corollary of the prior results. The differential equations for U and V have explicit solutions in this case.

Proposition 3. *Suppose that monitoring is impossible. Assume also that $r + \bar{a} > \rho$. The agent is incentivized to exert maximum effort if $\pi\bar{a}R_t \geq \lambda + U_t$. The optimal contract satisfies $C^* = 0$*

and $R_t^* = (\lambda + U_t)/(\pi\bar{a})$. *Set*

$$\alpha = \frac{\pi\bar{a}^2\Delta}{r+\bar{a}} + \frac{(\rho - r)\lambda\bar{a}}{(r+\bar{a})(r+\bar{a}-\rho)}$$

and $\beta = -\bar{a}/(r+\bar{a}-\rho)$. *Then,* $\alpha + \beta\underline{U} > L$. *The value function for the principal is*

$$V(U) = \alpha + \beta U - \left(\alpha + \beta\underline{U} - L\right)\left(\frac{\lambda\bar{a} - \rho U}{\lambda\bar{a} - \rho\underline{U}}\right)^{(r+\bar{a})/\rho}, \quad \textit{for } U \le \overline{U}, \tag{14}$$

where $\overline{U}$ *is defined in* (11). *The value function achieves its maximum at*

$$U_0 := \frac{\lambda\bar{a}}{\rho} - \left(\frac{\lambda\bar{a}}{\rho} - \underline{U}\right)\left(\frac{\bar{a}(\lambda\bar{a} - \rho\underline{U})}{(r+\bar{a}-\rho)(r+\bar{a})(\alpha + \beta\underline{U} - L)}\right)^{\rho/(r+\bar{a}-\rho)}. \tag{15}$$

At the optimal contract, the agent's continuation utility is

$$U_t = \frac{\lambda\bar{a}}{\rho} - \mathrm{e}^{\rho t}\left(\frac{\lambda\bar{a}}{\rho} - U_0\right). \tag{16}$$

If the project does not reach completion before, then it is terminated at the deterministic time

$$\tau = \frac{1}{\rho}\log\left(\frac{\lambda\bar{a} - \rho\underline{U}}{\lambda\bar{a} - \rho U_0}\right). \tag{17}$$

Figure 4 illustrates Proposition 3. Given $C^* = 0$ and $R_t^* = (\lambda + U_t)/(\pi\bar{a})$, the agent's continuation utility process depends on the termination date τ. Specifically, U_0 depends on the termination date, and U_t for $t > 0$ is then given by (16). The map $\tau \mapsto U_0$ is shown in Panel (a). The principal chooses τ, but, because the map $\tau \mapsto U_0$ is strictly monotone, this is equivalent to choosing U_0. Panel (b) shows how the principal's value depends on U_0. The principal chooses the maximizing value of U_0, which determines the optimal τ from Panel (a). Given the choice of τ, the agent's utility declines over time as shown in Panel (c), until hitting $\underline{U}$ at τ, when the project is terminated.

Our interest is in how the contract changes when monitoring efficiency changes. Figure 5 shows the agent's utility, the principal's value, and the expected deadweight loss at the project initiation for various values of σ. Panel (a) shows that as monitoring becomes less efficient (that is, as σ increases), the agent's utility and the deadweight loss

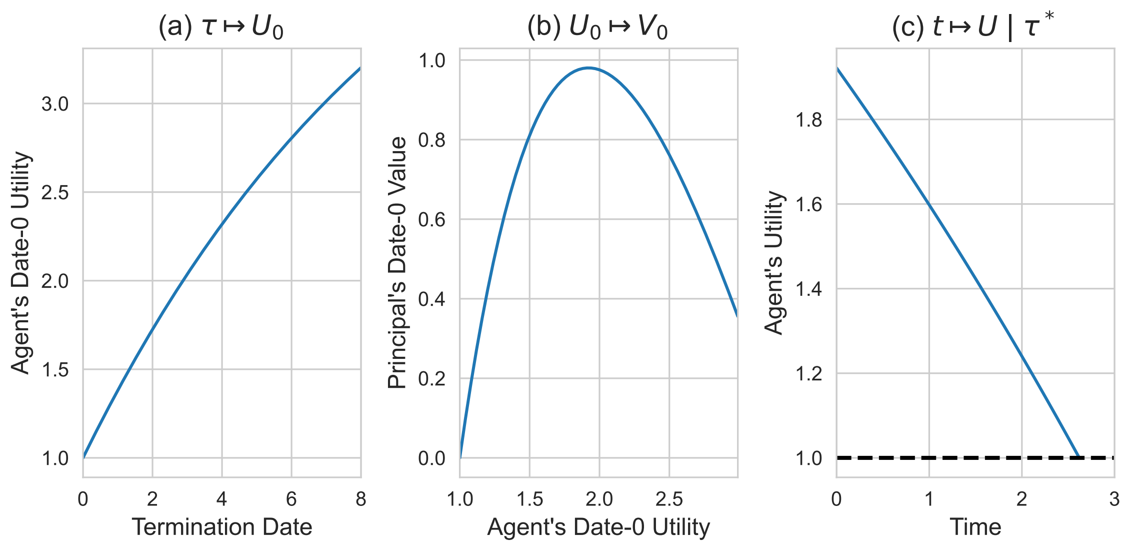


Figure 4. **Solution of the No-Monitoring Model**

Features of the optimal contract are shown when there is no monitoring and when $\rho = 0.1$, $r = 0.05$, $\bar{a} = 0.5$, $\lambda = 1$, $\Delta = 8$, $\pi = 1$, $\underline{U} = 1$, and $L = 0$.

increase, and the principal's value falls. Panel (b) shows that in the limit ($\sigma = \infty$) the agent's utility and the deadweight loss are larger, and the principal's value is smaller.

The agent's utility rises when monitoring efficiency falls because the anticipated reward is higher, due to the substitution of reward for conditioning by the principal. To assess this, we simulated the model with 50,000 Brownian paths B and 50,000 project completion dates ν. From these variables, we generated the agent's utility process and reward process for two different values of σ (0.2 and 0.4). We simulated sufficient time steps so that more than 92% of the simulations resulted in either project completion or termination, for each value of σ. Of those simulations in which the project was either completed or terminated, only 3.9% of the projects were terminated when σ was low, but 10.8% were terminated when σ was high. Furthermore, 20.2% would have been terminated if $\sigma = \infty$. This is consistent with Figure 5, which shows that the deadweight cost of termination is higher when monitoring is less efficient.

Figure 6 shows the distributions of the rewards at the time of project completion, for those simulations in which the project was completed. Comparing the two values $\sigma = 0.2$ and $\sigma = 0.4$, the figure shows that the reward is higher in the sense of first-order stochastic dominance when monitoring is less efficient ($\sigma = 0.4$). The same is nearly true

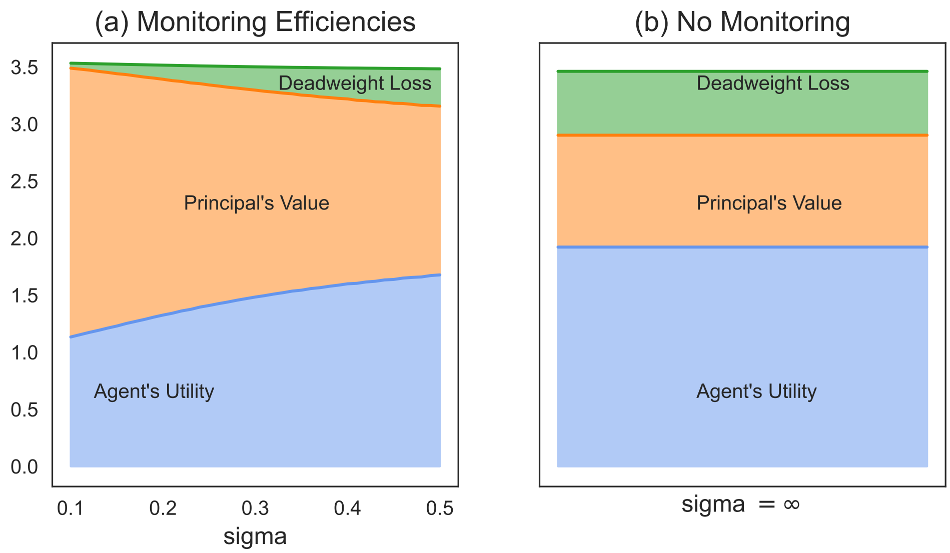


Figure 5. **Monitoring Efficiency and the Distribution of Value**

Panel (a) depicts outcomes of the optimal contract for various values of σ. The agent's utility is U_0, the principal's value is $V(U_0)$, and the deadweight loss is $\left[\pi\bar{a}^2\Delta - (\rho + \bar{a})U_0\right]/(r + \bar{a}) - V(U_0)$. The heights of the bars in panel (b) depict the same outcomes when there is no monitoring. The other parameter values are $\rho = 0.1$, $r = 0.05$, $\bar{a} = 0.5$, $\lambda = 1$, $\Delta = 8$, $\pi = 1$, $\underline{U} = 1$, and $L = 0$.

when comparing $\sigma = 0.4$ and $\sigma = \infty$, though there is a very small probability of receiving a higher reward when $\sigma = 0.4$ (following very positive monitoring signals) than is ever paid when $\sigma = \infty$.

The difference in rewards between less efficient and more efficient monitoring tends to increase when there are negative signals. This is shown in Table 1, which reports summary statistics across simulations of the time-series correlations between the Brownian shock and the change that the shock induces in the difference in rewards. The mean correlation is negative (with an untabulated t statistic of -153), and the entire interquartile range is well within negative territory. So, reducing the efficiency of monitoring has a larger effect on the size of the promised reward when there have been negative signals.

Our results in Figure 6 and Table 1 motivate us to propose two hypotheses, which we will bring to data in the next section:

(H1) When monitoring quality falls, pay-for-performance is increased in response.

(H2) The effect in (H1) is larger when there has been prior negative evidence.

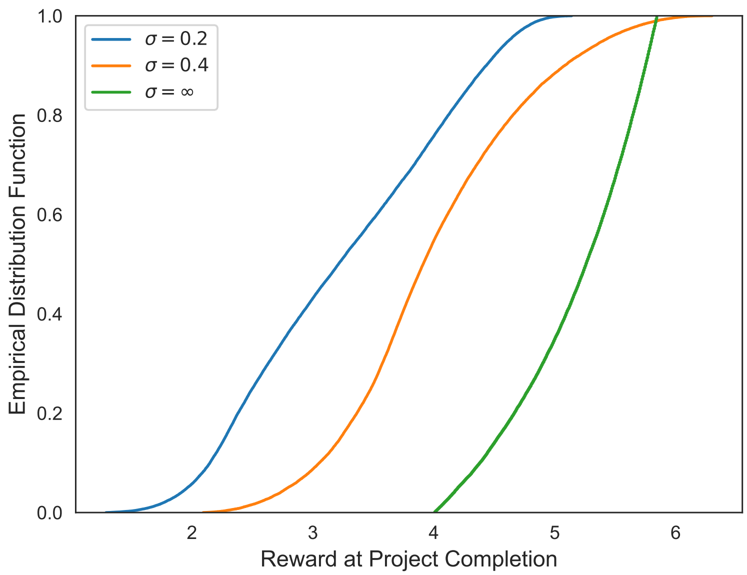


Figure 6. **Simulated Distributions of Rewards**

The model was simulated 50,000 times for $\sigma = 0.2$, $\sigma = 0.4$, and $\sigma = \infty$. The other parameter values are $\rho = 0.1$, $r = 0.05$, $\sigma = 0.2$, $\bar{a} = 0.5$, $\lambda = 1$, $\Delta = 8$, $\pi = 1$, $\underline{U} = 1$, and $L = 0$. The distribution functions of the rewards at the time of project completion are shown for those simulations in which the project was completed.

Table 1. **Summary Statistics of Time Series Correlations**

The model was simulated 50,000 times for $\sigma = 0.2$ and $\sigma = 0.4$, and the difference in rewards (the reward for $\sigma = 0.4$ minus the reward for $\sigma = 0.2$) was computed at each date. The correlation was computed in each simulation between the change in the difference in rewards and the contemporaneous Brownian shock to the signal process Y. The table reports summary statistics of the correlations, excluding simulations in which the project completed within the first two time steps. The other parameter values are $\rho = 0.1$, $r = 0.05$, $\sigma = 0.2$, $\bar{a} = 0.5$, $\lambda = 1$, $\Delta = 8$, $\pi = 1$, $\underline{U} = 1$, and $L = 0$.

count	49,741
mean	-0.434
std	0.631
25%	-0.867
50%	-0.751
75%	-0.253

4 Empirical Evidence

We conduct an empirical analysis designed to test the model hypotheses (H1) and (H2). We proxy for changes in signal quality using exogenous shifts in the availability of direct flights between the residences of the directors on the board and the headquarters of their respective companies. Corresponding to the model's framework, stock option awards provide agents with a long-term potential source of returns, and their payoff arises stochastically. We use option awards to capture the success reward empirically.

4.1 Data and Sample

We use data on publicly traded firms. Option awards are deferred compensation. In the US, employee stock options typically vest from one year to four years after the award.[2] Additionally, stock options have a nonlinear payoff structure that does not pay anything in the case of "failure" when the stock price is below the option strike price. Thus, we focus on option awards as the closest parallel to the reward in our model. The board of directors is mapped to the principal. Top executives, defined as C-level executives and the president, are mapped to the agent.

The ideal experiment to test our results would be to exogenously vary the signal quality of the information that the board of directors receives and examine its effect on option awards. However, we cannot directly measure the quality of the information a board of directors receives. Therefore, we use directors' access to direct flights between their residences and companies' headquarters as a proxy for monitoring ease. We assume that when a direct flight is available, directors can easily travel to the firm headquarters and obtain higher-quality information by interacting with executives in person and inspecting the firm. To avoid selection issues, we focus only on cases where a direct flight is added or removed between a director and the firm after the director has already started their tenure. Change in direct flight availability provides us with a plausibly exogenous firm-year level change to monitoring quality.

[2] One year after the award, 25% of the options vest, and the remaining 75% vest equally after one year for each of the following three years (Huddart and Lang, 1996) and see here. Some companies, such as Amazon, may opt for more back-loaded vesting schedules. See here and here.

4.1.1 Direct Flight Data

We use the Bureau of Transportation Statistics (BTS) dataset "T-100 Domestic Segment Data" for our exogenous monitoring variable.[3] This dataset covers all direct flights between US airports based on mandatory reporting from airline carriers. We construct a dataset of all airports connected by commercially available passenger flights in both directions in a given year.[4]

To identify airports near firms' headquarters, we extract the firms' zip codes from Compustat. We utilize data from the BoardEx database for information on directors' locations. BoardEx does not provide direct information about directors' primary residences, but it contains employment data for non-board positions with tenures and firm locations. We assume that inside directors are living locally to the firm and, therefore, do not consider them in our analyses.[5] For the remaining directors, we employ the zip code of the most recent non-director position held by a director as a proxy for their residence. Since board positions typically do not necessitate local residency, while work positions do, we believe the most recent work location serves as a reasonable approximation of a director's current residence. A potential selection issue is that directors who want to be highly engaged in monitoring might move to another place to obtain direct flight access or be local to the firm. Another possible selection issue is that directors who are less engaged in monitoring may be more likely to move from where a direct flight is available to somewhere it is not. To mitigate these potential selection issues, we consider only the latest available location, ensuring that the variation in our key independent variables is exclusively driven by direct flight availability. Despite potentially introducing noise into our data, using the latest address for directors should not be correlated with compensation outcomes and would only attenuate our results.

Our two primary independent variables of interest are the start or stop of a direct flight between the director's area of residence and the firm's region. We assume a director is local (and thus typically drives) to the firm if they reside within 240 kilometers of

[3]This data set is also referred to as "Data Bank 28DS".

[4]This dataset also includes other key data about the flight routes, such as the airline carrier, number of departures, and additional key information about the type of flight, such as whether it is a passenger or cargo flight and the type of airplane.

[5]Even if they do not live locally, they may still be required to travel to the firm's headquarters frequently enough that the availability of a direct flight is irrelevant.

the firm. For both the director and firm locations, we identify potential airports within an 80-kilometer radius. This is consistent with the cutoffs used in Bernile et al. (2018), converted to kilometers. Furthermore, if the closest airport is more than 40 kilometers away, we consider all airports within 40 kilometers of the closest airport. Thus, our results are not driven by the cutoff when a director lives far from all airports. We assume that a director might choose a nearby airport further than the closest one if a direct flight is only available there. We consider a direct flight to be available when a direct flight connects one of the airports in the director's area to an airport in the firm's region. We focus on changes in access to direct flights *after* a director's tenure has begun. A direct flight from their location is considered started or stopped for as long as it remains available or unavailable, respectively. Access to a direct flight *exogenously* increases or decreases the ease with which a director can visit and monitor a firm. An executive-firm-year is considered affected if at least one director whose direct flight access to that firm has been altered is on the firm's board that year. In approximately 80% of our observations (at the executive-firm-year level), where at least one director has been affected by either a direct flight starting or stopping, only one director on the board is affected. Thus, we focus our results on whether at least one director has been affected.

Consequently, our "Direct Stopped" variable is one for all executives at a firm where at least one board member in that year has lost access to a direct flight to the firm after joining the board. This requires that all airlines stop all direct flights between the regions. The "Direct Started" variable is one for all executives at a firm where at least one board member in that year has gained access to a direct flight from some airline to the firm after joining the board. Figure 7 demonstrates an example of treatment timing for a director, highlighting how this may lead to the three example executives being treated at the beginning, middle, or end of their tenures.

Figure 8 visually presents the locations of airports and headquarters for firms and airports with commercially available round-trip flights in 2021. Panel (a) displays the headquarters' locations, with one dot for each zip code containing a firm in our sample. The figure clearly shows a concentration of firms on the coast, though many headquarters are further inland. Panel (b) depicts the airports with round-trip, commercially available flights in 2021. In contrast to firms, we see that airports cover the country much more evenly.

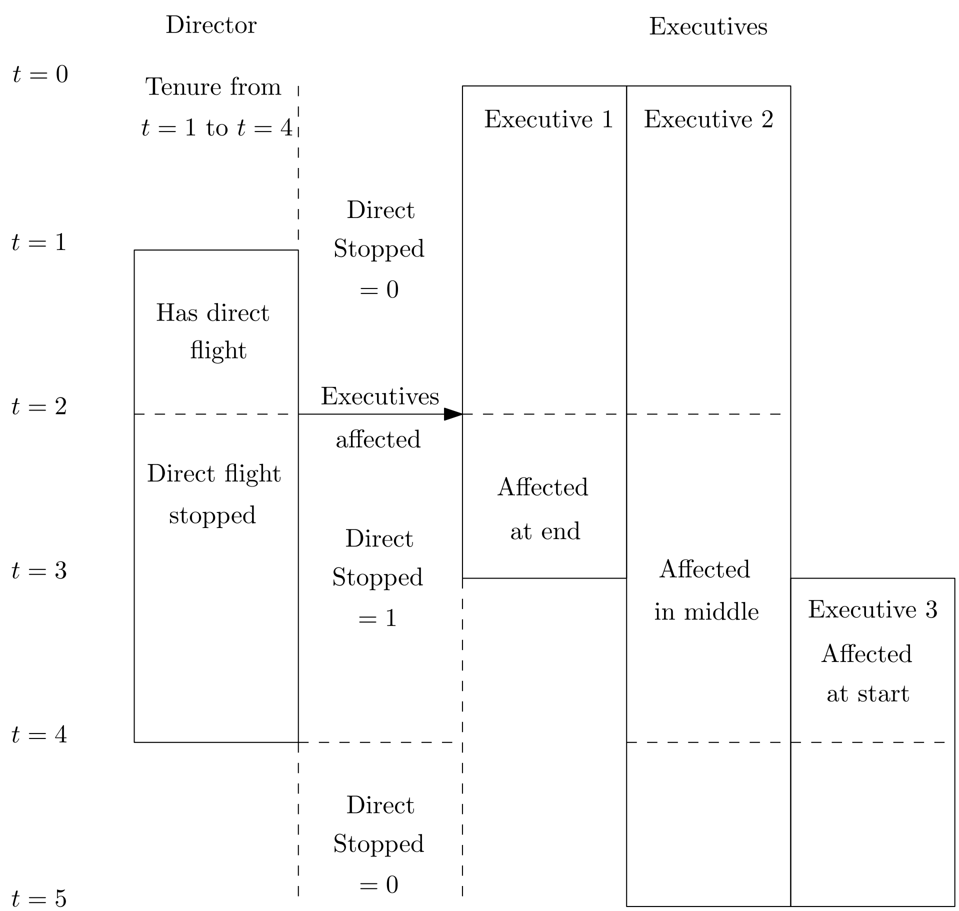
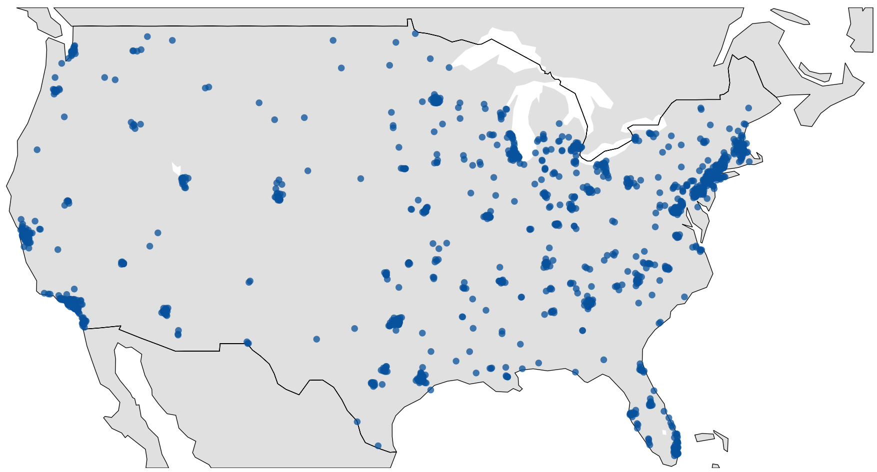


Figure 7. **Illustration of Effect Timing**

Notes: Illustrates how a sample board director losing access to a direct flight can affect executives at different times in their careers.

(a) Headquarters Locations



(b) Airport Locations

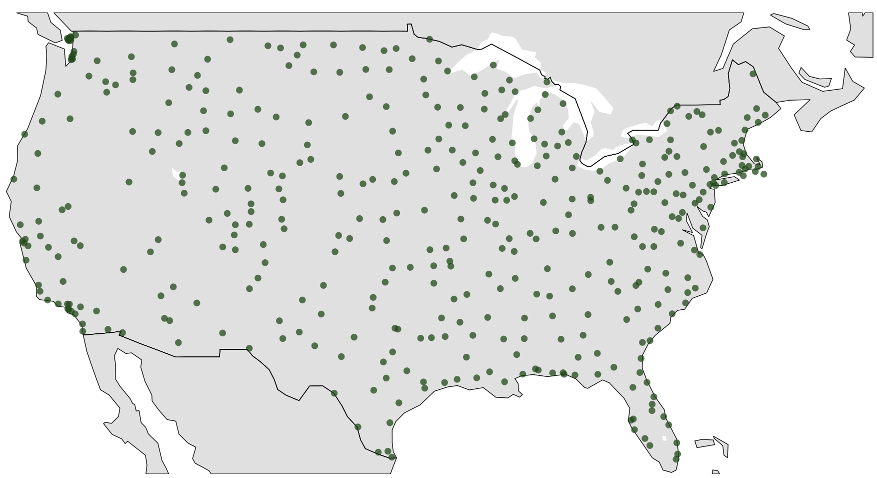


Figure 8. **Headquarters and Airport Locations in 2021**

Panel (a) plots the location of firm headquarters at the zip code level. There is one dot for every zip code with a firm's headquarters recorded in 2021 in our sample. Panel (b) plots airports with at least one commercially available round-trip direct flight in 2021. Data on firm zip codes come from Compustat. Data on zip code latitude and longitude come from SimpleMaps. Airport locations, latitudes, and longitudes (as well as flight data) come from the Bureau of Transportation Statistics.

4.1.2 Executive and Firm Data

We obtain option compensation in terms of fair value at the time it is awarded from Execucomp. We include all C-level executives and presidents indicated by Execucomp. We also use Execucomp data to determine in which years the CEO is also the chairperson (CEO duality). Firm characteristics are from Compustat. We use log total assets and log total employment as measures of firm size and profitability and log stock growth as measures of firm performance. Firm profitability is defined as operating income before depreciation divided by assets.[6] We calculate log stock return using monthly stock return data from CRSP and the fiscal year-end month specified in Compustat. We define industry at the granular 3-digit Standard Industrial Classification (SIC) code level. All firm and compensation variables are winsorized at the standard 1% level. The option compensation data in Execucomp began in 2006, and the completed BTS data was only available through 2021 at the time of downloading. Because Execucomp primarily covers S&P 1500 firms and is the smallest (in terms of the number of firms) in our data, our sample covers (generally speaking) S&P 1500 firms from 2006 to 2021. One data point is an executive-firm-year. More details about the data construction are included in Appendix OA.C.4.

4.1.3 Methodology

Considering the sparsity of option compensation data, with approximately half of the observations in our executive sample having a positive value, we utilize Poisson regression as suggested by Cohn et al. (2022). This enables the interpretation of regression coefficients as percentage changes in the value of option compensation and serves as a robust alternative to linear regression when logged variables cannot be used due to a high number of zeros. Poisson regression, a generalized linear model (GLM) developed for count data (non-negative integers), assumes the dependent variable has a Poisson distribution. In contrast to log regression, which estimates the expectation of the log of the dependent variable conditional on the covariates, Poisson regression estimates the log

[6] We cannot use a logged version of the profitability variable because some firms have negative operating income.

of the dependent variable's conditional expectation, as shown by the following equation:

$$\log(\mathbb{E}[y|X]) = X\beta.$$

Here, y is the dependent variable, X is a vector of the independent variables (including a constant and/or fixed effects), and β is the vector of estimated parameters. To ensure the value is defined, the expectation of the dependent variable must be positive, meaning that we can only examine executive-firm pairs where option compensation is greater than 0 in at least one year. Let

$$\lambda := \mathbb{E}(y \mid X) = e^{X\beta}$$

be the parameter of Poisson distribution for the dependent variable. The vector of regression coefficients β is determined via the maximum likelihood method. See Online Appendix OA.C.3 for additional detail on Poisson regression estimation.

Our baseline specification is designed to test (H1) from the model, utilizing a Poisson regression with fixed effects for industry-year, state-year, and executive-firm pairs. The executive-firm fixed effect captures non-time-varying factors influencing compensation, including industry, location, and executive skill. The industry-year and state-year fixed effects capture regional and industry compensation trends. More granular location fixed effects will also be examined in our robustness analyses. The primary dependent variable is the fair value of option awards at the time granted to an executive for that year by the firm. Our baseline regression specification is:

$$\begin{aligned} \mathbb{E}\left[\text{Options}_{i,j,t}\,|\mathbb{X}_{i,j,t}\right] = \exp\Big(&\beta_1 \text{ Direct Stopped/Started}_{j,t} \\ &+ \Lambda' X_{j,t} + \gamma_{t,n} + \gamma_{t,s} + \gamma_{i,j}\Big). \end{aligned} \tag{18}$$

In this specification, $\text{Options}_{i,j,t}$ represents executive i's option award value in year t at firm j. $\text{Direct Stopped/Started}_{j,t}$ is our main dependent variable. $\text{Direct Stopped}_{j,t}$ is a dummy variable with a value of one when at least one director of firm j who had access to a direct flight to the firm's headquarters loses access in year t. This requires all airlines to stop all direct flights. Its value remains one until the director either regains access to a direct flight or exits the board. $\text{Direct Started}_{j,t}$ is a dummy variable with a value of one when a director of firm j did not have access to a direct flight but gains access in year

t. Its value remains one until the director either loses access or exits the board. β_1 is the coefficient of interest. It can be interpreted as the percentage change in the option award value. $X_{j,t}$ is a vector of controls. It consists of two measures of firm size, log assets and log total employment, as well as two measures of firm performance, profitability, and log annual stock return. We also control for the log annual stock return from the previous year and whether or not the CEO is the chairperson. Λ is a vector of coefficients. $\gamma_{t,n}$ is the industry-year fixed effect where n indexes the industry of firm j, $\gamma_{t,s}$ is the state-year fixed effect where s indexes the state of firm j, and $\gamma_{i,j}$ is the executive-firm fixed effect. $\mathbb{X}_{i,j,t}$ is a vector containing all of the independent variables and fixed effects, indicating the expectation is conditional on these covariates.

Next, to assess (H2), we incorporate an interaction term between $\text{Direct Stopped/Started}_{j,t}$ and a dummy variable indicating whether a firm has below-median profitability as a proxy for subpar performance. We control for the level effect of below-median profitability; however, we also note that profitability is one of our standard control variables. Thus, the full specification is as follows:

$$
\begin{aligned}
\mathbb{E}\left[\text{Options}_{i,j,t} \,|\mathbb{X}_{i,j,t}\right] = \exp(&\beta_1 \text{ Direct Stopped/Started}_{j,t} \\
&+ \beta_2 \text{ Direct Stopped/Started}_{j,t} \times \text{ Below-Median Profitability}_{j,t} \\
&+ \beta_3 \text{ Below-Median Profitability}_{j,t} \\
&+ \Lambda' X_{j,t} + \gamma_{t,n} + \gamma_{t,s} + \gamma_{i,j}).
\end{aligned} \tag{19}
$$

$\text{Below-Median Profitability}_{j,t}$ is a dummy variable equal to one if a firm's profitability is below the industry median in our sample for that year. The sum of β_1 and β_2 reflects the overall impact of the $\text{Direct Stopped/Started}_{j,t}$ variable on executives at below-median profitability firms. Furthermore, β_2 denotes the difference in the effect of $\text{Direct Stopped/Started}_{j,t}$ on executives at above and below median firms.

Additionally, we consider another interaction specification examining the influence of the $\text{Direct Stopped/Started}_{j,t}$ variable in the context of CEO duality. We hypothesize that if our results are driven by board monitoring, then when the CEO also serves as the board's chairperson, no effect would be observed because the CEO likely has veto power over compensation policy. The specification we consider is:

$$\begin{aligned}\mathbb{E}\left[\text{Options}_{i,j,t}\,\middle|\mathbb{X}_{i,j,t}\right] = \exp(&\beta_1 \text{ Direct Stopped/Started}_{j,t} \\ &+ \beta_2 \text{ Direct Stopped/Started}_{j,t} \times \text{CEO Only}_{j,t} \\ &+ \beta_3 \text{ CEO Only}_{j,t} \\ &+ \Lambda' X_{j,t} + \gamma_{t,n} + \gamma_{t,s} + \gamma_{i,j}).\end{aligned} \tag{20}$$

CEO $\text{Only}_{j,t}$ is a dummy variable set to one if the CEO is not the chairperson and serves exclusively as the CEO for that year. As with the prior interaction specification, the sum of β_1 and β_2 denotes the overall effect of the Direct $\text{Stopped/Started}_{j,t}$ variable on executives at firms where the CEO and chairperson roles are separate, whereas β_2 captures the variation in the impact of Direct $\text{Stopped/Started}_{j,t}$ on firms depending on whether the CEO is also the chairperson or not.

In all specifications, we cluster standard errors at the firm level; because treatment occurs at the firm level, we would expect errors within a firm to not be distributed independently of each other.

4.1.4 Summary Statistics

Table 2 displays summary statistics for our sample utilized in the baseline Poisson regression. Each observation corresponds to an executive at a firm in one year. We first observe that numerous executive-firm-years do not receive option compensation. The Poisson regression omits executives who never receive option compensation and therefore data from these directors are not included in our summary statistics or analyses using Poisson regression. When we include these approximately 30,000 additional executive-firm-years in our sample , we find that around 48% of our executive-firm-years have a positive level of option compensation. We discover that 9% (8%) of director-firm-years have at least one board director for whom a direct flight started (stopped) after assuming the director position. Even though the likelihood of a director being impacted by a change in flight routes is small, we only need one director to be affected for our started/stopped dummy variables to have a value of one and a public firm generally has multiple directors. Consequently, the probability that a firm is affected is considerably greater than that for an individual director.

Table 2. **Summary Statistics**

One observation corresponds to one executive-firm-year. Our sample is C-level employees based on their title(s) in Execucomp. Direct flight start/stop variables constructed using BTS data on direct, scheduled flights and data on directors' prior non-director employment from BoardEx are used to approximate directors' locations. Option awards are the fair value of options awarded at the time they were awarded. CEO duality is one when the CEO of a firm is also the chairperson of the board, zero otherwise. Option awards, CEO, and chairperson information are from Execucomp. Firm characteristics, assets, profitability, employment, and location, are from Compustat. Log stock return is the log annual stock return from the previous year. Stock prices are from CRSP. Firm profitability is defined as operating income before depreciation divided by assets.

	N	Mean	SD	P25	Median	P75
Option Awards	68,328	648.16	1092.17	0.00	235.96	735.51
Direct Started	68,328	0.09	0.28	0.00	0.00	0.00
Direct Stopped	68,328	0.08	0.27	0.00	0.00	0.00
CEO Only	68,328	0.53	0.50	0.00	1.00	1.00
Profitability	68,328	0.12	0.10	0.07	0.12	0.17
Log Stock Return	68,328	0.07	0.40	-0.11	0.11	0.29
Lag Log Stock Return	68,328	0.06	0.40	-0.12	0.10	0.29
Log Assets	68,328	8.03	1.76	6.76	7.95	9.16
Log Employment	68,328	1.72	1.72	0.53	1.78	2.90

4.2 Results

We test the two hypotheses in Section 3. (H1) implies that option awards should increase when signal quality decreases due to a direct flight being stopped. (H2) predicts the increases in option awards when signal quality declines are concentrated among poorly performing firms.

Hypothesis 1. Table 3 reports our test of (H1). In column (1), we estimate equation (18) with the direct flight stopped variable and find that when a direct flight is stopped, the value of options awarded to executives increases by approximately 11.1%, statistically significant at the 5% level. With the heightened challenges in monitoring, option-based compensation is raised to emphasize incentives conditional on success. The executive-firm fixed effect controls for all non-time varying sources of variation related to the executive or firm, such as industry or location. Fixed effect variables for industry-year and state-year address concerns that time-varying industry or geographic trends could drive our results. For executive-firm years included in these regressions (which comprise executives who received positive option compensation in at least one year during their tenure), the median option compensation was around \$235,000. Our findings suggest an additional \$26,000 in supplementary compensation for the median executive. Since our sample is highly skewed, the marginal effect is likely to be much larger, given that the mean option compensation is \$648,160, almost triple the median which is much smaller due to the high number of zeros. One factor that may account for the magnitude of the effect size is that only non-local directors can be affected by direct flights. These non-local directors are more likely to be outside directors and less likely to be influenced by the CEO, thus having a more significant impact (see Fama and Jensen (1983); Adams et al. (2010)). In column (2), we estimate (18) with the direct flight started variable and find no statistically significant effect when a board director gains access to a direct flight. The sign of the estimated coefficient is negative, in line with theoretical predictions; however, the small estimated effect size may drive the lack of statistical significance. Although we might expect significant effect sizes in theory, it is plausible that in practice, the no-direct-flight treatment may have a more significant effect since these individuals may have been more actively monitoring the firm, and losing access to a direct flight disrupts the director's working style, necessitating an increase in option awards to substitute the missing monitoring; conversely, a director gaining access to a direct flight may not disrupt their working style.

Hypothesis 2. Table 4 presents our results for the test of (H2). We use profitability as a proxy for performance, as it is a stable measure of performance over time and is more directly influenced by firm executives than the stock price, which can be very volatile. We introduce a dummy equal to one for executive-firm years where the firm has below-median profitability for firms in the same industry that year. Additionally, to ensure a reasonable sample size for calculating the median, we only use firm years with at least 10 firms in that industry-year. Column (1) estimates equation 19 with the direct flight stopped variable using Poisson regression. We find a $21.9\% = (5.6\% + 16.3\%)$ increase in option compensation, statistically significant at the 5% level ($p = .012$), for executives at firms with below industry-year median profitability when a director loses access to a direct flight. The estimated effect of a direct flight for a director being stopped on

Table 3. **Effect of Direct Flight Availability on Option Compensation**

Direct flight start/stop variables are constructed using BTS data on direct, scheduled flights and directors' location which is approximated by BoardEx information on their prior non-director employment. Option awards are the fair value of option awards. Our sample is C-level employees and presidents based on their title(s) reported in Execucomp. The control variables are CEO-Chair, log stock return, lag log stock return, profitability, log assets, and log total employment. Firm characteristics, assets, profitability, employment, and location, are from Compustat. Stock return is log annual stock return from CRSP. Firm profitability is defined as operating income before depreciation divided by assets. Industry is defined at the SIC-3 level. Columns (1) and (2) present the result for the specification (18). t-statistics, using standard errors clustered by firm, are shown in parentheses. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

	(1) Option Awards	(2) Option Awards
Direct Stopped	0.111**	
	(2.21)	
Direct Started		-0.016
		(-0.35)
Controls	Yes	Yes
Industry $\times$ Year FE	Yes	Yes
State $\times$ Year FE	Yes	Yes
Executive $\times$ Firm FE	Yes	Yes
Observations	68,328	68,328

executives at a below-median firm is approximately four times the effect on executives at firms with above-median profitability, which is only 5.6%; furthermore, the difference between above and below-median firms is statistically significant at the 10% level. We cannot statistically reject that the effect of a board director losing access to a direct flight has no impact on at or above industry median profitability firms, which suggests that the below-median profitability firms drive our results. In column (2), we estimate equation (19) with the direct flight started variable. We find no statistical evidence of an effect on option compensation; nevertheless, the estimated effect of a direct flight being started for a director is negative and larger for below-median firms, consistent with the theoretical predictions. In both columns, we find a negative coefficient on the below-median profitability dummy variable suggesting greater usage of option compensation for more profitable firms within an industry. Note that we include profitability as one of our standard control variables.

CEO Duality. If signal quality drives our results, we should only observe an effect when board members can effectively monitor and act accordingly. A proxy for

Table 4. **Effect of Direct Flight Availability: Performance, Profitability**

Direct flight start/stop variables are constructed using BTS data on direct, scheduled flights and directors' location which is approximated by BoardEx information on their prior non-director employment. Option awards are the fair value of option awards. Our sample is C-level employees and presidents based on their title(s) reported in Execucomp. The control variables are CEO-Chair, log stock return, lag log stock return, profitability, log assets, and log total employment. Firm characteristics, assets, profitability, employment, and location, are from Compustat. Stock return is log annual stock return from CRSP. Firm profitability is defined as operating income before depreciation divided by assets. Industry is defined at the SIC-3 level. Columns (1) and (2) present the result for the specification (19). t-statistics, using standard errors clustered by firm, are shown in parentheses. *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

	(1) Option Awards	(2) Option Awards
Direct Stopped	0.056	
	(0.75)	
Dir. Stop, Below Median Prof.	0.163*	
	(1.79)	
Direct Started		0.051
		(0.75)
Dir. Start, Below Median Prof.		-0.032
		(-0.40)
Below Median Profitability	-0.035	-0.019
	(-1.08)	(-0.58)
Controls	Yes	Yes
Industry × Year FE	Yes	Yes
State × Year FE	Yes	Yes
Executive × Firm FE	Yes	Yes
Observations	42,341	42,341

a board's ineffectiveness is CEO duality when a CEO is also the board's chairperson. There is a long literature on CEO duality, recently reviewed by Krause et al. (2014). Zajac and Westphal (1994) find that CEO-duality leads to higher CEO compensation and, specifically, a lower percentage of compensation dependent on performance. Further, Cronqvist et al. (2009) found that more entrenched CEOs pay their workers more. Thus, when the CEO is also the board's chairperson, it is less likely that the board can monitor effectively and determine executives' compensation independently. To examine this question, we introduce an interaction term between the direct stopped/started treatment variable and a dummy for if the CEO is not also the chairperson ("CEO Only"). We proceed to test (H1), taking into account CEO duality. Table 5 estimates equation (20). In column (1), we find evidence that the effect of a director losing access to a direct flight is primarily driven by firms where the CEO is not the chairperson. There is an estimated $23\%(= 2.7\% + 20.3\%)$ increase in compensation for executives when the CEO is not the chairperson and a direct flight to a board member's location is stopped. This result is statistically significant at the 1% level and approximately double our baseline result from column (1) of Table 3. In contrast, we find no statistical evidence of an effect in executive-firm-years where the CEO is also the chairperson. Further, we can say that the effect when the CEO is not the chairperson is different at the 1% level of statistical significance. In column (2), we estimate that a direct flight being added for a director negatively affects the level of option compensation when the CEO is not the chairperson. This is directionally consistent evidence with our model for increasing signal quality, but the result is statistically insignificant. Although CEO duality is not randomly assigned, the results suggest that reduced monitoring only leads to increased option-based compensation to the executives when the board member can monitor and take corresponding action effectively. This suggests that board monitoring is the channel driving our empirical results. We focus on the specification split by CEO duality going forward in our robustness results.

4.3 Robustness

CEO and Not CEO Subsamples. Appendix Table OA.6 estimates equation (20) for the sample of executives excluding the CEO and solely for the executives who are the CEO.

Table 5. **Effect of Direct Flight Availability: CEO Duality**

Direct flight start/stop variables are constructed using BTS data on direct, scheduled flights and directors' location which is approximated by BoardEx information on their prior non-director employment. Option awards are the fair value of option awards. Our sample is C-level employees and presidents based on their title(s) reported in Execucomp. The control variables are CEO-Chair, log stock return, lag log stock return, profitability, log assets, and log total employment. Firm characteristics, assets, profitability, employment, and location, are from Compustat. Stock return is log annual stock return from CRSP. Firm profitability is defined as operating income before depreciation divided by assets. Industry is defined at the SIC-3 level. Columns (1) and (2) estimate specification 20. CEO Only is one for all executive-firm-years where the CEO is not also the chairperson based on Execucomp data. t-statistics, using standard errors clustered by firm, are shown in parentheses. *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

	(1) Option Awards	(2) Option Awards
Direct Stopped	0.027	
	(0.46)	
Dir. Stop, CEO Only	0.203***	
	(2.67)	
Direct Started		0.019
		(0.39)
Dir. Start, CEO Only		-0.091
		(-1.40)
CEO Only	0.040	0.066*
	(1.20)	(1.95)
Controls	Yes	Yes
Year FE	No	No
Industry × Year FE	Yes	Yes
State × Year FE	Yes	Yes
Executive × Firm FE	Yes	Yes
Observations	68,328	68,328

In both instances, we find that the impact of a director's direct flight being stopped is positive and significant at the 1% level, with effect sizes comparable to our full sample outcome. Furthermore, we find that the difference in effect in firm years where the CEO is not also the chairman is more substantial at the 5% level of statistical significance.

Enhanced Geographical Fixed Effects. One possible concern is the existence of highly localized compensation patterns at a finer geographical scale than the state. To address this issue, we revisit our fundamental specification using MSA-year fixed effects instead of state-year fixed effects.[7] Additionally, it is plausible that these tendencies could be industry-specific within a region. To assess whether highly localized industry-specific trends also affect our findings, we investigate the combination of industry, Metropolitan Statistical Area (MSA), and year fixed effects.

Table OA.7 columns (1) and (2) estimate equation (18) with direct flight stopped and started variables, integrating finer MSA-year fixed effects in place of state-year fixed effects. We observe that the effect magnitude and statistical significance of the direct flight stopped variable are in line with our baseline results. In fact, the estimated impact of the direct-flight-stopped variable with MSA-year fixed effects is slightly larger than our baseline estimate. As such, our findings are not determined by MSA-specific temporal trends.

Columns (3) and (4) of Table (OA.7) estimate equation (18) with direct flight stopped and started variables, employing combined industry-MSA-year fixed effects as opposed to distinct industry-year and state-year (or MSA-year) fixed effects. We discover that the effect magnitude and the statistical significance of the direct flight stopped variable consistent with our baseline finding. Furthermore, the estimated influence of the direct-flight-stopped variable with MSA-year fixed effects is substantially greater than our primary estimates. Hence, our results are not a product of joint industry-MSA-specific temporal trends.

Compensation Prior to Direct Flight Change. We address potential concerns regarding director selection effects. For instance, directors residing in regions with fluctuating direct flight access might also happen to support increased option compensation. To examine if this effect is present, we generate four variables representing executive-firm-years with

[7] Not all firms are located in an MSA; therefore, we also include Micropolitan Statistical Areas (μSA) for firms situated in such areas and not an MSA.

a director on the board who will lose direct flight access within three, five, eight, or ten years, capturing the effects of such directors before the change takes place. Our analysis in Appendix Table OA.8 unveils no evidence of increased option compensation before the treatment at the three-, five-, eight-, or ten-year time horizon. These findings indicate that our primary results are not influenced by director selection effects preceding the change in direct flight access.

Additional Selection Effects. We also address concerns regarding other selection effects that may influence our findings. By construction, certain selection effects may arise; for example, firms affected by changes in direct flight availability must have non-local directors, implying that they must be able to attract and compensate such directors, which is more achievable for larger firms. Although selection effects may influence our results, we suggest they are not a significant concern. Executive-firm pair fixed effects should capture all firm and individual-specific characteristics that do not vary over time. State-year fixed effects account for regional economic productivity fluctuations, while industry-year fixed effects should absorb industry-specific propensities for remote directors. We conduct linear regressions to investigate potential selection effects with distinct firm-year characteristics as dependent variables, retaining other controls. We use the executive years in our sample, where we have data on option compensation; this comprises executives who never receive option compensation, resulting in a larger sample. Appendix Table OA.9 displays the results which provide no evidence of selection on other firm-year characteristics in these executive-years. These outcomes are similar to a placebo test for our dependent variable concerning alternative consequences. They constitute a precise placebo test for the linear regressions we examine below. Moreover, we perform two robustness checks based on Bertrand and Mullainathan (2003) in Appendix Table OA.10. We identify all firms that ever experienced a director having a direct flight stopped or started and label these as ever-stopped and ever-started firms, respectively. First, we estimate (20) incorporating a set of cohort-year fixed effects exclusively for the ever-stopped or started cohort to correspond with the primary independent variable. We observe similar effect sizes and statistical significance, even after accounting for different time trends for affected and unaffected firms. Second, we estimate (20) restricting our sample to the ever-stopped or ever-started cohorts depending on the primary independent variable. Despite diminishing the sample size to approximately 20%, our estimated coefficients remain statistically significant, and the effect size is substantially larger than in the full sample. In conclusion, there is no evidence of firm selection conditional on observables, and our findings are robust to numerous additional robustness checks.

Flight Change as a Disruption. One may also consider a director losing access to a direct flight as a disruption to the board's signal quality, regardless of whether the affected director leaves the board. If the director stays, the director does less monitoring in person. If the director leaves the board, those responsibilities must be redelegated to other directors. Alternatively, a new director, unfamiliar with company and board specifics, must be hired. When responsibilities fall on fewer people or new people, it is reasonable to think that monitoring quality would decline. Thus, we should expect to see an effect over a short time horizon after a director loses access to a direct flight, regardless of whether that director remains on the board. We construct two new independent variables to test this effect, "Direct Stopped/Started (Any), $0 \leq t < T$" is equal to one if any director at the firm, who may or may not still be on the board, lost/gained access to a direct flight for the firm headquarters in the last T years where T is either one or two. Table OA.11 estimates specification (18) with these alternate key dependent variables instead of our baseline "Direct Stopped/Started" variables. In column (1), we find that when any board director has lost access to a direct flight in the current year or year prior, option compensation is typically 9.4% higher, statistically significant at the 5% level. In column (3), we find that when any board director has lost access to a direct flight within the last two years, option compensation is typically 11.1% higher, statistically significant at the 1% level. We find very small and insignificant estimates for the variables examining when a board director gains access to a direct flight for both time horizons in columns (2) and (4).

Normalization by Salary. We explore an alternative normalization of option awards: option awards divided by salary. (Cohn et al., 2022) proposes that rate regressions, where a measure of exposure normalizes the dependent variable, present another valid alternative to log regressions. We introduce division by salary as an alternative normalization method. The fixed effect absorbs the baseline ratio of options to salary.

Consequently, our results focus on changes in option compensation as a percentage of salary size. While not necessarily an ideal normalization scheme, salary is a good scale because it is a key, stock price invariant (over shorter time horizons) component of income. Appendix Table OA.12 employs this alternative dependent variable. Columns (1) and (2) replicate columns (1) and (2) of Table 5 using linear regression with the alternative dependent variable of option awards divided by salary. We find that when firms have a director who loses access to a direct flight, the value of options awarded to executives increases by 15.4% of salary if the CEO is not also the chairperson, which is statistically significant at the 1% level. To address the concern that time variation in salary may influence our outcomes, we compute the median salary for each executive-firm pair over time and utilize this time-invariant normalization of option awards. Columns (3) and (4) of Appendix Table OA.12 replicate columns (3) and (4) of Table 5 using the alternative dependent variable of option awards divided by the median salary, producing consistent results. The estimated effect of a direct flight being stopped when the CEO is not the chairman is similar and statistically significant at the 5% level. These outcomes eliminate the concern that time variation in salary drives our findings, as the divisor is fixed in these regressions.

Logarithm plus One. Given that the option compensation data is sparse, with around half of the observations in our executive sample having a positive value, we cannot use traditional linear regression with the log of option awards as our main dependent variable. When using linear regression, a common alternative to log regression is a log plus one transformation where one is added to the key dependent variable before the logarithm is taken. Cohn et al. (2022) highlight potential issues with this approach. To demonstrate the robustness of our findings, we also present results using log plus one regression in Appendix Table OA.13. In column (1), we replicate column (1) of Table 3 using linear regression and log options awards plus one as the dependent variable; we estimate a coefficient of .157 on the Direct Stopped variable, statistically significant at the 10% level. If interpreted as a semi-elasticity, this would suggest a 15.7% increase in option compensation when a director loses access to a direct flight, consistent with our results from Poisson regression. In column (3), we replicate column (1) of Table 5. When interpreting the result as a semi-elasticity, we estimate a 25% increase in option compensation when a director has their direct flight to the firm stopped, statistically significant at the 5% level ($p = .024$). Columns (2) and (4) examine analogous linear regression results to columns (1) and (3), respectively, for the direct started variable and find insignificant results.

Option Compensation Usage. We investigate an alternative measure of option compensation, option usage, defined as whether or not an executive receives any option awards. We leverage a conditional logit specification conditioning on the executive-firm pair using year fixed effects. Due to the nature of this specification, we can only use data on executives with variation in whether they receive options across years, which significantly reduces the sample size. Appendix Table OA.14 replicates columns (1) and (2) of Table 3 using the conditional logit specification. In column (1), we find that a direct flight being stopped between the firm and a director increases the odds of an executive receiving option compensation by 25%, statistically significant at the 10% level. In columns (3) and (4), we replicate columns (1) and (2) of Table 5. When focusing on cases where a direct flight is stopped, and the CEO is not the chairperson, we observe a 47% increase in the odds of option compensation usage, statistically significant at the 5% level ($p = 0.028$). Moreover, we cannot reject the null of no effect of a direct flight being stopped when the CEO is also the chairperson. Therefore, our results demonstrate increased option compensation in magnitude using linear regression with two dependent variables and increased option award usage employing a conditional logit model, emphasizing the robustness of our findings. Further description of the analyses is included in appendix subsection OA.C.1, and the robustness tables can be found in appendix subsection OA.C.2.

5 Conclusion

Monitoring and pay-for-performance are substitutes. Our model provides a simple depiction of their substitutability for motivating an agent. The model predicts that promised pay-for-performance rises following positive monitoring signals, and the sensitivity of future compensation to monitoring simultaneously falls. Symmetrically, that sensitivity rises and promised pay-for-performance falls following negative signals.

Relying on noisy monitoring to provide incentives creates volatility in the agent's continuation utility, which the principal dislikes. This effect is stronger when monitoring is noisier. Consequently, it is optimal to provide higher average pay-for-performance and to rely less on monitoring when monitoring is noisier. In our model, this effect of monitoring precision on pay-for-performance is stronger when negative signals accumulate. We find empirical support both for the linkage between monitoring efficiency and pay-for-performance that our model predicts and for the dependence of the linkage on prior evidence that our model predicts.

Our empirical analysis supports our model predictions, demonstrating that when a director loses access to a direct flight to the firm's headquarters, option-based compensation for executives increases, particularly in poorly performing firms. Furthermore, our findings are robust to various specifications and are not due to director selection effects. Our findings reinforce the critical role of monitoring in shaping executive compensation.

Appendix

A A Model of Optimal Monitoring Precision

Results in Section 2 show that when negative (positive) monitoring signals accumulate, conditioning pay-for-performance on monitoring signals is stronger (weaker); hence monitoring is more (less) important in the optimal contract. This suggests that the principal might prefer a precise signal and close monitoring when negative evidence accumulates and a less precise signal and loose monitoring when signals have been positive. We confirm this intuition by considering an extension of our basic model in which the principal can choose the precision of the signal. We show that when negative (positive) evidence about the agent's effort accumulates, the principal increases (decreases) the signal precision so that monitoring intensifies (abates).

We assume that the principal can decide how closely to monitor the agent by choosing the signal volatility σ at each time from a range $[\sigma_{min}, \sigma_{max}]$. We assume that monitoring introduces a flow cost to the principal

$$c(\sigma) = \frac{M}{\sigma^2} \tag{A.1}$$

with a positive constant M, so the cost of monitoring is proportional to the precision of the signal $1/\sigma^2$.

In this case, the principal's value satisfies the HJB equation

$$0 = \min \Big\{ 1 + V', \\ (r+\bar{a})V - \sup_{R,\varphi,\sigma} \Big\{ \pi \bar{a}^2 (\Delta - R) - \frac{M}{\sigma^2} + \big((\rho + \bar{a})U - \pi \bar{a}^2 R\big) V' + \frac{1}{2}\sigma^2 \varphi^2 V'' \Big\} \Big\}, \tag{A.2}$$

subject to $\pi \bar{a} R + \varphi \geq \lambda + U$, $R \geq 0$, $\sigma \in [\sigma_{\min}, \sigma_{\max}]$, and boundary condition $V(\underline{U}) = L$. Compared with (10), the information cost is deducted from the principal's expected payoff.

The following result summarizes the principal's optimal signal choice, together with the optimal contract.

Proposition 4. *Suppose that the principal can choose the signal volatility $\sigma \in [\sigma_{min}, \sigma_{max}]$, with $0 < \sigma_{min} < \sigma_{max}$, subject to monitoring cost in (A.1). Assume that (A.2) admits a solution and $\overline{U}$ is finite, moreover, V is smooth and satisfies a transversality, as described in Appendix B. Then all statements in Proposition 2 hold. In a neighborhood of $\overline{U}$, $\sigma^* = \sigma_{max}$. Moreover, when $R^* > 0$, the optimal signal precision is*

$$\sigma^* = \begin{cases} \sigma_{min}, & -\frac{\bar{a}^2(1+V')^2}{2V''} > M \\ \sigma_{max}, & -\frac{\bar{a}^2(1+V')^2}{2V''} \leq M \end{cases}. \tag{A.3}$$

When the principal can choose the signal precision, Proposition 4 shows that the principal always chooses the lowest signal precision in a neighborhood of $\overline{U}$. Moreover, monotonicity of the success reward and the contract sensitivity in monitoring also hold in this neighborhood.

To understand the optimal signal precision choice, we plug the interior optimal $R^* = \frac{1}{\pi\bar{a}}\left(\lambda + U + \frac{\bar{a}}{\sigma^2} \cdot \frac{1+V'}{V''}\right)$ into the right-hand side of (A.2) to obtain the following optimization in σ:

$$\max_{\sigma \in [\sigma_{\min}, \sigma_{\max}]} \left(-\frac{\bar{a}^2(1+V')^2}{2V''} - M\right)\frac{1}{\sigma^2}.$$

Because $V'' < 0$, the term $-\frac{\bar{a}^2(1+V')^2}{2V''}$ is positive, and we interpret it as the marginal benefit of signal precision. When the marginal benefit is larger than the marginal cost, M, the principal chooses the low signal volatility (highest signal precision) with $\sigma^* = \sigma_{\min}$; otherwise, the principal chooses the highest signal volatility (lowest precision) with $\sigma^* = \sigma_{\max}$. When R^* is binding at 0, the optimal σ^* could be interior.

Solving the HJB equation (A.2) together with the boundary condition $V(\underline{U}) = L$ numerically, we present the optimal contract and the optimal signal precision choice in Figure A-9. Panel (c) shows that the marginal benefit of the signal (green curve) crosses the marginal cost, M, at a threshold U^*. When $U < U^*$, the principal chooses the lowest volatility $\sigma_{\min}$; when $U > U^*$, the principal chooses the highest volatility $\sigma_{\max}$. Panel (a) presents the sensitivity of pay-for-performance to signal and the level of reward. When U reaches the threshold U^*, φ^* jumps down and R^* jumps up. When U exceeds U^*, φ^* decreases and R^* increases in U. As U approaches $\overline{U}$, φ^* vanishes and R^* converges to $(\lambda + \overline{U})/(\pi\bar{a})$. When $U < U^*$, there can be nonmonotonicity behavior. The reason is the following. When U reaches the threshold U^*, the principal optimally chooses the lowest signal precision, which reduces the cost of monitoring and improves the principal's welfare. When U is away from the termination boundary but approaches the threshold U^*, the principal reduces R^* so that the mean reverting speed of the agent's continuation utility increases (the drift of the agent's continuation utility increases), hence U reaches U^* faster and the principal benefits from a reduction in monitoring costs earlier. Panel (b) shows the distribution of value. Compared to Figure 1, the principal's value is smaller due to the monitoring cost which is included in the deadweight loss.

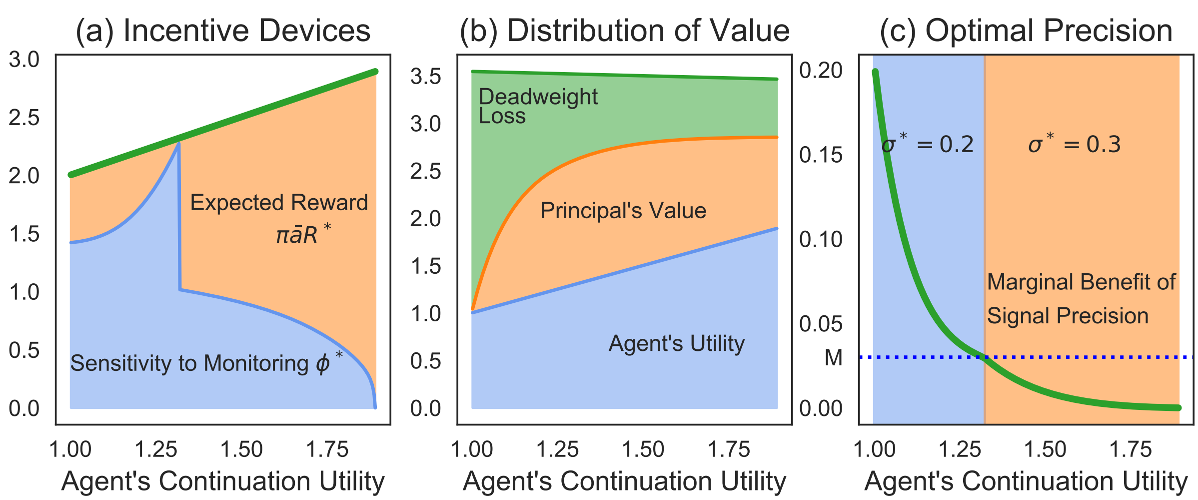


Figure A-9. **The Optimal Contract with Optimal Signal Precision**

Some features of the optimal contract are shown when $\rho = 0.1$, $r = 0.05$, $\sigma_{\min} = 0.2$, $\sigma_{\max} = 0.3$, $M = 0.03$, $\bar{a} = 0.5$, $\lambda = 1$, $\Delta = 8$, $\pi = 1$, $\underline{U} = 1$, and $L = 0$.

B Proofs

Following Sannikov (2008), we will work with the weak formulation throughout the proof. We consider a probability space $(\Omega, (\mathcal{F}_t)_{t\geq 0}, \mathbb{P})$ where the filtration $(\mathcal{F}_t)_{t\geq 0}$ is the completed natural filtration generated by a 1-dimensional Brownian motion B^0. For a given non-degenerated volatility process σ, the signal process Y evolves as

$$\mathrm{d}Y_t = \sigma_t \mathrm{d}B_t^0.$$

For a given agent's effort a, define a probability measure $\mathbb{P}^a$ via $\mathrm{d}\mathbb{P}^a/\mathrm{d}\mathbb{P}|_{\mathcal{F}_t} = \exp\big(-\int_0^t \frac{a_s^2}{2\sigma_s^2}\mathrm{d}s + \int_0^t \frac{a_s}{\sigma_s}\mathrm{d}B_s^0\big)$. Then $B_t^a = B_t^0 - \int_0^t \frac{a_s}{\sigma_s}\mathrm{d}s$ is a $\mathbb{P}^a$-Brownian motion and the signal process Y evolves as

$$\mathrm{d}Y_t = a_t \mathrm{d}t + \sigma_t \mathrm{d}B_t^a.$$

Expectations in (3) and (4) are taken with respect to $\mathbb{P}^a$.

Proposition 1 is proved below. In this proof, we consider the possibility that the principal pays the agent a severance pay R^f if the project fails. We show that the expected payoff at the project completion incentivizes the agent rather than the success reward or severance pay individually.

Proof of Proposition 1

We first use the following identities to transform the agent's objective in (5):

$$\mathbb{P}^a\big(\nu > s | \nu > t\big) = e^{-\int_t^s a_u \mathrm{d}u} \quad \text{and} \quad \mathbb{P}^a\big(\nu \in [s, s+ds) | \nu > t\big) = a_s \mathrm{d}s\, e^{-\int_t^s a_u \mathrm{d}u}. \tag{B.1}$$

The latter identity holds because the conditional probability $\mathbb{P}^a(\nu \in [s, s+ds)|\nu > t)$ is the product of the survival probability $\mathbb{P}^a(\nu > s|\nu > t) = e^{-\int_t^s a_u \mathrm{d}s}$ and the probability $\mathbb{P}^a(\nu \in [s, s+ds)|\nu > s) = a_s \mathrm{d}s$. (See Jacod (1975) for a rigorous treatment.) Utilizing the two identities in (B.1), the agent's objective function in (5) is transformed to

$$\begin{aligned}
&\mathbb{E}_t^a\Big[\int_t^\tau \mathbb{I}_{\{\nu>s\}}e^{-\rho(s-t)}\Big(\mathrm{d}C_s+\lambda(\bar{a}-a_s)\mathrm{d}s\Big)\\
&+\int_t^\tau \mathbb{I}_{\{\nu\in[s,s+ds)\}}e^{-\rho(s-t)}U_s^c\,\mathrm{d}s+\mathbb{I}_{\{\tau<\nu\}}e^{-\rho(\tau-t)}\underline{U}\Big]\\
&=\mathbb{E}_t^a\Big[\int_t^\tau e^{-\int_t^s a_u\mathrm{d}u}e^{-\rho(s-t)}\Big(\mathrm{d}C_s+\lambda(\bar{a}-a_s)\mathrm{d}s+a_sU_s^c\,\mathrm{d}s\Big)+e^{-\int_t^\tau a_u\mathrm{d}u}e^{-\rho(\tau-t)}\underline{U}\Big],
\end{aligned} \tag{B.2}$$

where $U_s^c=\pi a_sR_s+(1-\pi a_s)R^f$ is the expected payoff if the project is completed at time s. We consider the contracts with $R>R^f$ so that the agent does not strategically explore project failure, which is not in the best interest for principal.

For any agent's effort a, define its associated value U_t^a as the right-hand side of (B.2). Given that the agent's utility is finite, U_t^a is finite and $e^{-\int_0^t a_u\mathrm{d}u}e^{-\rho t}U_t^a+\int_0^t e^{-\int_0^s a_u\mathrm{d}u}e^{-\rho s}\big(\mathrm{d}C_s+\lambda(\bar{a}-a_s)\mathrm{d}s+a_sU_s^c\mathrm{d}s\big)$ is a $\mathbb{P}^a$-martingale until τ. The martingale representation theorem implies the existence of φ^a such that U^a follows the dynamics

$$\begin{aligned}
\mathrm{d}U_t^a=&(\rho+a_t)U_t^a\mathrm{d}t-\lambda(\bar{a}-a_t)\mathrm{d}t-a_tU_t^c\mathrm{d}t+\varphi^a\sigma\mathrm{d}B_t^a-\mathrm{d}C_t\\
=&\rho U_t^a\mathrm{d}t+\Big\{a_tU_t^a-\lambda(\bar{a}-a_t)-\pi a_t^2\big(R_t-R^f\big)-a_tR^f-\varphi_t^aa_t\Big\}\mathrm{d}t+\varphi_t^a\mathrm{d}Y_t-\mathrm{d}C_t,
\end{aligned}$$

with the terminal condition $U_\tau^a=\underline{U}+C_\tau-C_{\tau-}$. Equations (5) and (B.2) combined yield $U_t=\sup_a U_t^a$. It then follows from the comparison theorem for BSDEs (cf. El Karoui et al. (1997)) that U follows the dynamics

$$\begin{aligned}
\mathrm{d}U_t=&\rho U_t\mathrm{d}t-\sup_{a_t\in[0,\bar{a}]}\Big\{-a_tU_t+\lambda(\bar{a}-a_t)+\pi a_t^2\big(R_t-R^f\big)+a_tR^f+\varphi_ta_t\Big\}\mathrm{d}t\\
&+\varphi_t\mathrm{d}Y_t-\mathrm{d}C_t,
\end{aligned} \tag{B.3}$$

for some process φ.

These dynamics ensure that

$$\widetilde{U}_t=e^{-\int_0^t a_u\mathrm{d}u}e^{-\rho t}U_t+\int_0^t e^{-\int_0^s a_u\mathrm{d}u}e^{-\rho s}\big(\mathrm{d}C_s+\lambda(\bar{a}-a_s)\mathrm{d}s+a_sU_s^c\mathrm{d}s\big)$$

satisfies the martingale principle: $\widetilde{U}$ is a $\mathbb{P}^a$-supermartingale for arbitrary a and is a $\mathbb{P}^{a^*}$-martingale for the optimal a^*. Because $R>R^f$, the objective function of the maximization problem on the right-hand side of (B.3) is convex. Therefore the maximizer can only be achieved at $a = 0$ or $a = \bar{a}$. Comparing the values of these two actions, we obtain the optimal a^* as

$$a_t^* = \begin{cases} \bar{a}, & U_t^c + \varphi_t \geq \lambda + U_t, \\ 0, & \text{otherwise.} \end{cases}$$

This implies that the agent's optimal effort is incentivized by the expected reward U^c, rather than R and R^f individually.

To verify the optimality of a^*, observe that (B.3) implies $\mathrm{d}U_t \leq \big(\rho U_t + a_t U_t - \lambda(\bar{a} - a_t) - a_t U_t^c - \varphi_t a_t\big)\mathrm{d}t + \varphi_t \mathrm{d}Y_t - \mathrm{d}C_t$ for arbitrary a, and the inequality becomes an equality for a^*. Hence $\widetilde{U}_t$ is a $\mathbb{P}^a$-(local) supermartingale and a $\mathbb{P}^{a^*}$-(local) martingale when a is replaced by a^*. As a result, for a localization sequence $\{\xi_n\}_n$ with $\lim_{n\to\infty} \xi_n = \infty$ a.s., we obtain

$$\begin{aligned} U_t \geq \mathbb{E}_t^a\Big[\int_t^{\tau\wedge\xi_n} & e^{-\int_t^s a_u \mathrm{d}u} e^{-\rho(s-t)} \Big(\mathrm{d}C_s + \lambda(\bar{a} - a_s)\mathrm{d}s + a_s U_s^c \mathrm{d}s\Big) \\ & + e^{-\int_t^{\tau\wedge\xi_n} a_u \mathrm{d}u} e^{-\rho(\tau\wedge\xi_n - t)} U_{\tau\wedge\xi_n}\Big]. \end{aligned} \tag{B.4}$$

Sending $n \to \infty$, as the hitting time of U at the level $\underline{U}$, $\tau < \infty$ a.s. (due to the positive volatility of U). Then the last term on the right-hand side of (B.4) converges to $\mathbb{E}_t^a\big[e^{-\int_t^\tau a_u du} e^{-\rho(\tau-t)}\underline{U}\big]$. Therefore U_t is at least the agent's expected value when the agent exerts effort a. The inequality in (B.4) becomes an equality when a is replaced by a^*. This confirms the optimality of a^*. □

Due to the risk neutrality of the principal, the principal's value depends on the expected cash compensation $pR + (1-p)R^f$ at completion rather than R and R^f individually. Therefore, because both the agent's continuation utility and the principal's value depend on the expected reward rather than cash compensation in different states, we set $R^f = 0$ and (B.3) is reduced to (6).

Proof of Propositions 2 and 4

Propositions 2 and 4 invoke a smoothness condition on V. The specific assumption we make is that V is continuously differentiable on $(\underline{U}, \infty)$ and three times continuous differentiable except at $\overline{U}$. The transversality condition invoked in Propositions 2 and 4 is that $\lim_{n\to\infty} \mathbb{E}\left[e^{-(r+\bar{a})\xi_n} V(U_{\xi_n})\right] = 0$ for any sequence of stopping times $\{\xi_n\}$ with $\lim_{n\to\infty} \xi_n = \infty$.

We will prove the statements for Proposition 4. Proposition 2 is a special case with $M = 0$ and $\sigma_{\min} = \sigma_{\max} = \sigma$.

Equation (A.2). We now derive the differential equation that V satisfies. Consider the compensation $\mathrm{d}C_t = c_t \mathrm{d}t$ for some nonnegative and potentially unbounded c_t. Take the agent's continuation utility U in (8) as the state variable for the principal's problem. It follows from the dynamic programming that V satisfies the following Hamilton-Jacobi-Bellman (HJB) equation:

$$(r+\bar{a})V = \sup_{R,\varphi,\sigma,c} \left\{ \pi\bar{a}^2(\Delta - R) - \frac{M}{\sigma^2} + \big((\rho+\bar{a})U - \pi\bar{a}^2 R\big)V' + \frac{1}{2}\sigma^2\varphi^2 V'' - (1+V')c \right\}, \tag{B.5}$$

where $\pi\bar{a}R + \varphi \geq \lambda + U$, $R \geq 0$, and $\sigma \in [\sigma_{\min}, \sigma_{\max}]$. On the left-hand side of (B.5), $r + \bar{a}$ is the principal's effective discount rate. On the right-hand side, $\pi\bar{a}^2(\Delta - R)$ is the expected net payoff in $\mathrm{d}t$ time, $\big((\rho+\bar{a})U - \pi\bar{a}^2 R\big)V'$ is the marginal change in the principal's value due to changes in agent's continuation utility before compensation, and $\frac{1}{2}\sigma^2\varphi^2 V''$ represents the cost to the principal due to the variance of agent's continuation utility. The term $-(1+V')c$ measures the net value of flow compensation, and it is linear in c. Because c can be unbounded, in order for the right-hand side of (B.5) to have a finite value, it is necessary for $1 + V' \geq 0$. Consider $-V'$ to be the marginal benefit of paying the agent. Whenever $1 > -V'$, the marginal cost of paying the agent is larger than the marginal benefit, and the principal defers the payment by choosing $c = 0$.

Concavity of V. The term with φ is $\frac{1}{2}\sigma^2\varphi^2 V''$ on the right-hand side of (A.2). Because φ can be unbounded, V'' must be nonpositive, otherwise by choosing an infinite φ the right-hand side of (A.2) is negative infinite, which contradicts with (A.2).

We now show the strict concavity of V when $U < \overline{U}$. Due to $1 + V' > 0$, $V'' \leq 0$, and $R \geq 0$, we have from (A.2) that

$$(r+\bar{a})V(U) \leq \sup_{\sigma} \left\{ \pi\bar{a}^2\Delta - \frac{M}{\sigma^2} + (\rho+\bar{a})UV' \right\} = \pi\bar{a}^2\Delta - \frac{M}{\sigma^2_{\max}} + (\rho+\bar{a})UV'.$$

Sending $U \to \overline{U}$ and using $V'(\overline{U}) = -1$, we have from the previous inequality that

$$(r+\bar{a})V(\overline{U}) \le \pi\bar{a}^2\Delta - \frac{M}{\sigma_{\max}^2} - (\rho+\bar{a})\overline{U}. \tag{B.6}$$

Starting from $\overline{U}$ and moving to the left, it is necessary that $V(U) < \frac{1}{r+\bar{a}}\big(\pi\bar{a}^2\Delta - \frac{M}{\sigma_{\max}^2} - (\rho+\bar{a})U\big)$ for U in a left neighborhood of $\overline{U}$. Otherwise, there exists a sequence of points $U_n \to \overline{U}$ such that $V(U_n) \ge \frac{1}{r+\bar{a}}\big(\pi\bar{a}^2\Delta - \frac{M}{\sigma_{\max}^2} - (\rho+\bar{a})U_n\big)$. This would yield $V'(\overline{U}) \le -\frac{\rho+\bar{a}}{r+\bar{a}} < -1$ because $\rho > r$ and contradicts with $V'(\overline{U}) = -1$. If $V(U) < \frac{1}{r+\bar{a}}\big(\pi\bar{a}^2\Delta - \frac{M}{\sigma_{\max}^2} - (\rho+\bar{a})U\big)$ for U in a left neighborhood of $\overline{U}$, then $V'' < 0$ in the same neighborhood. To see this, suppose otherwise there is a U such that $V''(U) = 0$, then (A.2) is reduced to

$$\begin{aligned}(r+\bar{a})V =& \sup_{R,\sigma}\Big\{\pi\bar{a}^2(\Delta - R) - \frac{M}{\sigma^2} + \big((\rho+\bar{a})U - \pi\bar{a}^2R\big)V'\Big\}\\ =&\pi\bar{a}^2\Delta - \frac{M}{\sigma_{\max}^2} + (\rho+\bar{a})UV'\\ \ge&\pi\bar{a}^2\Delta - \frac{M}{\sigma_{\max}^2} - (\rho+\bar{a})U,\end{aligned}$$

where the second equality follows because $1 + V' \ge 0$, hence R maximizing $-\pi\bar{a}^2R(1+V')$ is zero, the inequality holds due to $V' \ge -1$. By choosing $\varphi = \lambda + U$, agent's incentive compactibility constraint is still satisfied. However, the inequality above contradicts with $V(U) < \frac{1}{r+\bar{a}}\big(\pi\bar{a}^2\Delta - \frac{M}{\sigma_{\max}^2} - (\rho+\bar{a})U\big)$. Once the concave function V is below the line $V(U) = \frac{1}{r+\bar{a}}\big(\pi\bar{a}^2\Delta - \frac{M}{\sigma_{\max}^2} - (\rho+\bar{a})U\big)$, it can never go above this line. We have just seen that V below this line implies the strict concavity of V, hence V is strictly concave on $(\underline{U}, \overline{U})$.

In the case of Proposition 2, we can further show $\overline{U} > \underline{U}$. Assume otherwise, then $V'(\underline{U}) = -1$. We obtain from (10) that

$$(r+\bar{a})V(\underline{U}) \ge \sup_{\varphi}\Big\{\pi\bar{a}^2\Delta - (\rho+\bar{a})\underline{U} + \frac{1}{2}\sigma^2\varphi^2V''\Big\}.$$

Choosing $\varphi = 0$ in the previous inequality, we obtain $(r+\bar{a})V(\underline{U}) + (\rho+\bar{a})\underline{U} \ge \pi\bar{a}^2\Delta$, contradicting with Assumption 1.

Optimal R^*, φ^*, and σ^*. The concavity of V implies that the optimal φ is $\lambda + U - \pi\bar{a}R^*$. When $U < \overline{U}$, the equation (A.2) is then reduced to

$$(r+\bar{a})V = \sup_{R,\sigma}\Big\{\pi\bar{a}^2(\Delta - R) - \frac{M}{\sigma^2} + \big((\rho+\bar{a})U - \pi\bar{a}^2R\big)V' + \frac{1}{2}\sigma^2(\lambda + U - \pi\bar{a}R)^2V''\Big\}. \tag{B.7}$$

For given σ, the first order condition in R yields

$$R^* = \max\Big\{\frac{1}{\pi\bar{a}}\Big(\lambda + U + \frac{\bar{a}}{\sigma^2}\frac{1+V'}{V''}\Big), 0\Big\}.$$

Because $1 + V' > 0$ and $V'' < 0$ when $U < \overline{U}$, the previous expression of R with $\sigma = \sigma^*$ implies that $\pi\bar{a}R^* < \lambda + U$, hence $\varphi^* > 0$.

When the optimal R^* is interior optimal, i.e., $R^* = \frac{1}{\pi\bar{a}}\big(\lambda + U + \frac{\bar{a}}{(\sigma^*)^2}\frac{1+V'}{V''}\big)$, plugging this expression into (A.2), we obtain

$$(r+\bar{a})V = \sup_{\sigma\in[\sigma_{\min},\sigma_{\max}]}\Big\{\pi\bar{a}^2\Delta - \bar{a}(\lambda+U) + V'(\rho U - \bar{a}\lambda) - \Big(\frac{\bar{a}^2(1+V')^2}{2V''} + M\Big)\frac{1}{\sigma^2}\Big\}. \tag{B.8}$$

Note that the optimization in $1/\sigma^2$ is linear. Therefore the optimal σ^* in (A.3) is confirmed.

Limits of R^* and φ^* as $U \to \overline{U}$. We will first prove by contradiction that R^* cannot be zero in a neighborhood of $\overline{U}$. Suppose otherwise, then equation (B.7) is simplified to

$$(r+\bar{a})V = \sup_{\sigma}\Big\{\pi\bar{a}^2\Delta - \frac{M}{\sigma^2} + (\rho+\bar{a})UV' + \frac{1}{2}\sigma^2(\lambda+U)^2V''\Big\}, \tag{B.9}$$

when U is in a neighborhood of $\overline{U}$. Moreover, because the constraint $R \geq 0$ is binding, (12) implies that

$$\frac{\bar{a}}{(\sigma^*)^2}\frac{1+V'}{V''} \leq -\lambda - U < 0$$

in this neighborhood of $\overline{U}$. Send $U \to \overline{U}$, because $V'(\overline{U}) = -1$, in order to have $\frac{\bar{a}}{(\sigma^*)^2}\frac{1+V'(\overline{U})}{V''(\overline{U})}$ to be bounded away from zero, it is necessary that $V''(\overline{U}) = 0$. As a result, $V''(U)$ is close to zero and $-\frac{M}{\sigma^2} + \frac{1}{2}\sigma^2(\lambda+U)^2V''$ is increasing in σ when $\sigma \in [\sigma_{\min}, \sigma_{\max}]$ with $\sigma_{\min} > 0$ and U is sufficiently close to $\overline{U}$. It then follows that $\sigma^* = \sigma_{\max}$ in a neighborhood of $\overline{U}$.

Taking the derivative with respect to U on both sides of (B.9) with $\sigma^* = \sigma_{\max}$ and when U is close to $\overline{U}$, we obtain

$$(r+\bar{a})V' = (\rho+\bar{a})V' + (\rho+\bar{a})UV'' + \sigma_{\max}^2(\lambda+U)V'' + \frac{1}{2}\sigma_{\max}^2(\lambda+U)^2V'''.$$

The previous equation and the fact that $V'(\overline{U}) = -1$ and $V''(\overline{U}) = 0$ imply that

$$\rho - r = \frac{1}{2}\sigma_{\max}^2(\lambda+\overline{U})^2V'''(\overline{U}).$$

Therefore, due to $r < \rho$, $V'''(\overline{U})$ is positive and finite. It then follows from L'Hôpital rule and $V''(\overline{U}) = 0$ that

$$\lim_{U\to\overline{U}}\frac{1+V'}{V''} = \lim_{U\to\overline{U}}\frac{V''}{V'''} = 0.$$

As a result, (12) implies that $\lim_{U\to\overline{U}} R^* = (\lambda+\overline{U})/(\pi\bar{a})$, which contracts with the assumption that R^* is zero in a neighborhood of $\overline{U}$.

Given that the constraint $R \geq 0$ is not binding in a neighborhood of $\overline{U}$, then

$$R^* = \frac{1}{\pi\bar{a}}\Big(\lambda + U + \frac{\bar{a}}{(\sigma^*)^2}\frac{1+V'}{V''}\Big) \quad \text{and} \quad \varphi^* = -\frac{\bar{a}}{(\sigma^*)^2}\frac{1+V'}{V''}, \tag{B.10}$$

in this neighborhood. Moreover, (B.8) holds in the same neighborhood. Because $V'' \leq 0$, $-\frac{\bar{a}^2}{\sigma^2}\frac{(1+V')^2}{2V''} \geq 0$, we then have from (B.8) that

$$\begin{aligned}(r+\bar{a})V \geq & \sup_{\sigma\in[\sigma_{\min},\sigma_{\max}]}\left\{\pi\bar{a}^2\Delta - \bar{a}(\lambda+U) + V'(\rho U - \bar{a}\lambda) - \frac{M}{\sigma^2}\right\} \\ = & \pi\bar{a}^2\Delta - \bar{a}(\lambda+U) + V'(\rho U - \bar{a}\lambda) - \frac{M}{\sigma_{\max}^2}.\end{aligned}$$

Sending $U \to \overline{U}$ and using $V'(\overline{U}) = -1$, the previous inequality implies

$$(r+\bar{a})V(\overline{U}) \geq \pi\bar{a}^2\Delta - (\rho+\bar{a})\overline{U} - \frac{M}{\sigma_{\max}^2}.$$

Comparing the previous inequality with (B.6), we must have

$$(r+\bar{a})V(\overline{U}) = \pi\bar{a}^2\Delta - (\rho+\bar{a})\overline{U} - \frac{M}{\sigma_{\max}^2}, \tag{B.11}$$

$$0 = \lim_{U\to\overline{U}} \frac{(1+V')^2}{V''}. \tag{B.12}$$

Combining (B.8) and (B.12), we conclude $\sigma^* = \sigma_{\max}$ in a neighborhood of $\overline{U}$. Therefore (B.8) becomes

$$(r+\bar{a})V = \pi\bar{a}^2\Delta - \frac{M}{\sigma_{\max}^2} - \bar{a}(\lambda+U) + (\rho U - \bar{a}\lambda)V' - \frac{\bar{a}^2}{2\sigma_{\max}^2}\frac{(1+V')^2}{V''} \tag{B.13}$$

in this neighborhood. Taking the derivative with respect to U on both sides of (B.13), we obtain

$$(r+\bar{a})V' = -\bar{a} + \rho V' + (\rho U - \bar{a}\lambda)V'' - \frac{\bar{a}^2}{2\sigma_{\max}^2}\Big(\frac{(1+V')^2}{V''}\Big)'. \tag{B.14}$$

Sending $U \to \overline{U}$ and using the boundary condition $V'(\overline{U}) = -1$, we obtain from the previous equation that

$$\rho - r = (\rho\overline{U} - \bar{a}\lambda)V''(\overline{U}) - \frac{\bar{a}^2}{2\sigma_{\max}^2}\Big(\frac{(1+V')^2}{V''}\Big)'(\overline{U}). \tag{B.15}$$

Because $\frac{(1+V')^2}{V''} \leq 0$ when $U < \overline{U}$ and (B.12) holds, then

$$\Big(\frac{(1+V')^2}{V''}\Big)'(\overline{U}) \geq 0. \tag{B.16}$$

Because $\rho > r$, (B.15) and (B.16) combined implies that

$$(\rho\overline{U} - \bar{a}\lambda)V''(\overline{U}) > 0. \tag{B.17}$$

Because $V''(\overline{U}) \leq 0$, the previous inequality implies that

$$\overline{U} < \frac{\bar{a}\lambda}{\rho} \quad \text{and} \quad V''(\overline{U}) < 0. \tag{B.18}$$

We now combine $V''(\overline{U}) < 0$ with $V'(\overline{U}) = -1$ and (12) to obtain

$$\lim_{U \to \overline{U}} R^* = \frac{1}{\pi \bar{a}}(\lambda + \overline{U}) \quad \text{and} \quad \lim_{U \to \overline{U}} \varphi^* = 0. \tag{B.19}$$

Monotonicity of R^* and φ^* in a neighborhood of $\overline{U}$. Because the constraint $R \geq 0$ is not binding and $\sigma^* = \sigma_{\max}$ in a neighborhood of $\overline{U}$,

$$R^* = \frac{1}{\pi \bar{a}}\Big(\lambda + U + \frac{\bar{a}}{\sigma_{\max}^2}\frac{(1+V')}{V''}\Big) \tag{B.20}$$

in the same neighborhood. Taking the derivative with respect to U and using (B.16), we obtain $(R^*)'(\overline{U}) > 0$, hence R^* increases in a neighborhood of $\overline{U}$ and converges to its limit $(\lambda + \overline{U})/(\pi \bar{a})$ as U approaches $\overline{U}$.

To examine the derivatives of R^* and φ^* at $\overline{U}$, we divide $1 + V'$ on both sides of (B.14) to obtain

$$\bar{a} + \frac{\bar{a}^2}{\sigma_{\max}^2} + \frac{(r-\rho)V' + (\bar{a}\lambda - \rho U)V''}{1+V'} = -\frac{\bar{a}^2}{2\sigma_{\max}^2}\Big[1 - \frac{(1+V')V'''}{(V'')^2}\Big]. \tag{B.21}$$

If $\rho - r + (\bar{a}\lambda - \rho\overline{U})V''(\overline{U}) < 0$, because $1 + V' \geq 0$ and converges to 0 as U approaches $\overline{U}$, the left-hand side of (B.21) converges to $-\infty$ as U approaches $\overline{U}$. Therefore

$$\lim_{U \to \overline{U}} 1 - \frac{(1+V')V'''}{(V'')^2} = \infty. \tag{B.22}$$

Note that

$$\Big(\frac{1+V'}{V''}\Big)' = 1 - \frac{(1+V')V'''}{(V'')^2}.$$

We then conclude from (B.20) that

$$(R^*)'(\overline{U}) = \infty \quad \text{and} \quad (\varphi^*)'(\overline{U}) = -\infty.$$

Optimal flow compensation. Plugging $\pi \bar{a} R^* + \varphi^* = \lambda + U$ into (8), we obtain

$$\mathrm{d}U_t = (\rho U_t - \lambda \bar{a})\mathrm{d}t + \varphi_t^* \mathrm{d}Y_t - \mathrm{d}C_t,$$

where $\varphi_t^* = \varphi^*(U_t)$ for a function φ^*. It follows from the previous equation that

$$\mathrm{d}e^{-\rho t}(U_t - \overline{U}) = e^{-\rho t}(\rho\overline{U} - \lambda\bar{a})\mathrm{d}t + e^{-\rho t}\varphi^*(U_t)\mathrm{d}Y_t - e^{-\rho t}\mathrm{d}C_t.$$

Consider a process $\widehat{U}$ whose dynamics follows

$$\mathrm{d}e^{-\rho t}\widehat{U}_t = e^{-\rho t}(\rho\overline{U}_t - \lambda\bar{a})\mathrm{d}t + e^{-\rho t}\varphi^*(\widehat{U}_t + \overline{U})\mathrm{d}Y_t.$$

It follows from Skorokhod (1961) and Harrison (1985) that

$$e^{-\rho t}(U_t - \overline{U}) = e^{-\rho t}\widehat{U}_t - \max\big\{\sup_{0\le s\le t} e^{-\rho s}\widehat{U}_s, 0\big\}.$$

Because the drift of $e^{-\rho t}\widehat{U}_t$ is negative due to (B.18) and its volatility vanishes when $\widehat{U} = 0$, therefore $\widehat{U}$ is always nonpositive. This implies $U_t = \overline{U} + \widehat{U}_t$ from the previous equation and $C \equiv 0$.

Verification of the value function. Given that V satisfies the smoothness condition in footnote 3, it follows from Itô's formula (see (Karatzas and Shreve, 1991, 3.6.24) for an Itô's formula for piecewise C^2 functions) that

$$\begin{aligned}
&\mathrm{d}\Big\{e^{-(r+\bar{a})t}V(U_t) + \int_0^t e^{-(r+\bar{a})s}\Big\{-\mathrm{d}C_s + \Big(\pi\bar{a}^2(\Delta - R_s) - \frac{M}{\sigma_s^2}\Big)\,\mathrm{d}s\Big\}\Big\}\\
=&e^{-(r+\bar{a})t}\Big\{\Big[-(r+\bar{a})V(U_t) + \pi\bar{a}^2(\Delta - R_t) - \frac{M}{\sigma_t^2}\\
&+\big((\rho+\bar{a})U_t - \pi\bar{a}^2R_t\big)V'(U_t) + \frac{1}{2}\varphi_t^2\sigma_t^2V''(U_t)\Big]\mathrm{d}t\\
&-\big(V'(U_t)+1\big)\mathrm{d}C_t + \varphi_t\sigma_tV'(U_t)\,\mathrm{d}B_t^{\bar{a}}\Big\}.
\end{aligned}$$

For any principal's strategy (φ, R, σ, C) satisfying the incentive compactibility constraint, it follows from (A.2) that $e^{-(r+\bar{a})t}V(U_t) + \int_0^t e^{-(r+\bar{a})s}\big\{-\mathrm{d}C_s + \big(\pi\bar{a}^2(\Delta - R_s) - \frac{M}{\sigma_s^2}\big)\mathrm{d}s\big\}$ is a local-supermartingale under $\mathbb{P}^{\bar{a}}$. Take a localization sequence $\{\xi_n\}$ satisfying

$\lim_{n\to\infty} \xi_n = \infty$ for the local martingale part, then

$$\begin{aligned}
V(U_t) \geq \; & \mathbb{E}_t^{\bar{a}}\Big[e^{-(r+\bar{a})(\xi_n\wedge\tau-t)}V(U_{\xi_n\wedge\tau}) \\
& \qquad + \int_t^{\xi_n\wedge\tau-t} e^{-(r+\bar{a})(s-t)}\Big\{-\mathrm{d}C_s + \Big(\pi\bar{a}^2(\Delta-R_s)-\frac{M}{\sigma_s^2}\Big)\,\mathrm{d}s\Big\}\Big] \\
= \; & \mathbb{E}_t^{\bar{a}}\Big[e^{-(r+\bar{a})(\tau-t)}L\,1_{\{\tau\leq\xi_n\}} + e^{-(r+\bar{a})(\xi_n-t)}V(U_{\xi_n})1_{\{\xi_n<\tau\}} \\
& \qquad + \int_t^{\xi_n\wedge\tau-t} e^{-(r+\bar{a})(s-t)}\Big\{-\mathrm{d}C_s + \Big(\pi\bar{a}^2(\Delta-R_s)-\frac{M}{\sigma_s^2}\Big)\,\mathrm{d}s\Big\}\Big]
\end{aligned}$$

Sending $\xi_n \to \infty$ and using the transversality condition, we obtain

$$\begin{aligned}
V(U_t) \geq & \sup_{\varphi,R,\sigma,C} \mathbb{E}_t^{\bar{a}}\Big[e^{-(r+\bar{a})(\tau-t)}L + \int_t^{\tau-t} e^{-(r+\bar{a})(s-t)}\Big\{-\mathrm{d}C_s + \Big(\pi\bar{a}^2(\Delta-R_s)-\frac{M}{\sigma_s^2}\Big)\,\mathrm{d}s\Big\}\Big] \\
= & \sup_{\varphi,R,\sigma,C} \mathbb{E}_t^{\bar{a}}\Big[e^{-r(\tau-t)}L1_{\{\tau<\nu\}} + e^{-r(\nu-t)}\pi\bar{a}(\Delta-R_\nu)1_{\{\tau\geq\nu\}} \\
& \qquad + \int_t^{\tau\wedge\nu} e^{-r(s-t)}1_{\{\nu\geq s\}}\Big\{-\mathrm{d}C_s - \frac{M}{\sigma_s^2}\,\mathrm{d}s\Big\}\Big],
\end{aligned}$$

where the equality follows from (B.1). When (φ, R, σ, C) is the strategy identified in Proposition 2, the previous inequality is an equality, confirming the optimality of this strategy.

Proof of Proposition 3

A proof similar to that for Proposition 1 shows that the agent exerts the maximum effort if $\pi\bar{a}R_t \geq \lambda + U_t$. The HJB equation satisfied by V is

$$0 = \min\Big\{1+V',\, (r+\bar{a})V - \sup_R \Big\{\pi\bar{a}^2(\Delta-R) + \big((\rho+\bar{a})U - \pi\bar{a}^2R\big)V'\Big\}\Big\}. \tag{B.23}$$

We first show that $\underline{U} < \overline{U}$. To this end, Assumption (1), $\underline{U} < \frac{\lambda\bar{a}}{\rho}$, and $\rho > r$ imply that

$$(r+\bar{a}-\rho)(\alpha+\beta\underline{U}-L)(r+\bar{a}) > (\rho-r)(\lambda\bar{a}-\rho\underline{U}) > 0. \tag{B.24}$$

Using (14) and the previous inequality, we obtain from caluclation that $V'(\underline{U}) > -1$, hence $\underline{U} < \overline{U}$. When $U \leq \overline{U}$, because $1+V' \geq 0$, the optimal reward satisfies $\pi\bar{a}R^* =$

$\lambda + U$. Calculation shows that V in (14) satisfies (B.23) and the boundary condition $V(\underline{U}) = L$.

The agent's continuation utility follows

$$\mathrm{d}U_t = \big((\rho + \bar{a})U_t - \pi \bar{a}^2 R_t^*\big)\mathrm{d}t - \mathrm{d}C_t.$$

Plugging $\pi \bar{a} R_t^* = \lambda + U_t$ into the previous dynamics, we obtain

$$\mathrm{d}U_t = (\rho U_t - \bar{a}\lambda)\mathrm{d}t - \mathrm{d}C_t. \tag{B.25}$$

It follows from (15), (B.24), and $\underline{U} < \lambda \bar{a}/\rho$ that $U_0 < \lambda \bar{a}/\rho$. Hence the drift of U is negative at U_0, U decreases deterministically, and its drift remains negative until U reaches $\underline{U}$ at time τ. Calculation shows that $V'(U_0) > -1$ and V is concave when $r + \bar{a} > \rho$. Then $V'(U_t) > -1$, hence $U_t < \overline{U}$, for any $t \in [0, \tau]$. As a result, $C \equiv 0$. Finally, we obtain (16) and (17) from (B.25).

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Online Appendix

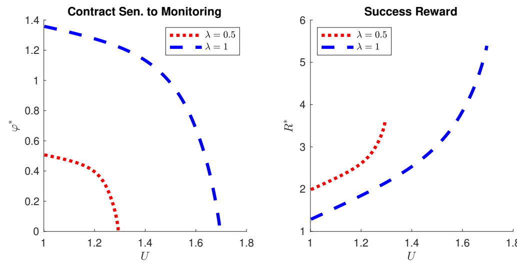
Monitoring and Pay-for-performance

This Online Appendix contains several supplementary analyses. These include the following:

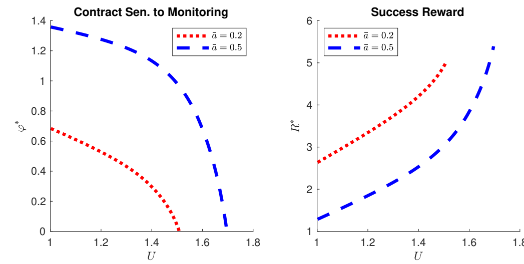
- Online Appendix OA.A contains additional comparative statics from the model.
- Online Appendix OA.B presents a simulation analysis when a unanticipated shock to the signal precision arrives at a deterministic time.
- Online Appendix OA.C contains robustness results and data construction details.
  - Subsection OA.C.1 describes the appendix tables.
  - Subsection OA.C.2 tabulates the appendix tables.
  - Subsection OA.C.3 includes additional details about Poisson regression estimation.
  - Subsection OA.C.4 includes additional description of the data.
    * Subsubsection OA.C.4.1 details the sample of firm and executives that we use.
    * Subsubsection OA.C.4.2 describes in detail the construction of our key dependent variable on direct flight availability.
    * Subsubsection OA.C.4.3 defines the variables used.

OA.A Model comparative statics

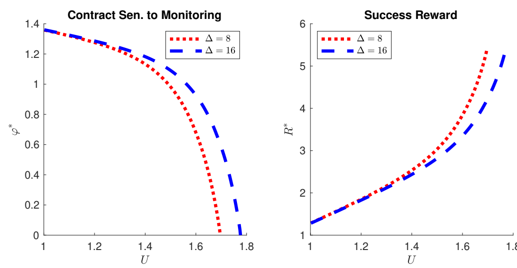
Figure OA-10 compares the optimal contract sensitivities and success rewards under different configurations of model parameters. Panel (a) shows that the contract sensitivity has a larger magnitude when the agent's private benefit from shirking is larger. When negative evidence is accumulating against the agent and the project is close to its termination, the success reward is also smaller for the agent with a higher benefit from shirking. When $\bar{a}$ decreases, the expected project length is longer. Panel (b) shows that the success reward is higher for a longer term project. Panel (c) shows that the principal monitors projects with larger payoffs more intensely and chooses a larger contract sensitivity. This is because, with the same value of L, termination is more inefficient for the project with the larger payoff. Panel (d) shows that when project termination is more costly (lower L), the principal chooses a larger contract sensitivity to monitor more.



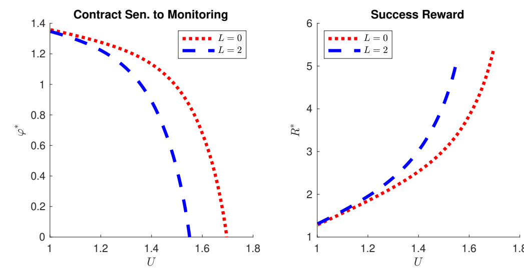
(a) **Different shirking benefit λ**



(b) **Different maximum effort $\bar{a}$**



(c) **Different project payoff Δ**



(d) **Different liquidation value L**

Figure OA-10. **Optimal contract sensitivity to monitoring and the success reward for different λ, $\bar{a}$, Δ, and L**

If not listed in the legend, parameters used are $\rho = 0.1$, $r = 0.05$, $S = 25$, $\bar{a} = 0.5$, $\lambda = 1$, $\Delta = 8$, $\pi = 1$, $\underline{U} = 1$, and $L = 0$.

OA.B Shock simulations

In this section, we perform a simulation experiment where the signal precision is reduced at an unanticipated deterministic time t_{shock}. We show that the average reward increases after the shock and this increase is more significant when the agent's continuation utility is below its median level at the shock time.

Assume that the principal has all the bargaining power and the signal precision is high at the beginning of the project. The project is initiated at U_{accurate}, which maximizes the principal's value with high signal precision ($\sigma = \sigma_{\text{low}}$), at time 0. At a deterministic time t_{shock}, a shock to the signal precision arrives, σ becomes σ_{high} after t_{shock}. This shock is assumed to be unanticipated by both the agent and the principal. At t_{shock}, the principal and the agent negotiate a new contract. The principal would like the agent to start his continuation utility at U_{noisy}, which maximizes the principal's value with low signal precision. However, the agent can reject the offer, in which case, because the principal committed on a long term contract at time 0, the agent can fall back to the old contract with $\varphi^*_{\text{accurate}}$ and R^*_{accurate}, however the principal updates the dynamics of agent's continuation utility using the low precision signal. We denote agent's value of this rejection option at t_{shock} as $U_{\text{rejection}}$.[8] Anticipating the agent's rejection value, the principal offers the agent to start a new contract, which is optimal for the low precision signal, with the agent's initial utility $\max\{U_{\text{noisy}}, U_{\text{rejection}}\}$. If $U_{\text{noisy}} > U_{\text{rejection}}$, the new contract is initiated at the principal's preferred point, which maximizes the principal's value, and the agent is also willing to accept the offer because its value is larger than the rejection value. When $U_{\text{rejection}} \geq U_{\text{noisy}}$, the new contract is initiated at the agent's rejection value, so that the agent weakly prefers the new contract and principal also achieves the best value conditional on agent's acceptance.

Figure OA-11 presents the result of the simulation experiment. At $t_{\text{shock}} = 0.5$, an unanticipated shock to the signal precision arrives, σ increases from 0.2 to 0.4. The left panel presents the average success reward conditional on project continuation before and after the shock. It shows that there is a positive jump in the mean success reward when the signal precision suddenly drops. In the right panel, simulations are split into two sub-classes depending on whether the agent's continuation utility right before t_{shock} is higher or lower than the median level. The right panel shows that the positive jumps in the mean success reward are more significant among poor performers before the shock.

[8] Because $\varphi^*_{\text{accurate}}$ and R^*_{accurate} satisfies the incentive compatibility constraint $\varphi^*_{\text{accurate}} + \pi\bar{a}R^*_{\text{accurate}} = \lambda + U$, the agent still exerts the maximum effort $\bar{a}$ in the rejection option. The value $U_{\text{rejection}}$ satisfies

$$U_{\text{rejection}} = \mathbb{E}_{t_{\text{shock}}}\left[\mathbb{I}_{\{\nu\leq\tau\}}e^{-\rho(\nu-t_{\text{shock}})}\pi a_\nu R^*_{\text{accurate},\nu} + \mathbb{I}_{\{\nu>\tau\}}e^{-\rho(\tau-t_{\text{shock}})}\underline{U}\right].$$

Here R^*_{accurate} depends on U which follows the dynamics $\mathrm{d}U_t = (\rho U_t - \lambda\bar{a})\mathrm{d}t + \varphi^*_{\text{accurate},t}\mathrm{d}Y_t$ with $\mathrm{d}Y_t = \bar{a}\mathrm{d}t + \sigma_{\text{high}}\mathrm{d}B_t$. We use a Monte Carlo procedure to identify $U_{\text{rejection}}$.

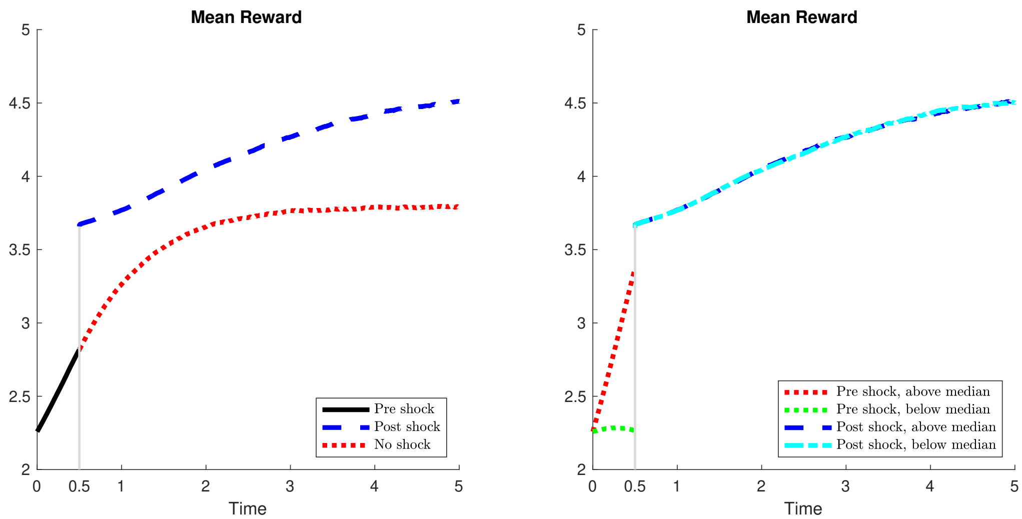


Figure OA-11. **Average success reward before and after t_{shock}**

Notes: The left panel presents the average success reward conditional on project continuation, i.e., $\mathbb{E}^{\bar{a}}[R_t^* \mid t \geq \nu \wedge \tau]$, *before and after* t_{shock}. *For the solid black line,* $R^* = R^*_{accurate}$; *for the blue dash line,* $R^* = R^*_{noisy}$. *The red dotted line presents the case without shock to the signal precision and* $R^* = R^*_{accurate}$. *In the right panel, simulations are split into two subclasses depending on whether the agent's continuation utility right before* t_{shock} *is higher or lower than the median level. The red dotted line presents* $\mathbb{E}^{\bar{a}}[R^*_{accurate,t} \mid t \geq \nu \wedge \tau, U_{t_{shock}} \geq median(U_{t_{shock}})]$ *and the green dotted line presents* $\mathbb{E}^{\bar{a}}[R^*_{accurate,t} \mid t \geq \nu \wedge \tau, U_{t_{shock}} < median(U_{t_{shock}})]$. *Parameters used are* $t_{shock} = 0.5$, $\rho = 0.1$, $r = 0.05$, $\bar{a} = 0.5$, $\lambda = 1$, $\Delta = 8$, $\pi = 1$, $\underline{U} = 1$, *and* $L = 0$. *Conditional expectations are calculated from* 10^5 *Monte Carlo simulations.*

OA.C Empirical Appendix

OA.C.1 Additional Tables

In this subsection, we further describe the appendix tables in subsection OA.C.2.

CEO and Not CEO Subsamples. Table OA.8 in the Appendix presents estimates for equation (20) on two separate samples: executives other than the CEO, and only the executives who are the CEO. For both samples, we observe a positive and statistically significant at the 1% level effect of a director experiencing a direct flight being stopped when the CEO is not also the chairman. The effect sizes are similar to those obtained in our full sample analysis. Moreover, we find that the effect is more pronounced when the CEO does not also hold the position of the chairman of the board, with statistical significance at the 5% level.

Enhanced Geographical Fixed Effects. One concern is that there might be highly local compensation trends at a more granular level than the state. To address this concern, we revisit our baseline specification using MSA-year fixed effects instead of state-year fixed effects.[9] Further, it is possible that these trends are industry specific within a region. To check if extremely local industry-specific trends are also driving our results, we consider joint industry, Metropolitan Statistical Area (MSA), and year fixed effects.

Columns (1) and (2) of Table OA.7 estimate equation (18) with the direct flight stopped and started variables with the inclusion of more granular MSA-year instead of state-year fixed effects. We find that the effect size and statistical significance of the direct flight stopped variable is similar to our baseline results. The estimated effect of the direct-flight-stopped variable with MSA-year fixed effects is slightly larger than our baseline estimate. Therefore, our results are not driven by MSA-specific trends over time.

Columns (3) and (4) of Table OA.7 estimate equation (18) with the direct flight stopped and started variables with joint industry-MSA-year fixed effects instead of separate industry-year and MSA-year fixed effects. We find that the effect size and statistical significance of the direct flight stopped variable is similar to our baseline results. The estimated effect of the direct-flight-stopped variable with MSA-year fixed effects is notably larger than our baseline estimates. Therefore, our results are not driven by joint industry-MSA-specific trends over time.

Compensation Prior to Direct Flight Change. An additional consideration we

[9] To be precise, we also include Micropolitan Statistical Areas if firms fall into one of these instead of an MSA.

address is director selection. It may be that, for some reason, directors who lose access to direct flights are increasing CEOs' option compensation or select firms that do. We calculate a variable to capture the effect of these directors, before the change in direct flight access, as executive-firm-years with a director on the board who will lose access to a direct flight to the firm within three, five, eight, or ten years. This is to say that we look at executive-firm-years for the number of years before the change where the director that will be impacted is already on the board. Since we only focus on changes after the director is on the board, this variable will cover all affected firms for at least one year.[10] The results of this exercise are shown in Appendix Table OA.8. We do not find any evidence of elevated option compensation before the treatment at the three-, five-, eight-, or ten-year time horizon. This suggests that director selection effects are not driving our results.

Additional Selection Effects. An alternative concern about our results is that other selection effects related to the type of firm may drive them. Some selection effects are by construction. For example, the firm must have non-local directors to be affected by a change in direct flight availability. This requires the firm to be able to both attract and accordingly compensate directors, which will be more feasible for larger firms with more assets. While a selection effect may affect our results, we do not believe it is a significant concern.

Most importantly, executive-firm pair fixed effects should capture all firm and person-specific characteristics that don't time vary. State-year fixed effects should also capture regional variation in economic productivity, which may affect flight availability over time. Additionally, if specific industries are more likely to have distant directors, our industry-year fixed effects should absorb these selection effects. More problematically, there could be a selection for a type of firm in a particular period. For example, perhaps when a director's flight is stopped, the director meddles less with the executives increasing profitability, leading to an increase in option compensation. To examine whether there is evidence of a selection effect, we run linear regressions with the dependent variable as different firm-year characteristics we use as controls while keeping the other controls as controls. We continue to do this at the executive-year, as opposed to firm-year, level to retain the same firm-year weighting as in our linear regressions. Appendix Table OA.9 presents the results. We find no statistical evidence that our key dependent variable has any predictive power for log assets, profitability, log stock return, and whether

[10] In the event that a director experiences the same start/stop of a direct flight more than once, we focus only on the time prior to the first change.

or not the CEO is the chairperson. These results suggest that, conditional on the observables included in our regressions, there is no evidence of selection on other firm-year characteristics in our sample. One can also view these results as a placebo test of our dependent variable for these alternative outcomes, particularly with respect to our linear specifications. To further address selection concerns, we also implement two additional robustness checks based on Bertrand and Mullainathan (2003) in Appendix Table OA.10. First, we allow for separate trends in firms that ever had at least one director affected by the start or stop of a direct flight in our sample and those that were never affected by the start or stop. In columns (1) and (2), we replicate columns (1) and (2) of Table 5 with the relevant set of additional annual fixed effects. In column (1), we find a similar effect size and statistical significance of a director losing access to a direct flight to our prior results, even after allowing for firms ever affected or never affected by a direct flight being stopped to have different time trends. In column (2), we observe a negative, insignificant effect of a direct flight being started in firm-years without the CEO as the chairperson, consistent with Table 5. The next robustness check that we run is limiting our sample to the firms that ever had a direct flight stopped or started between the firm and one of its directors for the associated dependent variable. In columns (3) and (4) of Appendix Table OA.10, we replicate columns (1) and (2) of Table 5, limiting the sample to firms ever affected by a direct flight being stopped or started, respectively. In column (3), we find that even though our sample is about 20% of its original size, our estimated coefficient on a direct flight being stopped in firm-years where the CEO is not the chairperson is statistically significant at the 1% level and has an estimated effect of about a 38% increase in option awards when a director loses access to a direct flight. We still find an insignificant effect in the sample of firms who ever had a direct flight to the firm started. In conclusion, there does not appear to be any evidence of firm selection conditional on observables, and our results are robust to multiple additional checks.

Flight Change as a Disruption. One may also think that a director losing access to a direct flight may act as a disruption to the board's signal quality regardless of whether the affected director leaves the board. In the case that the director stays, the director does less monitoring in person. If the director leaves the board, those responsibilities must be redelegated to other directors, or a new director, who will be unfamiliar with company and board specifics, must be hired. When responsibilities fall on a smaller number of people or new people, it is reasonable to think that monitoring quality would decline. Thus, over a short time horizon, we should expect to see an effect after a director loses access to a direct flight, regardless of whether that director remains on the board. We construct two new independent variables to test this effect, "Direct Stopped/Started (Any), $0 \leq t < T$" is equal to one if any director at the firm, who may or may not still be on the board, lost/gained access to a direct flight for the firm headquarters in the last T years where T is either one or two. Appendix Table OA.11 estimates specification (18) with these alternate key dependent variables instead of our baseline "Direct Stopped/Started" variables. In column (1), we find that when any board director has lost access to a direct flight in the current year or year prior, then option compensation is typically 9.4% higher, statistically significant at the 5% level. In column (3), we find that when any board director has lost access to a direct flight within the last two years, then option compensation is typically 11.1% higher, statistically significant at the 1% level. We find very small and insignificant estimates for the variables examining when a board director gains access to a direct flight for both time horizons in columns (2) and (4).

Normalization by Salary. A key empirical challenge when examining option compensation is that the data is sparse. Only about one-half of the observations in our executive sample have a positive value. While taking the log allows us to interpret the effect as a percent increase, it is not possible to take the log without dropping a large number of observations due to the high number of zeros. Another natural normalization of compensation, the fraction of total compensation, suffers from the issue that option awards and stock awards, which may be highly correlated due to the value of the stock, appear in the denominator. Thus, we rely on the salary to normalize the option award value. The fixed effect absorbs the base ratio of options to salary. Therefore, our results look at the change in option compensation as a percentage of salary. While not the perfect normalization scheme, it provides a salary scale normalized by a key, stock price invariant (over shorter time horizons) component of income.

Appendix Table OA.12 implements this alternative dependent variable. Columns (1) and (2) of Appendix Table OA.12 replicate columns (1) and (2) of Table 5 using linear regression with the alternative dependent variable of option awards divided by the salary. We find that when firms have a director who loses access to a direct flight, comparable to signal quality decreasing (or S decreasing) in the model as a company becomes more difficult to observe, then the value of options awarded to executives rises by 15.4% of salary if the CEO is not also the chairperson. This effect is statistically significant at the 1% level. In column (2), when a director gains access to a direct flight, we again find directionally consistent but statistically insignificant results.

The primary potential concern about this alternative dependent variable is that salary variation, and not option variation, is driving our analyses. However, from the perspective of theory, this is broadly consistent with our results about option compensation increasing relative to fixed pay. Nevertheless, to address the concern that time variation in salary is driving our results, we calculate the median salary for each executive-firm pair over time and use this time-invariant normalization of option awards.[11] Columns (3) and (4) of Table OA.12 replicates columns (3) and (4) of Table 5 using linear regression and the alternative dependent variable of option awards divided by the median salary. We find very similar results in columns (3) and (4). Using the dependent variable with median salary, the estimated effect of a director losing access to a direct flight when the CEO is not also the chairman is slightly smaller and statistically significant at the 5% level. The smaller coefficient does not necessarily suggest that the salary component drives some component of our results. For example, the attrition could be caused by measurement error induced by using the mean salary instead of the more time-relevant contemporaneous salary. Regardless of the reason for the attrition in the coefficient magnitude, these results eliminate the concern that time variation in the salary is driving our results as the divisor is fixed in these regressions.

Logarithm plus One. Considering that the option compensation data is sparse, with around half of the observations in our executive sample having a positive value, we cannot use the log of option awards as our main dependent variable. When using linear regression, a common alternative to log regression is a log plus one transformation where one is added to the key dependent variable. Cohn et al. (2022) highlights potential issues with this approach; however, we also present results using log plus one regression in Appendix Table OA.13. In column (1), we replicate column (1) of Table 3 using linear regression and log options awards plus one as the dependent variable; we estimate a coefficient of .157 on the Direct Stopped variable statistically significant at the 10% level. If interpreted as a semi-elasticity, this would suggest a 15.7% increase in option compensation when a director loses access to a direct flight, consistent with our results from Poisson regression. In column (3), we replicate column (1) of Table 5. When interpreting the result as a semi-elasticity, we estimate a 25% increase in option compensation when a director has their direct flight to the firm stopped, statistically significant at the 5% level ($p = .024$). Columns (2) and (4) examine analogous linear

[11] The median salary over time would be the median salary a CEO received over all the fiscal years they worked at the firm. If salary is weakly monotonically increasing over time, this would be the salary they received in the middle of their tenure.

regression results to columns (1) and (3), respectively, for the direct started variable and find insignificant results.

Option Compensation Usage. We also look at an alternative way to measure option compensation when the data is sparse: option usage, defined as whether or not an executive receives any options.[12] We use a conditional logit specification conditioning on the executive-firm pair. Due to the nature of this specification, we can only use data on executives with variation in whether they receive options across years significantly reducing this sample. We use year fixed effects primarily due to the issues with introducing many fixed effects into a logit (or any non-linear) model. The two-way fixed effects case is best studied, and Monte Carlo simulations suggest that for less than 20 time periods (which our sample adheres to), the bias should be small (Katz, 2001; Coupé, 2005). Appendix Table OA.14 replicates Table 3 using the conditional logit specification and finds qualitatively and statistically similar results. Given that this model is very different, this speaks to the robustness of our findings. In column (1), we find that a direct flight between the firm and a director being stopped increases the odds an executive receives option compensation by 25%. [13] In column (3), when we focus on the direct flight stopped case where the CEO is not also the chairperson, we see an increase in the odds of option compensation usage by 47%.[14] We also cannot reject the null of no effect of a direct flight being stopped when the CEO is also the chairperson. Thus, we have found evidence of an increase in option compensation in magnitude using linear regression with two dependent variables and of usage using a conditional logit model, which highlights our results being highly robust.

[12]Some executives appear to receive negative valued options in Compustat. We assume these executives do not receive options.

[13]Based on the odds ratio of 1.25.

[14]Based on the odds ratio of 1.47.

OA.C.2 Appendix Tables

Table OA.6. **Effect of Direct Flight Availability: CEO Split**

Direct flight start/stop variables are constructed using BTS data on direct, scheduled flights and directors' location which is approximated by BoardEx information on their prior non-director employment. Option awards are the fair value of option awards. Our sample is C-level employees and presidents based on their title(s) reported in Execucomp. The control variables are CEO-Chair, log stock return, lag log stock return, profitability, log assets, and log total employment. Firm characteristics, assets, profitability, employment, and location, are from Compustat. Stock return is log annual stock return from CRSP. Firm profitability is defined as operating income before depreciation divided by assets. Industry is defined at the SIC-3 level. CEO Only is one for all executive-firm-years where the CEO is not also the chairperson based on Execucomp data. Columns (1) and (2) estimate specification (20) for the sample of executive-firm-years where the executive is not the CEO. Columns (3) and (4) estimate specification (20) for the sample of executive-firm-years where the executive is the CEO. t-statistics, using standard errors clustered by firm, are shown in parentheses. *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

	(1) Option Awards	(2) Option Awards	(3) Option Awards	(4) Option Awards
Direct Stopped	0.039		0.025	
	(0.65)		(0.39)	
Dir. Stop, CEO Only	0.213**		0.195**	
	(2.33)		(2.07)	
Direct Started		-0.010		0.024
		(-0.20)		(0.41)
Dir. Start, CEO Only		-0.041		-0.090
		(-0.57)		(-1.04)
CEO Only	0.016	0.035	0.007	0.035
	(0.43)	(0.97)	(0.13)	(0.66)
Controls	Yes	Yes	Yes	Yes
Year FE	No	No	No	No
Industry × Year FE	Yes	Yes	Yes	Yes
State × Year FE	Yes	Yes	Yes	Yes
Executive × Firm FE	Yes	Yes	Yes	Yes
Sample	Not CEO	Not CEO	CEOs	CEOs
Observations	51,088	51,088	14,316	14,316

Table OA.7. **Effect of Direct Flight Availability: Enhanced Geography**

Direct flight start/stop variables are constructed using BTS data on direct, scheduled flights and directors' location which is approximated by BoardEx information on their prior non-director employment. Option awards are the fair value of option awards. Our sample is C-level employees and presidents based on their title(s) reported in Execucomp. The control variables are CEO-Chair, log stock return, lag log stock return, profitability, log assets, and log total employment. Firm characteristics, assets, profitability, employment, and location, are from Compustat. Stock return is log annual stock return from CRSP. Firm profitability is defined as operating income before depreciation divided by assets. Industry is defined at the SIC-3 level. CEO Only is one for all executive-firm-years where the CEO is not also the chairperson based on Execucomp data. Columns (1) and (2) estimate specification (18) with joint MSA-year fixed effects instead of state-year fixed effects. Columns (3) and (4) estimate specification (18) with joint industry-MSA-year fixed effects instead of industry-year and state-year fixed effects. *t*-statistics, using standard errors clustered by firm, are shown in parentheses. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

	(1) Option Awards	(2) Option Awards	(3) Option Awards	(4) Option Awards
Direct Stopped	0.132**		0.255**	
	(2.25)		(2.05)	
Direct Started		-0.019		-0.049
		(-0.32)		(-0.39)
Controls	Yes	Yes	Yes	Yes
Industry $\times$ Year FE	Yes	Yes	No	No
MSA $\times$ Year FE	Yes	Yes	No	No
MSA$\times$ Industry $\times$ Year FE	No	No	Yes	Yes
Executive $\times$ Firm FE	Yes	Yes	Yes	Yes
Observations	63,330	63,330	53,690	53,690

Table OA.8. **Effect of Direct Flight Availability: Director Selection**

Direct flight start/stop variables are constructed using BTS data on direct, scheduled flights and directors' location which is approximated by BoardEx information on their prior non-director employment. Option awards are the fair value of option awards. Our sample is C-level employees and presidents based on their title(s) reported in Execucomp. The control variables are CEO-Chair, log stock return, lag log stock return, profitability, log assets, and log total employment. Firm characteristics, assets, profitability, employment, and location, are from Compustat. Stock return is log annual stock return from CRSP. Firm profitability is defined as operating income before depreciation divided by assets. Industry is defined at the SIC-3 level. Columns (1)-(4) Poisson regress option awards on a dummy for if a direct flight from at least one of the directors' locations to the firm's location will stop being available within the next three, five, eight, and ten years, respectively, with control variables, year fixed effects, and executive-firm pair fixed effects. t-statistics, using standard errors clustered by firm, are shown in parentheses. *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

	(1) Option Awards	(2) Option Awards	(3) Option Awards	(4) Option Awards
Direct Stopped, $-3 \leq t < 0$	-0.003			
	(-0.08)			
Direct Stopped, $-5 \leq t < 0$		0.004		
		(0.08)		
Direct Stopped, $-8 \leq t < 0$			-0.002	
			(-0.03)	
Direct Stopped, $-10 \leq t < 0$				-0.020
				(-0.39)
Controls	Yes	Yes	Yes	Yes
Industry × Year FE	Yes	Yes	Yes	Yes
State × Year FE	Yes	Yes	Yes	Yes
Executive × Firm FE	Yes	Yes	Yes	Yes
Observations	68,328	68,328	68,328	68,328

Table OA.9. **Effect of Direct Flight Availability: Firm Characteristic Selection**

Direct flight start/stop variables are constructed using BTS data on direct, scheduled flights and directors' location which is approximated by BoardEx information on their prior non-director employment. Option awards are the fair value of option awards. Our sample is C-level employees and presidents based on their title(s) reported in Execucomp. The control variables are CEO-Chair, log stock return, lag log stock return, profitability, log assets, and log total employment. Firm characteristics, assets, profitability, employment, and location, are from Compustat. Stock return is log annual stock return from CRSP. Firm profitability is defined as operating income before depreciation divided by assets. Industry is defined at the SIC-3 level. Columns (1)-(4) regress log total assets, profitability, log stock return, and CEO Only, respectively, on a dummy for if a direct flight from at least one of the directors' locations to the firm's location stops being available with control variables, state-year fixed effects, industry-year fixed effects, and executive-firm pair fixed effects. t-statistics, using standard errors clustered by firm, are shown in parentheses. *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

	(1)	(2)	(3)	(4)
	Log Assets	Profitability	Log Stock Return	CEO Only
Direct Stopped	-0.006	-0.001	0.003	0.001
	(-0.54)	(-0.46)	(0.23)	(0.09)
Other Controls	Yes	Yes	Yes	Yes
Industry × Year FE	Yes	Yes	Yes	Yes
State × Year FE	Yes	Yes	Yes	Yes
Executive × Firm FE	Yes	Yes	Yes	Yes
Observations	100,480	100,480	100,480	100,480

Table OA.10. **Effect of Direct Flight Availability: Firm Type Selection**

Direct flight start/stop variables are constructed using BTS data on direct, scheduled flights and directors' location which is approximated by BoardEx information on their prior non-director employment. Option awards are the fair value of option awards. Our sample is C-level employees and presidents based on their title(s) reported in Execucomp. The control variables are CEO-Chair, log stock return, lag log stock return, profitability, log assets, and log total employment. Firm characteristics, assets, profitability, employment, and location, are from Compustat. Stock return is log annual stock return from CRSP. Firm profitability is defined as operating income before depreciation divided by assets. Industry is defined at the SIC-3 level. CEO Only is one for all executive-firm-years where the CEO is not also the chairperson based on Execucomp data. Column (1) Poisson regresses option awards on a dummy for if a direct flight from at least one of the directors' locations to the firm's location stops being available and this variable interacted with a dummy for if the CEO is also the chairman with control variables, state-year fixed effects, industry-year fixed effects, and executive-firm pair fixed effects. We also include a set of year fixed effects for firms that ever has a director's direct flight access to the firm be stopped during our sample period and a separate set of year fixed effects for firms that never have a director experience this. Column (2) Poisson regresses option awards on a dummy for if a direct flight from at least one of the directors' locations to the firm's location starts being available and this variable interacted with a dummy for if the CEO is also the chairman with control variables, state-year fixed effects, industry-year fixed effects, and executive-firm pair fixed effects. We also include a set of year fixed effects for firms that ever has a director's direct flight access to the firm be stopped during our sample period and a separate set of year fixed effects for firms that never have a director experience this. Column (3) Poisson regresses option awards on a dummy for if a direct flight from at least one of the directors' locations to the firm's location stops being available and this variable interacted with a dummy for if the CEO is also the chairman with control variables, state-year fixed effects, industry-year fixed effects, and executive-firm pair fixed effects for the sample of firms that ever has a director's direct flight access to the firm be stopped during our sample period. Column (4) Poisson regresses option awards on a dummy for if a direct flight from at least one of the directors' locations to the firm's location starts being available and this variable interacted with a dummy for if the CEO is also the chairman with control variables, state-year fixed effects, industry-year fixed effects, and executive-firm pair fixed effects for the sample of firms that ever has a director's direct flight access to the firm be started during our sample period. *t*-statistics, using standard errors clustered by firm, are shown in parentheses. *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

	(1) Option Awards	(2) Option Awards	(3) Option Awards	(4) Option Awards
Direct Stopped	0.023		0.071	
	(0.39)		(0.85)	
Dir. Stop, CEO Only	0.204***		0.311***	
	(2.66)		(2.60)	
Direct Started		0.020		0.059
		(0.40)		(0.80)
Dir. Start, CEO Only		-0.091		-0.110
		(-1.40)		(-1.27)
CEO Only	0.043	0.067**	-0.102	0.081
	(1.27)	(1.99)	(-0.99)	(1.00)
Controls	Yes	Yes	Yes	Yes
Ever Stopped × Year FE	Yes	No	No	No
Ever Added × Year FE	No	Yes	No	No
Industry × Year FE	Yes	Yes	Yes	Yes
State × Year FE	Yes	Yes	Yes	Yes
Executive × Firm FE	Yes	Yes	Yes	Yes
Sample	Full	Full	Ever Stopped	Ever Added
Observations	68,328	68,328	13,422	15,101

Table OA.11. **Effect of Direct Flight Availability: Flight Change as a Disruption**

Direct flight start/stop variables are constructed using BTS data on direct, scheduled flights and directors' location which is approximated by BoardEx information on their prior non-director employment. Option awards are the fair value of option awards. Our sample is C-level employees and presidents based on their title(s) reported in Execucomp. The control variables are CEO-Chair, log stock return, lag log stock return, profitability, log assets, and log total employment. Firm characteristics, assets, profitability, employment, and location, are from Compustat. Stock return is log annual stock return from CRSP. Firm profitability is defined as operating income before depreciation divided by assets. Industry is defined at the SIC-3 level. CEO Only is one for all executive-firm-years where the CEO is not also the chairperson based on Execucomp data. Columns (1) and (3) Poisson regress option awards on a dummy for if a direct flight from at least one of the directors' locations to the firm's location stopped being available in the current or prior year, alternatively in the last two years, respectively with control variables, year fixed effects, and executive-firm pair fixed effects. Columns (2) and (4) Poisson regress option awards on a dummy for if a direct flight from at least one of the directors' locations to the firm's location started being available in the current or prior year, alternatively in the last two years, respectively, with control variables, year fixed effects, and executive-firm pair fixed effects. *t*-statistics, using standard errors clustered by firm, are shown in parentheses. *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

	(1) Option Awards	(2) Option Awards	(3) Option Awards	(4) Option Awards
Dir. Stop (Any), $0 \leq t \leq 1$	0.094**			
	(2.36)			
Dir. Start (Any), $0 \leq t \leq 1$		0.002		
		(0.04)		
Dir. Stop (Any), $0 \leq t \leq 2$			0.111***	
			(2.70)	
Dir. Start (Any), $0 \leq t \leq 2$				0.019
				(0.49)
Controls	Yes	Yes	Yes	Yes
Industry × Year FE	Yes	Yes	Yes	Yes
State × Year FE	Yes	Yes	Yes	Yes
Executive × Firm FE	Yes	Yes	Yes	Yes
Observations	68,328	68,328	68,328	68,328

Table OA.12. **Effect of Direct Flight Availability: Salary Normalization**

Direct flight start/stop variables are constructed using BTS data on direct, scheduled flights and directors' location which is approximated by BoardEx information on their prior non-director employment. Option awards are the fair value of option awards. Our sample is C-level employees and presidents based on their title(s) reported in Execucomp. The control variables are CEO-Chair, log stock return, lag log stock return, profitability, log assets, and log total employment. Firm characteristics, assets, profitability, employment, and location, are from Compustat. Stock return is log annual stock return from CRSP. Firm profitability is defined as operating income before depreciation divided by assets. Industry is defined at the SIC-3 level. CEO Only is one for all executive-firm-years where the CEO is not also the chairperson based on Execucomp data. Column (1) regresses option awards divided by salary on a dummy for if a direct flight from at least one of the directors' locations to the firm's location stops being available and this variable interacted with a dummy for if the CEO is also the chairman with control variables, state-year fixed effects, industry-year fixed effects, and executive-firm pair fixed effects. Column (2) regresses option awards divided by salary on a dummy for if a direct flight from at least one of the directors' locations to the firm's location starts being available and this variable interacted with a dummy for if the CEO is also the chairman with control variables, state-year fixed effects, industry-year fixed effects, and executive-firm pair fixed effects. Column (3) regresses option awards divided by median salary for a CEO-firm pair on a dummy for if a direct flight from at least one of the directors' locations to the firm's location stops being available and this variable interacted with a dummy for if the CEO is also the chairman with control variables, state-year fixed effects, industry-year fixed effects, and executive-firm pair fixed effects. Column (4) regresses option awards divided by median salary for a CEO-firm pair on a dummy for if a direct flight from at least one of the directors' locations to the firm's location starts being available and this variable interacted with a dummy for if the CEO is also the chairman with control variables, state-year fixed effects, industry-year fixed effects, and executive-firm pair fixed effects. *t*-statistics, using standard errors clustered by firm, are shown in parentheses. *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

	(1) Option Awards / Salary	(2) Option Awards / Salary	(3) Option Awards / Median Salary	(4) Option Awards / Median Salary
Direct Stopped	-0.018		-0.014	
	(-0.40)		(-0.36)	
Dir. Stop, CEO Only	0.172***		0.136**	
	(2.65)		(2.35)	
Direct Started		0.027		0.029
		(0.66)		(0.75)
Dir. Start, CEO Only		-0.042		-0.059
		(-0.79)		(-1.20)
CEO Only	0.026	0.044*	0.022	0.038*
	(1.01)	(1.67)	(0.98)	(1.67)
Controls	Yes	Yes	Yes	Yes
Industry × Year FE	Yes	Yes	Yes	Yes
State × Year FE	Yes	Yes	Yes	Yes
Executive × Firm FE	Yes	Yes	Yes	Yes
Observations	100,204	100,204	100,281	100,281

Table OA.13. **Effect of Direct Flight Availability: Log Plus One**

Direct flight start/stop variables constructed using BTS data on direct, scheduled flights and BoardEx data for information on director's prior employment used to determine their location. Log option awards (+1) is one plus the logarithm of fair option award value. Our sample is C-level employees and presidents based on their title(s) in Execucomp. The control variables are CEO-Chair, log stock return, lag log stock return, profitability, log assets, and log total employment. CEO-Chair is based on Execucomp data. Firm characteristics, assets, profitability, employment, and location, are from Compustat data. Stock return is based on CRSP stock data. Firm profitability is defined as operating income before depreciation divided by assets. Industry is defined at the SIC-3 level. CEO Only is one for all executive-firm-years where the CEO is not also the chairperson based on Execucomp data. Column (1) regresses log option awards plus one on a dummy for if a direct flight from at least one of the directors' locations to the firm's location stops being available with control variables, state-year fixed effects, industry-year fixed effects, and executive-firm pair fixed effects. Column (2) regresses log option awards plus one on a dummy for if a direct flight from at least one of the directors' locations to the firm's location starts being available with control variables, state-year fixed effects, industry-year fixed effects, and executive-firm pair fixed effects. Column (3) regresses log option awards plus one on a dummy for if a direct flight from at least one of the directors' locations to the firm's location stops being available and this variable interacted with a dummy for if the CEO is also the chairman with control variables, state-year fixed effects, industry-year fixed effects, and executive-firm pair fixed effects. Column (4) regresses log option awards plus one on a dummy for if a direct flight from at least one of the directors' locations to the firm's location starts being available and this variable interacted with a dummy for if the CEO is also the chairman with control variables, state-year fixed effects, industry-year fixed effects, and executive-firm pair fixed effects. t-statistics, using standard errors clustered by firm, are shown in parentheses. *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

	(1) Log Option Awards (+1)	(2) Log Option Awards (+1)	(3) Log Option Awards (+1)	(4) Log Option Awards (+1)
Direct Stopped	0.157*		0.062	
	(1.78)		(0.55)	
Dir. Stop, CEO Only			0.188	
			(1.35)	
Direct Started		0.028		0.114
		(0.35)		(1.03)
Dir. Start, CEO Only				-0.174
				(-1.43)
CEO Only	-0.021	-0.020	-0.035	-0.006
	(-0.38)	(-0.37)	(-0.63)	(-0.10)
Controls	Yes	Yes	Yes	Yes
Industry × Year FE	Yes	Yes	Yes	Yes
State × Year FE	Yes	Yes	Yes	Yes
Executive × Firm FE	Yes	Yes	Yes	Yes
Observations	100,480	100,480	100,480	100,480

Table OA.14. **Effect of Direct Flight Availability: Use of Option Compensation**

Direct flight start/stop variables constructed using BTS data on direct, scheduled flights and BoardEx data for information on director's prior employment used to determine their location. Options awarded (Y/N) is a dummy variable equal to one if the fair value of option awards from Execucomp is positive. Our sample is C-level employees and presidents based on their title(s) in Execucomp. The control variables are CEO-Chair, log stock return, lag log stock return, profitability, log assets, and log total employment. CEO-Chair is based on Execucomp data. Firm characteristics, assets, profitability, employment, and location, are from Compustat data. Stock return is based on CRSP stock data. Firm profitability is defined as operating income before depreciation divided by assets. Industry is defined at the SIC-3 level. CEO Only is one for all executive-firm-years where the CEO is not also the chairperson based on Execucomp data. Column (1) fits a conditional logit model to estimate whether or not a CEO receives option compensation on a dummy for if a direct flight from at least one of the directors' locations to the firm's location stops being available with control variables and year fixed effects stratifying on the executive-firm pair. Column (2) fits a conditional logit model to estimate whether or not a CEO receives option compensation on a dummy for if a direct flight from at least one of the directors' locations to the firm's location starts being available with control variables and year fixed effects stratifying on the executive-firm pair. Column (3) fits a conditional logit model to estimate whether or not a CEO receives option compensation on a dummy for if a direct flight from at least one of the directors' locations to the firm's location stops being available and this variable interacted with a dummy for if the CEO is also the chairman with control variables and year fixed effects stratifying on the executive-firm pair. Column (4) fits a conditional logit model to estimate whether or not a CEO receives option compensation on a dummy for if a direct flight from at least one of the directors' locations to the firm's location starts being available and this variable interacted with a dummy for if the CEO is also the chairman with control variables and year fixed effects stratifying on the executive-firm pair. t-statistics, using standard errors clustered by firm, are shown in parentheses. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

	(1) Options Awarded (Y/N)	(2) Options Awarded (Y/N)	(3) Options Awarded (Y/N)	(4) Options Awarded (Y/N)
Direct Stopped	0.239*		0.087	
	(1.65)		(0.44)	
Direct Started		-0.009		0.111
		(-0.07)		(0.57)
Dir. Stop, CEO Only			0.282	
			(1.25)	
Dir. Start, CEO Only				-0.229
				(-1.04)
CEO Only	-0.005	-0.006	-0.028	0.013
	(-0.06)	(-0.06)	(-0.31)	(0.15)
Year FE	Yes	Yes	Yes	Yes
Executive × Firm Strata	Yes	Yes	Yes	Yes
Observations	45,009	45,009	45,009	45,009

OA.C.3 Poisson Regression Estimation

In this subsubsection we include additional details about Poisson regression. The probability mass function (PMF) for the Poisson distribution is defined as

$$P(y = y_i|\lambda) = \frac{\lambda^{y_i}}{y_i!}e^{-\lambda}. \tag{OA.C.26}$$

The log-likelihood function is then

$$L(\beta \mid \mathbf{X}, Y) = \prod_{i=1}^{m} \frac{e^{y_i X_i \beta} e^{-e^{X_i \beta}}}{y_i!},$$

with $\mathbf{X}$ being a matrix of independent variables with vectors x_i and Y being a vector of outcomes with elements y_i. The log-likelihood can thus be written as

$$\ell(\beta \mid \mathbf{X}, Y) = \sum_{i=1}^{m} \left(y_i X_i \beta - e^{X_i \beta} \right),$$

since we can drop $y_i!$ as it now enters the equation linearly and is not a function of β. We utilize the standard approach to estimation noted in Cohn et al. (2022) and compute the Poisson Pseudo Maximum Likelihood (PPML) estimator by solving the series of first-order conditions

$$\sum_{i=1}^{n} \left[y_i - \exp\left(X_i \beta \right) \right] X_i = 0$$

numerically (Gourieroux et al., 1984; Correia et al., 2020).

OA.C.4 Data Details

OA.C.4.1 Sample

Our sample begins with all firms that can be matched between BoardEx, CRSP, and Compustat using the WRDS linking table. We further limit to firms with a zip code listed in Compustat.[15] Our sample period is chosen as 2006 to 2021. The lower bound is motivated by the availability of our measure of options in Execucomp as it begins being available only in 2006. The upper bound is chosen due to the availability of BTS data

[15] We also require that the zip code is in our very comprehensive zip code data which includes all current USPS zip codes.

which at the time of beginning inning analyses was only available completely through 2021.[16] We include all C-level executives and presidents. We do this by including all executives in Execucomp who have "CEO", "chief", "Chief", "pres", "Pres", "COO", "CIO", "CTO", "CMO", "CRO", or "CCO" in their title.[17]

OA.C.4.2 Flight Stopped/Started Variable Construction

In this section, we describe the computation of our direct flight-based variables. The primary starting point for our construction of this variable is data on firm directors from the BoardEx "Individual Profile Employment" data. We first identify the set of relevant directors for our firms.We define director positions based on the official BoardEx definition, using the "BrdPosition" variable, and also include directors who have "Independent Director" in their role name, given by the variable "RoleName", as this seems to be a likely miscoding.[18] Next, we need to identify the locations where these directors reside. The first assumption we make is that all inside directors are local to the firm. We determine inside directors as those for whom Boardex specifies are inside directors and those whose title suggests they work for the company.[19] Then, we try to identify the living locations of the remaining outside directors. The second assumption we make is that directors live in the last location they worked, not as board directors. We slightly generalize this assumption by using the last available non-board work location with a zip code in the data.[20] We get the locations of businesses from the "Company Profile Details" in BoardEx. We define location at the zip code level. Since most people do not live in the immediate vicinity of the firm, we assume directors live in or close to the zip code of the firm. Using the last known non-board work location may not be the most precise location, compared to the alternative of looking at director work locations over time; however, it eliminates selection issues, and while it may introduce noise, it should not introduce bias into our estimates. Thus we define the directors' locations as the last business they worked at in a non-board capacity with a zip code available in the

[16]Data was downloaded on February 7, 2023.

[17]As given by the variable TITLEANN in Execucomp.

[18]By the official BoardEx definition of directors, we mean all positions where "BrdPosition" is "Yes", "Inside", or "Outside".

[19]We classify all directors with titles that include "CEO", "CFO", "VP", "COO", "President", "Chief", "Senior", "Partner", "Merchandising Director", "ED", "MD", "Corporate Secratary", "Director - ", "Regional Head", "Regional Director", "CTO", "Division Director", "HR Director", "Regional Executive" as inside directors.

[20]This eliminates non-US addresses from our sample. We also only include zip codes in our very comprehensive zip code data which includes all current USPS zip codes.

BoardEx data. While many locations of firms are missing in the BoardEx data, we were able to assign a location to a very high percentage of the outside directors. Further, a high percentage of these were also the last non-board job a director held. Symmetrically, we define firm location also using its zip code from Compustat. We geocode the zip codes to specific latitudes and longitudes using data from SimpleMaps which includes all current USPS zip codes. We consider all directors within 240 km of the firm as local, which closely follows Bernile et al. (2018).

Next, we turn to calculating if a direct flight is available between two locations. Airport locations, latitudes, and longitudes come from the BTS Master Coordinate table. Data on direct flights come from "Data Bank 28DS - T-100 Domestic Segment Data" from the Bureau of Transportation Statistics (BTS). This comprehensive data covers all direct flights between US airports and is based on *required* reporting from airline carriers. It also includes other key data about the flight routes, such as the airline carrier, number of departures, and other key information about the type of flight. We limit the set of direct flights to scheduled passenger flights which can be understood as commercially available passenger flights. Flights that don't generate revenue are not reported and are not in public schedules (by definition); therefore, unscheduled passenger flights in our data generally must be charter flights since they generate revenue.[21] We also impose that included flight routes (the level of observation in the data which specifies the route, the airline, the type of airplane, and other variables) have a positive number of departures scheduled, departures performed, and passengers. We then aggregate this data to the yearly level for each route, a direct flight between two airports, and also check that there was a positive number of seats listed for this route across all of the specific flight routes. We also check that the route satisfies these conditions in both directions. Routes that meet all these conditions are considered available. This provides us with a set of direct flights between US airports.

Next, we need to calculate the set of airports for each location. We use cutoffs very close to those used in Bernile et al. (2018); however, we use kilometers instead of miles. First, we define the available airports for a location as the set of airports within 80 kilometers if there is at least one airport within 40 kilometers. If the closest airport is more than 40 kilometers away, we consider all airports within 40 kilometers of the closest airport as available for the destination. This ensures that our results are not driven by the cutoff when a director lives far from all airports. It is reasonable to think that a director

[21]The BTS definition of a scheduled departure is "Takeoffs scheduled at an airport, as set forth in published schedules."

might not choose the closest airport if a direct flight is available at another nearby airport. Thus for each year, we consider a director to have access to a direct flight if there is a direct flight as defined above between an airport available around the director's location to an airport available near the firm's location.

We construct two primary independent variables of interest. We focus only on changes in access to direct flights after an executive's tenure has started. We identify directors who lose access to a direct flight to the firm during their tenure and consider them affected until their tenure ends or they regain access to a direct flight. Similarly, we identify directors who gain access to a direct flight during their tenure and consider them affected until their tenure ends or they lose access to this direct flight. An executive-firm-year is considered affected if at least one treated director is on the board that year. Thus our "Direct Stopped" variable is one for all executives at a firm in which at least one member of the board of directors in that year has lost access to a direct flight to the firm after joining the board. In turn, the "Direct Started" variable is one for all executives at a firm in which at least one member of the board of directors in that year has gained access to a direct flight to the firm after joining the board.

OA.C.4.3 Data Definitions

Table OA.15. **Data Definitions**

Variable	**Definition**
Below Median Profitability	Defined as one if profitability, defined below, is below its median level among firms in our sample for that industry in that year.
CEO-Only	Defined as zero in firm years where the CEO in Execucomp, as denoted by the CEOANN variable, has a title, based on code TITLEANN, that contains "Chmn", "chmn", "Chair", or "chair", but not "Vice" or "vice" and one otherwise.

Direct Stopped	Defined is one for all executives at a firm in which at least one member of the board of directors in that year has lost access to a direct flight to the firm after joining the board and zero otherwise. All direct flights between the two regions from all airlines need to be stopped for the value to be one.
Direct Started	Defined as one for all executives at a firm in which at least one member of the board of directors in that year has gained access to a direct flight from some airline to the firm after joining the board and zero otherwise.
Direct Started (Any), $0 \leq t \leq 1$	Defined as one for the year of or following at least one member of the board of directors gaining access to a direct flight to the firm regardless of whether or not the director is still on the board. In the event that a director experiences the same start/stop of a direct flight more than once, we focus only on the time prior to the first change.
Direct Started (Any), $0 \leq t \leq 2$	Defined as one for the year of and two years following at least one member of the board of directors gaining access to a direct flight to the firm regardless of whether or not the director is still on the board. If a director experiences the same start/stop of a direct flight more than once, we focus only on the time prior to the first change.
Direct Stopped, $-3 \leq t < 0$	Defined as one for the three years prior to at least one member of the board of directors losing access to a direct flight to the firm after joining the board if the director that will be impacted is already on the board and zero otherwise. If a director experiences the same start/stop of a direct flight more than once, we focus only on the time prior to the first change.

Direct Stopped, $-5 \leq t < 0$	Defined as one for the five years prior to at least one member of the board of directors losing access to a direct flight to the firm after joining the board if the director that will be impacted is already on the board and zero otherwise. In the event that a director experiences the same start/stop of a direct flight more than once, we focus only on the time prior to the first change.
Direct Stopped, $-8 \leq t < 0$	Defined as one for the eight years prior to at least one member of the board of directors losing access to a direct flight to the firm after joining the board if the director that will be impacted is already on the board and zero otherwise. If a director experiences the same start/stop of a direct flight more than once, we focus only on the time prior to the first change.
Direct Stopped, $-10 \leq t < 0$	Defined as one for the ten years prior to at least one member of the board of directors losing access to a direct flight to the firm after joining the board if the director that will be impacted is already on the board and zero otherwise. If a director experiences the same start/stop of a direct flight more than once, we focus only on the time prior to the first change.
Direct Stopped (Any), $0 \leq t \leq 1$	Defined as one for the year of or following at least one member of the board of directors losing access to a direct flight to the firm regardless of whether or not the director is still on the board. If a director experiences the same start/stop of a direct flight more than once, we focus only on the time prior to the first change.
Direct Stopped (Any), $0 \leq t \leq 2$	Defined as one for the year of and two years following at least one member of the board of directors losing access to a direct flight to the firm regardless of whether or not the director is still on the board. In the event that a director experiences the same start/stop of a direct flight more than once, we focus only on the time prior to the first change.

Ever Stopped	Defined as one if the firm ever had an executive for which Direct Stopped is equal to one and zero otherwise.
Ever Started	Defined as one if the firm ever had an executive for which Direct Started is equal to one and zero otherwise.
Industry	Defined as the first three digits of the Standard Industry Classification code, variable code SIC, from Compustat.
Log Assets	Defined as the natural log of total assets, code AT, from Compustat. Winsorized at the 1% level.
Log Option Awards	Defined as the natural log of one plus the grant date fair value of options granted, code OPTION_AWARDS_FV, from Execucomp. Winsorized at the 1% level.
Log Stock Return	Using monthly stock return, code RET, from CRSP and the fiscal year end month, code FYR, from Compustat, the fiscal year stock return is calculated for the 12-month period ending in the month the fiscal year ends noted in the Compustat data. Winsorized at the 1% level.
Log Total Employment	Defined as the natural log of employment, code EMP, from Compustat. Winsorized at the 1% level.
Lag Log Stock Return	Defined the same as "Log Stock Return" but for the previous fiscal year.
Option Awarded (Y/N)	Defined as one if the grant date fair value of options granted, code OPTION_AWARDS_FV, is greater than zero and zero otherwise. Data from Execucomp.
Option Awards	Defined as the grant date fair value of options granted, code OPTION_AWARDS_FV. Data from Execucomp. Winsorized at the 1% level.
Option Awards / Salary	Defined as the grant date fair value of options granted, code OPTION_AWARDS_FV, divided by salary, code SALARY, from Execucomp. Winsorized at the 1% level.

Option Awards / Median Salary	Defined as the grant date fair value of options granted, code OPTION_AWARDS_FV, divided by median salary, code SALARY, for all years that executive worked at the company in Execucomp from 1992 to 2021. Data from Execucomp. Winsorized at the 1% level.
MSA	Address is based on the zip code listed in Compustat, variable code ADDZIP. We then match each zip code with the Metropolitan Statistical Area (or Micropolitan Statistical rea) in which the majority of its population resides using data from the 2020 Census provided by the Missouri Census Data Center via "Geocorr 2022: Geographic Correspondence Engine".
Profitability	Defined as operating income before depreciation, code OIDBP, divided by total assets, code AT, from Compustat. Winsorized at the 1% level.
State	The state is based on the state listed in Compustat, variable code STATE.