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Contractual Managerial Incentives with Stock Price Feedback†

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We study the effect of financial market frictions on managerial compensation. We embed a market microstructure model into an otherwise standard contracting framework, and analyze optimal pay-for-performance when managers use information they learn from the market in their investment decisions. In a less frictional market, the improved information content of stock prices helps guide managerial decisions and thereby necessitates lower-powered compensation. Exploiting a randomized experiment, we document evidence that pay-for-performance is lowered in response to reduced market frictions. Firm investment also becomes more sensitive to stock prices during the experiment, consistent with increased managerial learning from the market. (*JEL* D83, G12, G14, G32, G34, M12, M52)

Managers may fail to maximize firm value either because the information they possess is limited or because their incentives are misaligned. Economists often argue that CEO compensation is designed to improve firm outcomes, and separately, that financial markets convey information that is not otherwise available to corporate managers.[1] In this paper, we first develop a simple model in which information production in financial markets reduces the need for explicit contractual incentives for managers, and then document empirical evidence for this effect.

We analyze optimal pay-for-performance in a model in which managerial decisions are endogenous to trading due to informational feedback from

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[1] See, for example, Hayek (1945) and Dow and Gorton (1997). Also, see Bond, Edmans, and Goldstein (2012) for a review and online Appendix A for a brief summary of the empirical evidence.

stock prices. Specifically, we embed a stylized market microstructure model into an otherwise standard contracting model, and allow managers to learn and use information contained in the stock price for their investment decisions. By switching on and off the measure for stock market information, we nest the standard agency model and make the mechanism transparent. To gauge the empirical relevance of our theory, we exploit a randomized experiment that exogenously reduced market frictions for treated firms and thereby helped reward information production in the market. We find consistent evidence that financial market frictions play an important role in shaping executive compensation, particularly through the managerial learning channel.

A key theoretical insight is that information production in the financial market substitutes, in part, for incentive provision in managerial compensation contracts. By aggregating the information of many market participants, the market can guide managers in their decisions by conveying information that is not otherwise available to them. Anticipating that managers are guided by the market, shareholders find it less necessary to offer direct incentives in compensation.

In addition, an endogenous response of trading to executive pay can generate an amplification mechanism: low-powered compensation leads to increased uncertainty in firm value, which raises speculators' expected return from private information and thus encourages information production in the market. To take advantage of this incentivizing effect, shareholders further lower incentive pay.

A new testable implication follows from these mechanisms: a reduction in market frictions (i.e., anything that makes it easier for traders to profit from information) enables stock prices to better guide managerial decisions by revealing useful information, thereby rendering incentive compensation less necessary. We test this implication using a natural experiment, the Regulation SHO (Reg SHO) Pilot Program. The Reg SHO program removed short-sale restrictions for randomly selected (pilot) firms from May 2005 to August 2007, and existing studies have shown that this regulatory change effectively lowered trading frictions for pilot firms.[2] We find confirming evidence that managerial incentives in compensation, measured by scaled wealth-performance sensitivity (WPS), were significantly reduced in pilot firms during the program.

Naturally, one would expect that the compensation response should be concentrated in firms that made tangible changes in their compensation policy during Reg SHO, as such changes might not be immediate for all firms. We build a new dataset on CEO compensation contracts and find that our result is indeed driven largely by the pilot firms that announced changes in their CEO compensation policy, providing reassuring evidence that the reduced managerial incentives we document reflect firms' deliberate contracting decisions.

As our mechanism builds on managerial learning, a first-order prediction of our theory is that managers in pilot firms learn more information from the market and use that in their real decisions, such as investment. We assess this mechanism directly by examining whether Reg SHO affected investment-to-price sensitivity, a measure of managerial learning. Value-maximizing managers should

[2] See Alexander and Peterson (2008) and Diether, Lee, and Werner (2009) for example.

use all information available at that point to make their investment decisions, including both the information contained in stock prices and other information that managers have but that has not been incorporated into the prices yet. Investment will thus be more sensitive to stock prices when the price provides more information that is otherwise unknown to managers. We find consistent evidence that investment-to-price sensitivity increased significantly in pilot firms during Reg SHO, indicating a managerial learning channel. Our finding of greater investment-to-price sensitivity when market information increases is also consistent with Chen, Goldstein, and Jiang (2007), despite using different data and a different proxy for information content.

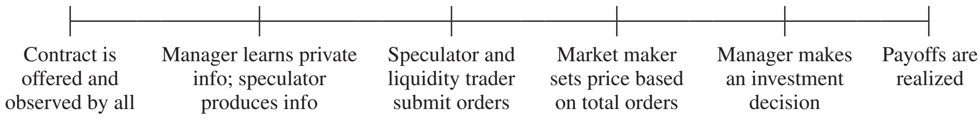
We also explore the role of an alternative mechanism: if stock volatility increased during the experiment, pilot firms might respond by reducing the exposure of compensation to share prices due to risk-sharing considerations. However, we find no evidence of significant changes in stock volatility for pilot firms. While we cannot rule out the alternative mechanism, the data patterns we document suggest that the risk-sharing consideration may not be the primary channel driving the compensation response to Reg SHO.

The literature broadly identifies two channels through which financial markets may affect real decisions. First, managers learn new information from stock prices and use this information to guide their real decisions, i.e., the feedback effect. Second, although managers do not learn new information from market prices, their incentives to take actions depend on the extent to which these actions will be reflected in stock prices. The existing papers that study managerial incentives in conjunction with stock markets focus on the second channel (for example, Diamond and Verrecchia 1982, Holmström and Tirole 1993, and Jayaraman and Milbourn 2012) and show a complementary relationship: shareholders increasingly tie compensation to a firm's stock price, as it better reflects managerial performance. However, the literature on managerial pay largely ignores the first channel that is at the heart of our analysis. Thus, our analysis provides a complementary view on the role of financial market conditions in structuring CEO pay, and presents empirical evidence that substitution between incentive compensation and information provision by the stock market can be an important consideration.

The next section outlines a contracting model with stock price feedback. Section II solves the equilibrium and derives testable implications. Section III presents our empirical findings, and Section IV concludes. The proofs are in the Mathematical Appendix.

I. The Model

To derive the contracting implications of stock price feedback, we integrate a market microstructure model into a contracting framework. Consider a one-period economy with a firm whose stock is traded in the financial market. Shareholders design a compensation contract, and based on the incentives in compensation, the firm's manager makes an investment that influences output and stock prices. The critical departure from a standard contracting environment is that our model includes a financial-market speculator whose information may be revealed in stock prices and subsequently be used in the manager's investment decision.



The above timeline chronicles the sequence of events in the model. At the beginning of the period, shareholders offer a compensation contract to the manager, which is observed by all agents in the economy. The underlying economic state, denoted by S, can be either good or bad, $S \in \{g, b\}$, and the manager privately knows the probability that the state is good, denoted by p. Upon observing the contract, a speculator decides how much information to produce, and he trades in the market if he becomes informed about the state. A liquidity trader simultaneously submits his market order, which is unrelated to the state realization. The market maker observes the total order flow and sets the stock price such that his expected profit is zero. After observing the stock price, the manager subsequently makes an investment. At the end of the period, the payoffs to all parties are realized based on the state realization.

The key ingredient in our contracting model is the feedback from stock prices to corporate investment. The speculator may have insights into the state realization that the manager missed. The manager observes the share price and subsequently uses this information to update his belief about the profitability of investment opportunities. Note that the feedback effect is taken into account by shareholders when designing the contract, by the speculator when producing information, and by the market maker when setting the price.

Manager.—A risk-neutral manager is hired to operate the firm and make an investment decision. The manager must choose one of two mutually exclusive investment opportunities, $I \in \{I_H, I_L\}, I_H > I_L$, where I_H and I_L represent high and low investment, respectively.[3] Investment of I_i costs I_i, and the investment payoff at the end of the period is $I_i(1+\eta)$ if the state is good (i.e., $S = g$) and $I_i(1-\eta)$ if the state is bad (i.e., $S = b$), where $0 < \eta < 1$, for $i \in \{H, L\}$. That is, with a baseline firm value of V_0, the firm has a terminal value of $V_0 + \eta I_i$ in the good state and $V_0 - \eta I_i$ in the bad state, for $i \in \{H, L\}$. The manager is privately informed about the probability of a good state (p). The probability p is a random variable, and all the other agents only know that p is uniformly distributed on the interval $[0,1]$.[4]

The manager's utility is of the form $U_m(w, I) = w + \delta I$, where w represents the manager's compensation payment, and the second term represents his empire-building motive: he derives private benefits from making investments, which are proportional to the size of capital invested.[5] If the stock price reveals the speculator's information, the manager will rationally update his belief and choose

[3] We do not set I_L to zero for ease of exposition related to investment-to-price sensitivity; in addition, this specification allows I_L to take negative values, capturing divestment.

[4] The expected value of p is 0.5, which implies that the ex ante probability of the good state is 0.5.

[5] Private benefits are not in terms of the consumption good and cannot be seized. It has been suggested by many papers that managers engage in value-destroying empire building, e.g., Jensen (1986, 1993); Stulz (1990); and Masulis, Wang, and Xie (2007). This assumption of empire-building managers has been widely used in the theoretical literature, e.g., Harris and Raviv (1990), Hart and Moore (1995), and Eisfeldt and Rampini (2008).

the corresponding optimal investment. Otherwise, the manager makes the investment decision responding to incentives in compensation given his private information (p). The manager's reservation utility is normalized to zero, and the manager also has limited liability, that is, his compensation cannot be negative.

Shareholders.—Risk-neutral shareholders design a compensation contract to maximize the expected firm value net of managerial pay. For tractability, the contract consists of β shares of stocks. The optimal contract contains zero base salary, which is an immediate result of the manager's zero reservation utility combined with the non-negativity of compensation. The contract implements a target investment policy, denoted by q (corresponding to a threshold p above which I_H is chosen). We will show later that there is a one-to-one correspondence between pay-for-performance β and target investment policy q. As the compensation contract is observed by all agents, the target investment policy q is also known to all agents.

Traders and Market Maker.—There is a speculator who produces information at a cost. In particular, the speculator can choose to observe the state with probability θ at a quadratic cost $C(\theta) = \frac{1}{2}A\theta^2$. The more cost the speculator incurs, the more likely he learns the state. With probability θ, the speculator perfectly observes the state; with probability $(1-\theta)$, his costly effort results in no learning. Trading in the market also incurs a fixed cost, denoted by c. A larger c implies lower trading profit for any given amount of information (θ) the speculator produces. Thus, we interpret a larger c as representing a more frictional market that makes it more difficult for the speculator to profit from information.

The speculator decides how much information (θ) to optimally produce and submits a market order, $z_s \in \{-1, 0, 1\}$, to maximize his trading profit.[6] The liquidity trader simultaneously submits either a buy or sell order of size 1 with equal probabilities: $z_\ell \in \{-1, 1\}$. The market maker can only observe the total order flow $X = z_s + z_\ell$ but not its individual components. Possible order flows are $X \in \{-2, -1, 0, 1, 2\}$. The market maker sets the price equal to the expected firm value, based on available information, including information contained in the total order flow and the incentives in the compensation contract: $P = E[V|X, \beta]$ (which can also be expressed as $E[V|X, q]$ because of a one-to-one correspondence between β and q), where V denotes the end-of-period firm value. In particular, the total order flow may contain information about the state realization when a speculator is present.[7]

The Perfect Bayesian Equilibrium we study is defined as follows: (i) an information production strategy and a trading strategy by the speculator, $T : \{\beta\} \rightarrow \{\theta, z_s\}$, that maximize his expected trading profit given the contract, the price-setting rule, and the speculator's information about the state; (ii) an investment strategy by the manager, $M : \{\beta, p, P\} \rightarrow \{I\}$, that maximizes his expected utility given the compensation contract, his private knowledge about the state, and the information revealed in the

[6] Our model results carry through in a setup with limit orders, which can allow for higher trading profit for the speculator.

[7] As is standard in the feedback literature, trades are anonymous, and the speculator cannot credibly communicate his private information to the manager outside the trading process.

stock price; (iii) a price-setting strategy by the market maker, $R: \{X, \beta\} \rightarrow \{P\}$, that allows him to break even in expectation given the information in the total market orders and the contract; and (iv) a compensation contract that includes a payment structure by shareholders, $\{\beta\}$, that maximizes the expected firm value net of compensation given the manager's strategy, the speculator's strategy, and the price-setting rule. Moreover, (v) using Bayes' rule, the market maker updates his belief based on the total order flow, and the manager updates his belief based on the price he observes in the market. Each player's belief about the other players' strategies is correct in equilibrium.

II. Equilibrium Contracting with Feedback

To characterize the equilibrium, we begin by taking compensation as given and analyzing the manager's investment decision as a response to incentives in the compensation contract. Then, for a given contract, we study the speculator's decision to produce information and trade. After solving for the strategies of the manager and the speculator, we endogenize the design of compensation, taking into account how compensation affects both managerial investment and the speculator's information production.

A. *Investment Policy Incentivized by Compensation*

We begin by analyzing the investment policy incentivized by a given contract in the case of no information production by the speculator; that is, θ is exogenously set to zero. Because the investment payoffs are symmetric about zero, the first-best investment policy is to choose high investment if $p \geq 1/2$.[8] With the managerial empire-building motive, it is straightforward to show that the investment policy implemented by compensation has a threshold property. The manager chooses high investment (I_H) if and only if p is at least as large as a threshold, denoted by q.[9] For a given investment policy with a threshold q, the expected firm value, denoted by $\mathcal{V}(q)$, is derived as follows: $\mathcal{V}(q) = V_0 + \int_0^q I_L[\eta p + (-\eta)(1-p)]dp + \int_q^1 I_H[\eta p + (-\eta)(1-p)]dp = V_0 + (I_H - I_L)\eta(q - q^2)$. It is clear that the first-best investment policy is $q = 1/2$. With agency frictions, increasing q (closer to the first best) enhances firm value, but it also increases the compensation necessary to induce q, resulting in a q that is lower than the first-best level. As the manager never chooses $q \geq 1/2$, we focus on $q < 1/2$ throughout the paper.[10]

For a given target investment policy with a threshold q (i.e., high investment is chosen if and only if $p \geq q$), we characterize the incentive-compatible pay-for-performance below. There is a one-to-one correspondence between β

[8] The expected return from the investment is $\eta p - \eta(1-p) = \eta(2p-1) \geq 0$ when $p \geq 1/2$.

[9] The investment policy has a threshold property in our model because the manager's utility differential between making high and low investments is strictly increasing in p.

[10] The incentive compatibility constraint is given by $\beta = \delta/[(1-2q)\eta]$, so $q \geq 1/2$ is not implementable; even if $q \geq 1/2$ is implementable, shareholders have no incentives to do so because inducing q above $1/2$ reduces both the expected investment payoff and information production in the market.

and q: to implement a higher q (and hence a lower likelihood of high investment) that is closer to the first-best strategy, higher-powered compensation is required.

OBSERVATION 1 (Pay-for-Performance): *For any given recommended investment policy* q $(< 1/2)$, *the incentive-compatible pay-for-performance is represented by* $\beta = \delta/[(1-2q)\eta]$. *Managerial pay-for-performance is thus increasing in the target investment policy* (q).

It is worth noting that the monotonic relation between β and q extends to the case with stock price feedback (i.e., $\theta > 0$). As shown in Section IIB, our model features are such that information revealed in the stock price affects only the manager's posterior belief about the state (i.e., $\Pr(S = g|p,P)$) but not his incentives. That is, given the compensation β, the manager chooses high investment if and only if the posterior belief of the good state $\Pr(S = g|p,P)$ is no less than q. The one-to-one relationship between β and q that is characterized in Observation 1 thus also holds in the presence of feedback and is independent of information production (θ) in our model.

B. *Information Production and Trading*

Recall that the speculator produces information (θ) at a cost $C(\theta) = \frac{1}{2}A\theta^2$. With probability θ, the speculator perfectly observes the state; with probability $(1-\theta)$, he fails to learn anything. If the speculator trades, there is a fixed cost, c. If c is sufficiently large, the speculator will not trade or produce any information, and this case is thus irrelevant to our analysis. As long as c is not too large, there is an equilibrium with information gathering and information-based trade, which we focus on throughout our analysis.

OBSERVATION 2: *Given the compensation contract, there exists a threshold* $c^* > 0$ (*independent of* β *and* q) *such that if* $c \leq c^*$, *there is an equilibrium with information production and information-based trade. In this equilibrium, the speculator will submit a buy* (*sell*) *order of size* 1 *if he observes that the state is good* (*bad*), *and the speculator does not trade if he does not observe the state.*

Following Kyle (1985), orders are submitted simultaneously to a market maker who sets the price and absorbs the order flows out of his inventory. A critical departure from Kyle (1985) is that firm value is endogenous in our model because it depends on the manager's investment, which is in turn based on information revealed in the stock price. Information contained in total order flows is identical to that in prices; thus, observing total order flows is equivalent to observing stock prices.

We characterize the stock price and the speculator's profits in each possible case in the table below. If there are two buy (sell) orders in the market, everyone in the economy understands that the speculator has observed a good (bad) state.[11]

[11] We allow market information to be noisy in online Appendix C and show broadly similar results.

The manager will update his belief and optimally choose high (low) investment. The market maker understands the feedback effect and sets the share price equal to $V_0 + \eta I_H$ $(V_0 - \eta I_L)$. In all the other cases, the total order flow does not reveal new information, as either the speculator's information gets contaminated with the liquidity trader's order or the speculator receives no information (and thus does not trade); the manager follows the investment policy (q) incentivized by the contract (β) given his private information p.[12] The stock price equals the expected firm value in the case of no information production (i.e., θ is exogenously set to zero), that is, $\mathcal{V}(q)$, in those cases.

Total order flow		Manager's updated $\Pr(S = g \mid p, P)$	Manager's investment	Stock price	Speculator's profit $\Pi(q)$
2 buy	$\rightarrow$	1	I_H	$V_0 + \eta I_H$	0
1 buy	$\rightarrow$	p	I_H if and only if $p \geq q$	$\mathcal{V}(q)$	0
1 buy 1 sell					$+$ (decr. in q)
1 sell					0
2 sell	$\rightarrow$	0	I_L	$V_0 - \eta I_L$	0

The speculator can extract information rents, denoted by Π, only when his private information is not fully priced in, and the information rents decrease with q. Recall that a smaller q (corresponding to a smaller β) implies an ex ante larger likelihood of high investment. The state-contingent rise and fall are correspondingly large for high investment, raising the value of information about the state. Increased uncertainty in firm value creates opportunities for trading profit and incentivizes information production.

The speculator's problem is to maximize his trading profit net of the costs, given the contract: $\max_\theta E\left[\Pi(q) \middle| \theta\right] - \frac{1}{2}A\theta^2 - c\theta$. Note that as the speculator trades with probability θ, the expected trading cost is $c\theta$. The solution represents the optimal information production, which is the speculator's reaction function given the managerial contract: $\theta = \frac{\eta}{2A}\left[I_H - q(I_H - I_L) - \frac{2c}{\eta}\right]$. Combining this with Observation 1, we derive the following results.

OBSERVATION 3 (Information Production): *The amount of information produced by the speculator is a decreasing function of market frictions* (c) *and of managerial pay-for-performance* (β).

Low-powered pay (a low β) corresponds to a low q, which implies greater uncertainty in firm value, consequently increasing the speculator's expected return

[12] Since the liquidity trader submits either a buy or a sell order with equal probability, if the total order flow is $X = -1$ or 1, it is clear that the order is submitted by the liquidity trader, revealing that the speculator receives no information and does not trade. The manager does not update his belief in this case. We extend the liquidity trader's trading behavior in online Appendix D by allowing for no trading by the liquidity trader; the manager will then update his belief when the total order flow is $X = -1$ or 1 because it may be coming from the speculator. We show similar results in the extended model.

from trading on his private information; the speculator will optimally produce more information. When market frictions become lower (i.e., a smaller c), all else being equal, the speculator anticipates higher trading profit and thus produces more information.[13]

C. *Firm Value*

Firm value is now endogenous to trading, as the manager optimally uses information revealed in stock prices to guide his investment decision. The expected firm value, denoted by $\mathcal{V}_F(q,\theta)$, can be derived as $\mathcal{V}(q) + \frac{\theta(I_H - I_L)\eta}{2}\left(\frac{1}{2} - q + q^2\right)$. We can see that an increase in firm value can arise from two sources: (i) the value created by directly implementing a desired investment policy using compensation (i.e., the first term) and (ii) the value created by the feedback from information revealed in stock prices (i.e., the second term). Shareholders effectively search for an optimal mix of these two vehicles that deliver value. The following result describes how firm value $\mathcal{V}_F(q,\theta)$ responds to an exogenous change in information production (θ) by the speculator.

OBSERVATION 4 (Firm Value): *For any given compensation contract*, *when the amount of information produced by the speculator exogenously increases*,

(*i*) *firm value increases* $\left(\frac{\partial \mathcal{V}_F}{\partial \theta} > 0\right)$;

(*ii*) *the marginal effect of incentive pay on firm value diminishes* $\left(\frac{\partial}{\partial \theta}\left(\frac{\partial \mathcal{V}_F}{\partial q}\right) < 0\right)$.

Information produced by the speculator constitutes firm value, because it guides real decisions and helps correct managerial bias. Shareholders can free-ride on the information the speculator produces and benefit from it. In addition, the marginal benefit of using compensation decreases with the amount of information produced by the speculator: when the improved information content of stock prices helps guide the manager's investment decisions, there is less necessity to use incentive pay.

D. *Optimal Pay-for-Performance*

Shareholders design an optimal compensation contract, understanding how the manager reacts given the incentives and how the speculator responds to managerial pay. Shareholders choose the number of shares (β^*) that maximizes the expected firm value net of managerial pay. Formally, the optimal contract solves

[13] The feature that an ex ante propensity for overinvestment increases market speculators' incentives to gather information is reminiscent of the traders' incentives studied in Dow, Goldstein, and Guembel (2017). In their model, this feature generates an informational amplification effect of shocks to firm value, making a market breakdown possible in response to a small decline in fundamentals. Our paper complements theirs by showing that this claim also amplifies the response in compensation when the financial market environment changes.

$\max_{\beta}(1-\beta)\mathcal{V}_F$, subject to $\beta^* = \delta/[(1-2q^*)\eta]$ and $E[U_m(w,I)] \geq 0$ (where w is the compensation $\beta^* V_F$). The first constraint is the incentive compatibility constraint on investment strategy (Observation 1). The second constraint is the participation constraint, which is automatically satisfied given the non-negativity of compensation. As a benchmark, we solve the case with no information production (i.e., θ is exogenously set to zero) and derive the optimal pay-for-performance $(\hat{\beta})$ and corresponding investment policy $(\hat{q})$ in online Appendix B.

To illustrate our main mechanism, we first take information production (θ) as exogenous and derive its influence on the design of managerial incentives. Suppose that the speculator exogenously produces more information (i.e., a larger θ). As the additional information revealed in prices helps clarify the outcome of managerial actions and thereby guides managers in their decisions, there is less need to provide direct incentives (Observation 4 (ii)). Improved information content of stock prices thus lowers managerial pay-for-performance, formalized as follows.

OBSERVATION 5 (Substitution between Market Information and Pay): *Optimal pay-for-performance decreases when the amount of information produced by the speculator* (θ) *exogenously increases.*

The information content of stock prices is endogenous in our model, as the speculator decides how much information to optimally produce (θ). We summarize the contracting results in Proposition 1.

PROPOSITION 1 (Contracting with Feedback): *Suppose that* $c \leq c^*$. *The optimal pay-for-performance in the presence of the feedback effect is lower than that in the case of no information production by the speculator.*

Two reinforcing mechanisms deliver this result. First, there is a substitution relationship between market information and incentive pay (Observation 5): stock prices can reveal information to a manager and guide his investment decisions, thereby necessitating lower-powered compensation. Second, an amplification effect arises from the endogenous response of information production to managerial pay (Observation 3): anticipating that low-powered compensation encourages information production by the speculator, the shareholders can take advantage of being the first mover by lowering incentive pay even more and thereby induce the speculator to produce more information.

In addition, the feedback from stock prices to managerial real decisions, such as an investment decision, induces a positive response of firm investment to stock price. That is, investment sensitivity to price is higher when the manager bases his investment decisions on the information he extracts from stock prices, as formally stated below.

OBSERVATION 6 (Investment-to-Price Sensitivity): *Suppose that* $c \leq c^*$. *The investment-to-price sensitivity in the presence of the feedback effect is greater than that in the case of no information production by the speculator.*

E. *Effects of Market Frictions*

To rigorously test our theory, we use market frictions (c) to derive a testable implication of how the feedback effect affects managerial compensation, as formally stated below.

IMPLICATION 1 (Effect of Market Conditions on Pay): *Suppose that $c \leq c^*$. As market frictions (c) decline, managerial compensation becomes less high-powered in the sense that β falls.*

When c decreases, reduced market frictions encourage information production and trading, which enables the market to reveal more information to the manager and guide his actions, rendering incentive compensation less necessary.

Our mechanisms are transparent enough that we expect them to hold in a more general environment. There are three key features: (i) the manager learns new information from stock prices and uses that in his real decisions; (ii) there are agency frictions; and (iii) the speculator's information production responds to managerial pay. The first two features are sufficient for delivering the substitution relationship between incentive contracting and market information (Observation 5; Implication 1). The last element can further amplify the effect of stock market conditions on managerial pay.[14]

III. Empirical Tests

A. *Methodology and Data*

Our model yields a testable implication new to the literature: a reduction in market frictions results in lower optimal pay-for-performance in CEO compensation. We test this implication using a natural experiment that better enables market participants to trade and profit from their private information in the US stock market: the Reg SHO pilot program. The Securities and Exchange Commission (SEC) randomly selected one-third of the Russell 3000 Index firms as pilot firms and removed the short-sale restrictions (uptick rule) for pilot firms from May 2005 to August 2007.[15] Specifically, the SEC sorted the 2004 Russell 3000 Index firms first by listing market and then by average daily dollar volume from June 2003 through May 2004, and it selected every third company starting with the second within each listing market.[16] The experiment has been shown to

[14] We discuss model robustness in detail in online Appendix E.

[15] The uptick rule is a trading restriction that allows short selling only on an uptick: the short must be either at a price above the last traded price of the security or at the last traded price when the most recent movement between traded prices was upward.

[16] In the fiscal year before the pilot program, pilot and non-pilot firms are similar with regard to firm characteristics including R&D spending, capital expenditure, size, growth, profitability, leverage, and dividend payout.

be effective in reducing trading costs.[17] We use this regulatory change to proxy for a plausibly exogenous reduction in market frictions for pilot firms.[18]

Following the literature (e.g., Edmans, Gabaix, and Landier 2009; Kim and Lu 2011; and Roosenboom, Schlingemann, and Vasconcelos 2014), we use the scaled wealth-performance sensitivity (WPS) to measure CEO pay-for-performance. WPS is calculated as the dollar change in CEO wealth for a one-percentage-point change in firm value, divided by annual compensation.[19] WPS is viewed as the elasticity of CEO pay to firm value and reflects changes in the value of a CEO's existing portfolio, including both new and existing grants. The key advantages of using WPS in our analysis are that (i) it is invariant to firm size and is thus comparable across firms and over time, and (ii) it is consistent with the multiplicative production function in our theory: Edmans, Gabaix, and Landier (2009) show that when managerial decision has a percentage effect on firm value and CEO utility, the percentage change in pay for a percentage change in firm value is the relevant incentive measure.

Data on stock prices and returns are from CRSP, and accounting data are from Compustat. The institutional ownership ratio and institutional ownership concentration are from Thomson Reuters Institutional (13F) Holdings.

B. *Compensation Response*

Full-Sample Analysis.—We examine whether the Reg SHO Pilot Program leads to a reduction in managerial incentives in compensation by employing a difference-in-differences technique in the following regression:

$$\beta_{i,t} = a_i + a_t + a_1 \cdot \mathbf{1}^{Pilot} \times \mathbf{1}^{During} + a_2 \cdot X_{i,t-1} + \epsilon_{i,t}, \tag{1}$$

where $\beta_{i,t}$ is the WPS for firm i in year t.[20] Here, a_i and a_t represent the firm fixed effects and year fixed effects, respectively. The time period is one year in our specification. The variable $\mathbf{1}^{Pilot}$ is a dummy for the treated firms, which equals one if firms are selected as pilot firms and zero for the other firms in the Russell 3000 Index (i.e., the control group); $\mathbf{1}^{During}$ is a year dummy that equals one for 2005 through 2007 and zero for 2001 through 2003. We exclude the year 2004, as that is the year when the SEC announced the pilot program.[21] The term $X_{i,t-1}$ denotes a set of control variables, including firm size, Tobin's Q, leverage ratio, a dividend payout dummy, firm age, institutional ownership, cash-to-asset ratio, capital expenditure, and return volatility.[22] We do not include $\mathbf{1}^{Pilot}$ or $\mathbf{1}^{During}$ separately in the regression, owing

[17] Alexander and Peterson (2008) find that the effective spreads of trades initiated by short sellers decreased significantly for pilot stocks. Diether, Lee, and Werner (2009) find that the relative bid depth increased significantly for pilot stocks.

[18] We study two additional experiments that lead to plausibly exogenous variations in trading frictions, namely, decimalization and Russell 1000/2000 indexing, and report coherent results in online Appendix F.

[19] WPS data are obtained from Alex Edmans' website: http://alexedmans.com/data/.

[20] We winsorize WPS at the 1 percent level to mitigate the influence of extreme outliers.

[21] Including the year 2004 does not change our results.

[22] A contemporaneous paper by De Angelis, Grullon, and Michenaud (2017) studies the *decomposition* of incentives and finds that pilot firms granted relatively more options for risk-shifting considerations. Our results are different from theirs in that we net out substitutions across compensation vehicles and study total incentives in compensation; further, we present a theory and supporting evidence for an information-based explanation.

Table 1—The Effects of Reg SHO on WPS

	WPS	WPS
$\mathbf{1}^{Pilot} \times \mathbf{1}^{During}$	−0.174	−0.203
	(0.077)	(0.079)
Size		0.019
		(0.058)
Q		0.031
		(0.022)
Leverage		0.001
		(0.001)
Dividend		−0.115
		(0.088)
Age		−0.005
		(0.009)
IOR		−0.101
		(0.159)
Cash		0.559
		(0.423)
INV		0.074
		(0.082)
IOC		−0.314
		(0.237)
RetStd		−0.046
		(0.274)
Year dummies	Yes	Yes
Firm dummies	Yes	Yes
Observations	9,400	7,657
R^2	0.709	0.742

Notes: This table presents the effects of Reg SHO on WPS. $\mathbf{1}^{Pilot}$ is a dummy variable that equals one for pilot firms and zero for the remaining firms in the Russell 3000 Index. $\mathbf{1}^{During}$ is a time dummy that equals one from 2005 through 2007 and zero for 2001 through 2003. WPS measures CEO pay-for-performance. *Size* is the logarithm of total assets. *Q* (Tobin's Q) is the ratio of the market value of assets to the book value of assets, where the market value of assets is defined as the book value of assets (data 6) plus the market value of common equity (data 25 times data 199) less the book value of common equity (data 60) and balance-sheet deferred taxes (data 74). *Leverage* is the sum of short-term debt (data 34) and long-term debt (data 9) divided by the sum of short-term and long-term debt and stockholders equity (data 216). *Dividend* is a dummy variable equal to one if a firm distributes dividends that year and zero otherwise. *Age* is calculated based on the first time the firm's accounting information appeared in Compustat. *IOR* is the institutional investors' ownership ratio. *Cash* is the ratio of cash (data 126) to total assets (data 6). *INV* is the investment-to-capital ratio, which is capital expenditure (data 128) divided by fixed assets (data 8). *IOC* measures the concentration of institutional ownership, which is the sum of the ownership ratio among the top five institutional investors. *RetStd* is the standard deviation of monthly stock returns. Standard errors are clustered at the firm level and reported in parentheses.

to collinearity with year- and firm-fixed effects. The standard errors are clustered at the firm level.

Table 1 presents the results. We find that the coefficient of $\mathbf{1}^{Pilot} \times \mathbf{1}^{During}$ is significantly negative, suggesting that pilot firms experienced a reduction in CEO incentive compensation during the program, compared with control firms. The economic magnitude of the effect is also sizable.[23] The point estimate from

[23] Our results are qualitatively similar using an alternative incentive measure based on dollar change in executive wealth per $1,000 change in firm value (Jensen and Murphy, 1990; Core and Guay, 2002).

the second column in Table 1 suggests that in response to a 100-percentage-point change in firm value, the response of pay in pilot firms is about 20 percentage points less than that in control firms during the experiment. Our result is in line with the idea that managerial incentive pay is lower when managers can learn more information from a less frictional market.

Subsample Analysis.—To further assess the validity of our claim, one natural test is to evaluate whether our results work through changes in CEO contract terms, as the contract change might not be immediate for all firms. Since there is no publicly available dataset on CEO contract changes, we build a new dataset on CEO contracts and assess whether our results are concentrated in the pilot firms that announced tangible changes in their CEO compensation policy.

We start by manually collecting CEO contract data from SEC filing exhibits in 8-K forms. Form 8-K, available in the SEC's EDGAR database, is the report companies must file with the SEC to announce major events that shareholders should know about, including updates about CEO compensation packages. We read each pilot firm's 8-K forms and obtain announcements regarding changes, amendments, and revisions of CEO contracts or compensation plans.[24] To ensure that the disclosed information is consistent across filings, we read and obtain information about pilot firms' CEO compensation contracts from Form 10-K, a comprehensive annual report that firms file with the SEC that is also available in the SEC's EDGAR database.[25] Firms' 10-Ks often do not contain information on compensation plans and thus serve as a cross-checking benchmark to avoid missing disclosed changes. We compare our data collected from 8-Ks with those collected from 10-Ks, and re-examine every firm-year pair for which the data differ. The resulting data indicate any disclosed changes in CEO compensation policy, including CEO compensation contracts and compensation plans. Overall, 51 percent of pilot firms announced changes in their CEO compensation policy during Reg SHO.

We then split pilot firms into two groups—firms that announced changes in their CEO compensation policy and those that did not—with the expectation that the subsample with the contract-change group should have stronger results than the subsample with the no-contract-change group.[26] We continue to retain the non-pilot firms as the control group in both subsamples. We re-run our equation (1) specification in the two subsamples and report our results in columns 1 through 4 of Table 2. Consistent with the idea that the compensation response to Reg SHO is largely driven by firms that made changes in their CEO compensation policy, we

[24] Changes in compensation plans also apply to the firm's other executives, in addition to the CEO.

[25] In addition to human reading of 10-Ks, we also utilize the standard language in 10-Ks to develop a computer-automated EDGAR scraper that identifies the dates of CEO contracts and subsequent amendments. In particular, we exploit Item 401(b) in 10-Ks, which specifies "describe briefly any arrangement or understanding between him and any other person(s) pursuant to which he was or is to be selected as an officer." We isolate (and store) sentences containing a quadruple of (i) the name of the CEO in question, (ii) "employment" or "stock (award)," or "stock option," or "bonus," (iii) "agreement" or "contract," and (iv) "effective." We then record the dates that appear in these sentences. As 10-K results represent a subset of information that can be extracted from 8-Ks, we use the results from 10-Ks (human-reading and computer-automated) to avoid missing disclosed changes (false negatives).

[26] For the contract-change subsample, we include all pilot firms that announced changes in CEO contracts or compensation plans in 2005 or 2006, as changes in 2007 may not immediately affect compensation payout that year. Only 0.03 percent of pilot firms changed their CEO compensation policy in 2007, compared with 42 percent in 2005 and 38 percent in 2006; thus, including compensation policy changes in 2007 generates very similar results.

Table 2—Effects in Firms that Changed/Did Not Change Compensation Policy

	Contract change		No contract change		Contract/CEO change		No contract/CEO change	
	WPS (1)	WPS (2)	WPS (3)	WPS (4)	WPS (5)	WPS (6)	WPS (7)	WPS (8)
$\mathbf{1}^{Pilot} \times \mathbf{1}^{During}$	−0.218	−0.232	−0.118	−0.159	−0.228	−0.252	−0.052	−0.065
	(0.112)	(0.114)	(0.090)	(0.088)	(0.095)	(0.098)	(0.111)	(0.099)
Size		−0.003		0.043		0.010		0.032
		(0.058)		(0.061)		(0.057)		(0.062)
Q		0.039		0.020		0.041		0.019
		(0.025)		(0.023)		(0.025)		(0.023)
Leverage		0.004		0.001		0.004		0.001
		(0.005)		(0.001)		(0.005)		(0.001)
Dividend		−0.082		−0.137		−0.083		−0.139
		(0.089)		(0.103)		(0.097)		(0.095)
Age		−0.004		−0.003		−0.008		0.001
		(0.009)		(0.010)		(0.009)		(0.010)
IOR		−0.163		−0.164		−0.187		−0.134
		(0.168)		(0.174)		(0.168)		(0.174)
Cash		0.503		0.353		0.508		0.323
		(0.451)		(0.425)		(0.438)		(0.436)
INV		0.156		0.018		0.065		0.044
		(0.144)		(0.063)		(0.080)		(0.140)
IOC		−0.300		−0.302		−0.275		−0.320
		(0.260)		(0.240)		(0.255)		(0.242)
RetStd		−0.188		−0.062		−0.185		−0.058
		(0.277)		(0.246)		(0.271)		(0.251)
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	7,935	6,501	7,903	6,328	8,298	6,813	7,540	6,016
R^2	0.698	0.725	0.709	0.741	0.693	0.718	0.715	0.750

Notes: The first four columns of this table present the effects of Reg SHO on WPS in two subsamples: firms that disclosed changes in CEO compensation policy (denoted as *Contract change*) and those that did not (denoted as *No contract change*); the non-pilot firms continue to be the control group in both subsamples. The last four columns of this table present the effects of Reg SHO on WPS in the following two subsamples: firms that disclosed changes in CEO compensation policy or had CEO change (denoted as *Contract/CEO change*) and those that did not do either (denoted as *No contract/CEO change*); the non-pilot firms continue to be the control group in both subsamples. Definitions of all variables are listed in Table 1. Standard errors are clustered at the firm level and reported in parentheses.

find that the result is economically and statistically stronger for the contract-change group.

Some of the firms in the no-contract-change group might have experienced a new CEO appointment during the experiment, rendering an opportunity to revise their CEO compensation policy. To identify all situations that likely imply tangible changes in CEO contract terms, we conduct an alternative exercise in which we include the pilot firms that entered into a new contract due to a new CEO appointment in the contract-change group. That is, we split pilot firms into two groups—firms that either announced changes in their CEO compensation policy or appointed a new CEO, and those that did not do either—retaining the non-pilot firms as the control group in both subsamples. The result in the contract/CEO-change group becomes more significant, which suggests that despite the potential compounding effects when the CEO changes, the new contracts offered by pilot firms during the experiment appear to have taken Reg SHO into consideration.[27] Moreover, the coefficient for the no-contract/CEO-change group is insignificant and very small (as shown in columns 7 and 8 of Table 2), providing reassurance that the compensation result documented in Table 1 indeed reflects deliberate contracting decisions.

C. *Managerial Learning from the Market*

A first-order prediction of our theory is that there is increased managerial learning from the market in pilot firms during Reg SHO. We assess this mechanism directly by examining the sensitivity of investment to stock price, a proxy for managerial learning (see, for example, Chen, Goldstein, and Jiang 2007 and Foucault and Fresard 2012, 2014). When managers decide on the level of investment, they should use all relevant information, including their own private information and new information revealed in stock prices. Investment will thus be more sensitive to stock price when the price provides more information that is not otherwise available to managers; information that managers already had will move the price but not affect the investment decision (as it has already affected past investments), thereby decreasing the sensitivity of investment to price (e.g., Chen, Goldstein, and Jiang 2007). Therefore, increased sensitivity of investment to stock price would be consistent with the notion that managers extract more information from stock prices that is new to them and use it in their investment decisions.

Following the literature, we use firms' Q (denoted by Q) to measure the (normalized) stock price. It is calculated as the market value of equity plus the book value of assets minus the book value of equity, scaled by book assets.[28] We perform the following regression:

$$
\begin{aligned}
I_{i,t} = {} & a_i + a_t + a_1 \cdot \mathbf{1}^{Pilot} \times \mathbf{1}^{During} \times Q_{i,t-1} + a_2 \cdot \mathbf{1}^{Pilot} \times \mathbf{1}^{During} \\
& + a_3 \cdot Q_{i,t-1} + a_4 \cdot \mathbf{1}^{During} \times Q_{i,t-1} + a_5 \cdot \mathbf{1}^{Pilot} \times Q_{i,t-1} \\
& + a_6 \cdot Controls + \epsilon_{i,t},
\end{aligned}
$$

where $I_{i,t}$ denotes firm i's investment in year t and is measured as either R&D spending or R&D and CAPX together (Bai, Philippon, and Savov 2016).[29] Following Chen, Goldstein, and Jiang (2007), we include current cash flow to control for the effect of cash flow on investment, the value-weighted market adjusted future three-year cumulative return to control for managers' market timing of

[27] The coefficients for the two subsamples are statistically different at the 10 percent level based on SUR estimation.

[28] Following Chen, Goldstein, and Jiang (2007) and Foucault and Fresard (2012), the market value is calculated as price times shares outstanding from CRSP, and the book value is (Item 6–Item 60 in Compustat).

[29] Bai, Philippon, and Savov (2016) demonstrate increased price informativeness by showing that stock prices have become stronger predictors of investment as measured by either R&D alone or R&D and CAPX together (not CAPX alone, though). They argue that market information is particularly useful for real decisions like R&D. They also find a declining importance of CAPX.

Table 3—The Effects of Reg SHO on Investment-to-Price Sensitivity

	R&D	R&D	R&D + CAPX	R&D + CAPX
$Q \times \mathbf{1}^{Pilot} \times \mathbf{1}^{During}$	0.004	0.005	0.004	0.005
	(0.001)	(0.001)	(0.002)	(0.002)
$\mathbf{1}^{Pilot} \times \mathbf{1}^{During}$	−0.006	−0.007	−0.006	−0.008
	(0.002)	(0.002)	(0.005)	(0.005)
Q	0.005	0.004	0.013	0.012
	(0.001)	(0.001)	(0.002)	(0.002)
$Q \times \mathbf{1}^{During}$	−0.000	−0.000	0.000	−0.000
	(0.001)	(0.001)	(0.001)	(0.002)
$Q \times \mathbf{1}^{Pilot}$	−0.003	−0.003	−0.003	−0.002
	(0.001)	(0.001)	(0.002)	(0.002)
CF		−0.050		−0.006
		(0.016)		(0.027)
Future 3yr ret		0.000		−0.006
		(0.000)		(0.001)
1/AT		2.803		4.704
		(0.925)		(1.902)
Year dummies	Yes	Yes	Yes	Yes
Firm dummies	Yes	Yes	Yes	Yes
Observations	8,307	7,779	8,267	7,746
R^2	0.921	0.924	0.845	0.845

Notes: This table presents the effects of Reg SHO on investment-to-price sensitivity. $\mathbf{1}^{Pilot}$ and $\mathbf{1}^{During}$ are defined in Table 1. *R&D* is R&D expenses (Compustat Annual Item 128 plus Item 46) scaled by beginning-of-year book assets (Item 6); *CAPX* is capital expenditures scaled by beginning-of-year book assets. Q is the ratio of the market value of assets to the book value of assets, where the market value of assets is defined as the book value of assets (data 6) plus the market value of common equity (data 25 times data 199) less the book value of common equity (data 60) and balance-sheet deferred taxes (data 74). *CF* (cash flow) is computed as the sum of income before extraordinary items and depreciation, scaled by assets, in the current period. *Future 3yr ret* is the value-weighted market adjusted future three-year cumulative return. $1/AT$ is the reverse of lagged total assets. Standard errors are clustered at the firm level and reported in parentheses.

investment, and the reverse of lagged total assets to isolate the correlation induced by the common scaling variable.[30]

Table 3 shows a positive and significant coefficient for the triple interaction between the pilot firm dummy, the pilot period dummy, and Q. Reg SHO can double the investment-to-price sensitivity, consistent with the notion that the content of increased information is useful to managers such that managers rely more on stock prices for their investment decisions. Our finding of higher sensitivity of corporate investment to price is also consistent with Chen, Goldstein, and Jiang (2007), albeit using an alternative proxy for information content and different data.

D. *Alternative Explanation*

An alternative explanation for the compensation response to Reg SHO is that stock volatility might increase in pilot firms, leading firms to respond by reducing

[30] Our results are robust to alternative control variables, including the controls used in Foucault and Fresard (2012), for example.

the exposure of managerial compensation to stock prices due to the risk-sharing consideration (Holmström and Milgrom 1987). However, Diether, Lee, and Werner (2009) show that returns and volatility at the daily level are unaffected in pilot firms during Reg SHO. In addition, Deng, Gao, and Kim (2017) show that stock crash risk is reduced in pilot firms, consistent with the argument in Hong and Stein (2003) that crash risk declines with short selling because stock prices incorporate negative information faster.

To further gauge the role of stock volatility in accounting for the changes in CEO compensation during Reg SHO, we examine whether Reg SHO affects stock volatility at the annual level in pilot firms, as long-term volatility may be more relevant for contracting purposes than daily volatility. We use the difference-in-differences methodology as in the following regression:

$$vol_{i,t} = a_i + a_t + a_1 \cdot \mathbf{1}^{Pilot} \times \mathbf{1}^{During} + a_2 \cdot X_{i,t-1} + \epsilon_{i,t}, \tag{2}$$

where $vol_{i,t}$ is firm i's stock return volatility in year t, measured by both total volatility (denoted by *tvol*), which is the standard deviation of daily stock returns, and idiosyncratic volatility (denoted by *ivol*), calculated as the residuals of the Fama-French 3-factor regression (Ang et al. 2006). All the other variables are the same as defined in equation (1). As shown in Table 4, there are no significant differences in volatility between pilot and control firms during Reg SHO.[31] Although we cannot rule out the alternative mechanism, the patterns we document suggest that the risk sharing consideration may not be the key driver of the compensation response to Reg SHO.[32]

IV. Conclusion

Existing studies have analyzed managerial compensation and stock price feedback in isolation. As the feedback effect directly influences managerial behavior, compensation should optimally adjust for it. In this paper, we study the contracting implications of the feedback effect and show, both theoretically and empirically, that when the financial market becomes less frictional, information provision in the stock market substitutes, in part, for incentive compensation. The reason is that information revealed in stock prices clarifies the outcome of managerial actions ex ante, helping to prevent managers from engaging in harmful activities and thus making incentive compensation less necessary. We document significant decreases in incentive compensation in response to exogenous reductions in market frictions, and we also find patterns in the data that are consistent with a managerial learning mechanism. Our empirical analysis yields a set of results that are difficult to coherently rationalize with an alternative theory. Collectively, these results point to the feedback effect as the most consistent explanation. We do not, however, attribute

[31] We also find no significant changes in stock volatility in either the contract-change group or the no-contract-change group, as reported in online Appendix F.

[32] Using a logit regression, we find that the likelihood of CEO compensation policy changes is significantly and negatively related to the firm's prior trading frictions but not stock volatility, as reported in online Appendix F.

Table 4—The Effects of Reg SHO on Stock Volatility

	tvol	*tvol*	*ivol*	*ivol*
$\mathbf{1}^{Pilot} \times \mathbf{1}^{During}$	0.324	0.544	0.266	0.388
	(0.581)	(0.507)	(0.487)	(0.454)
Size		3.064		2.009
		(0.731)		(0.632)
Q		0.948		0.501
		(0.200)		(0.120)
Leverage		−0.058		−0.049
		(0.024)		(0.019)
Dividend		1.739		1.967
		(0.728)		(0.697)
Age		−1.399		−1.307
		(0.132)		(0.111)
IOR		−5.664		−7.040
		(1.886)		(1.743)
Cash		−4.432		−3.271
		(7.480)		(7.105)
INV		4.853		3.142
		(1.782)		(1.209)
IOC		4.829		6.277
		(2.760)		(2.537)
RetStd		40.491		31.363
		(4.665)		(3.940)
Year dummies	Yes	Yes	Yes	Yes
Firm dummies	Yes	Yes	Yes	Yes
Observations	9,140	7,654	9,140	7,654
R^2	0.756	0.811	0.755	0.799

Notes: This table presents the effects of Reg SHO on stock volatility. *tvol* is total volatility, measured as the standard deviation of daily stock returns. *ivol* is idiosyncratic volatility, calculated based on the Fama-French 3-factor model. The other variables are defined in Table 1. Standard errors are clustered at the firm level and reported in parentheses.

the compensation changes *entirely* to feedback. Given the mounting evidence on informational feedback from stock prices, this paper is a first attempt to examine whether and how financial market conditions affect the design of executive compensation through a managerial learning channel. Certainly more work lies ahead to better understand the quantitative importance of the feedback effect in shaping executive pay.

Mathematical Appendix

PROOF OF OBSERVATION 1:

To implement a target investment policy with a threshold q—high investment is chosen if and only if $p \geq q$—incentive compatibility requires that the manager prefers high investment for all $p \geq q$, which implies that the manager is indifferent between high and low investment when $p = q$: $\beta[qI_H\eta - (1-q)I_H\eta] + \beta V_0 + \delta I_H = \beta[qI_L\eta - (1-q)I_L\eta] + \beta V_0 + \delta I_L$.

Recall that compensation is fully characterized by pay-for-performance (β) in our model, due to the assumption of linearity and non-negativity. The incentive-compatible pay-for-performance is thus given by $\beta = \frac{\delta}{(1-2q)\eta}$. Thus, β is strictly increasing in q. ∎

PROOF OF OBSERVATION 2:

Suppose that $c \leq c^*$, where $c^* = \frac{\eta}{2}\left(\frac{1}{4}I_H + \frac{3}{4}I_L\right)$. We prove the existence of the equilibrium below. Suppose that the market's belief on the speculator's trading strategy is that he will buy on good news, sell on bad news, and not trade with no news. We will verify that the speculator will collect information and his optimal trading strategy is consistent with the market's belief. Recall that $q < 1/2$ in equilibrium. If the speculator receives good news, then his expected payoff will be $\frac{1}{2}(1-q)(V_0 + \eta I_H - \mathcal{V}(q)) + \frac{1}{2}q(V_0 + \eta I_L - \mathcal{V}(q)) - c$ $= \frac{1}{2}\eta[(1-q)^2 I_H + q(2-q)I_L] - c > 0$ if he submits a buy order; 0 if he does not trade; $-\eta I_L - \frac{1}{2}\eta[(1-q)^2 I_H + q(2-q)I_L] - c < 0$ if he submits a sell order; thus, the speculator's optimal strategy is to submit a buy order. Similarly, if the speculator receives bad news, then his expected payoff will be $\frac{1}{2}(1-q)$ $\times (\mathcal{V}(q) + \eta I_H - V_0) + \frac{1}{2}q(\mathcal{V}(q) + \eta I_L - V_0) - c = \frac{1}{2}\eta\left[\left(1-q^2\right)I_H + q^2 I_L\right] -$ $c > 0$ if he submits a sell order; 0 if he does not trade; and $-\eta I_H - \frac{1}{2}\eta\left[\left(1-q^2\right)I_H + q^2 I_L\right] - c < 0$ if he submits a buy order; thus, the speculator's optimal strategy is to submit a sell order if he receives bad news. If the speculator does not receive any news, then his expected payoff will be $\frac{1}{2}(\mathcal{V}(q) - V_0 - \eta I_H) - c < 0$ if he submits a buy order; 0 if he does not trade; and $\frac{1}{2}(V_0 - \eta I_L - \mathcal{V}(q)) - c < 0$ if he submits a sell order; thus, the speculator's optimal strategy is to not trade in this case. Thus, we have verified that there exists an equilibrium in which the speculator produces information and submits a buy order of size 1 if he observes a good state, submits a sell order of size 1 if he observes a bad state, and does not trade if he does not observe the true state. This strategy is consistent with the market's belief. ∎

PROOF OF OBSERVATION 3:

The speculator's expected trading profits are calculated as follows:

$$E[\Pi(q)|\theta] = \int_0^q \left[\frac{p\theta}{2}(\eta I_L + V_0 - \mathcal{V}(q)) + \frac{(1-p)\theta}{2}(\mathcal{V}(q) + \eta I_L - V_0)\right] dp$$
$$+ \int_q^1 \left[\frac{p\theta}{2}(\eta I_H + V_0 - \mathcal{V}(q)) + \frac{(1-p)\theta}{2}(\mathcal{V}(q) + \eta I_H - V_0)\right] dp$$
$$= \frac{\theta\eta}{2}(I_H - q(I_H - I_L)).$$

The first-order condition for the speculator's problem yields $\theta = \frac{\eta}{2A}\left(I_H - q(I_H - I_L) - \frac{2c}{\eta}\right)$. ∎

PROOF OF OBSERVATION 4:

In the model, with probability $\frac{p\theta}{2}$, the manager learns from the market that the state is good and consequently chooses high investment; with probability $\frac{(1-p)\theta}{2}$, the manager learns about the bad state and thus chooses low investment. The expected firm value, denoted by $\mathcal{V}_F(q,\theta)$, can be derived as follows: $\mathcal{V}_F(q,\theta) = E\Big[\frac{p\theta}{2}(V_0 + I_H\eta) + \frac{(1-p)\theta}{2}(V_0 - I_L\eta) + \big(1 - \frac{\theta}{2}\big)\mathcal{V}(q)\Big] = \mathcal{V}(q) + \frac{\theta(I_H - I_L)\eta}{2}\big(\frac{1}{2} - q + q^2\big)$. Recall that $\mathcal{V}(q)$ in the proof of Observation 1 in this Appendix. As $\frac{\theta(I_H - I_L)\eta}{2}\big(\frac{1}{2} - q - q^2\big) > 0$, for $0 < q < 1/2$, we have $\mathcal{V}_F(q,\theta) > \mathcal{V}(q)$, $\forall q$. Denote $\Delta = I_H - I_L$. We have (i) $\frac{\partial\mathcal{V}_F}{\partial\theta} = \frac{\Delta\eta}{2}\big(\frac{1}{2} - q + q^2\big) > 0$, (ii) $\frac{\partial}{\partial\theta}\left(\frac{\partial\mathcal{V}_F}{\partial q}\right) = \frac{\Delta\eta}{2}(-1 + 2q) < 0$. ∎

PROOF OF OBSERVATION 5:

The shareholders' objective function is given by $\max_q (1-\beta)\mathcal{V}_F$, where $\beta = \frac{\delta}{(1-2q)\eta}$. Taking the first-order condition yields that $(1-\beta)\frac{\partial\mathcal{V}_F}{\partial q} - \frac{2\beta}{1-2q}\mathcal{V}_F = 0$. Let $G(q,\theta)$ denote the left-hand side of the first-order equation. Since $\frac{\partial G}{\partial q}\Big|_{q=q^*} < 0$ and by Observation 4, $\frac{\partial G}{\partial\theta} = (1-\beta)\frac{\partial}{\partial\theta}\left(\frac{\partial\mathcal{V}_F}{\partial q}\right) - \frac{2\beta}{1-2q}\frac{\partial\mathcal{V}_F}{\partial\theta} < 0$, we obtain $\frac{\partial q^*}{\partial\theta} < 0$ and $\frac{\partial\beta^*}{\partial\theta} < 0$ by the Implicit Function Theorem. ∎

PROOF OF PROPOSITION 1:

As the case of no information production corresponds to $\theta = 0$, it immediately follows from Observation 5 that $\beta^* < \hat{\beta}$. ∎

PROOF OF OBSERVATION 6:

We derive the investment-to-price sensitivity, $\beta_{IP} \equiv \frac{\text{cov}(I,P)}{\text{var}(P)}$, in our model. Without the feedback effect, the manager always follows his own private information when making investment decisions. The stock price is set accordingly to be $\mathcal{V}(q)$, and the investment is unrelated to stock price. That is, the investment-to-price sensitivity equals zero in the case of no information production.

In the presence of the feedback effect, we can calculate that

$$E[I \times P] = E\Big[\frac{p\theta}{2}I_H(V_0 + I_H\eta) + \frac{(1-p)\theta}{2}I_L(V_0 - I_L\eta) + \Big(1 - \frac{\theta}{2}\Big)I_0\mathcal{V}(q)\Big]$$

$$= \frac{\theta}{4}I_H(V_0 + I_H\eta) + \frac{\theta}{4}I_L(V_0 - I_L\eta) + \Big(1 - \frac{\theta}{2}\Big)I_0\mathcal{V}(q),$$

where $I_0 = (1-q)I_H + qI_L$,

$$
\begin{aligned}
E[I] &= E\left[\frac{p\theta}{2}I_H + \frac{(1-p)\theta}{2}I_L + \left(1-\frac{\theta}{2}\right)I_0\right] = \frac{\theta}{4}I_H + \frac{\theta}{4}I_L + \left(1-\frac{\theta}{2}\right)I_0,\\
E[P] &= E\left[\frac{p\theta}{2}(V_0 + I_H\eta) + \frac{(1-p)\theta}{2}(V_0 - I_L\eta) + \left(1-\frac{\theta}{2}\right)\mathcal{V}(q)\right]\\
&= \frac{\theta}{4}(V_0 + I_H\eta) + \frac{\theta}{4}(V_0 - I_L\eta) + \left(1-\frac{\theta}{2}\right)\mathcal{V}(q),\\
\operatorname{cov}(I,P) &= E[I \times P] - E[I]\cdot E[P]\\
&= \frac{\theta}{4}I_H\eta\left[\frac{\theta}{4}(I_H - I_L) + \left(1-\frac{\theta}{2}\right)(I_H - I_0)\right]\\
&\quad + \frac{\theta}{4}I_L\eta\left[\frac{\theta}{4}(I_H - I_L) + \left(1-\frac{\theta}{2}\right)(I_0 - I_L)\right]\\
&\quad + \left(1-\frac{\theta}{2}\right)(I_H - I_L)\,\eta\left(q-q^2\right)\frac{\theta}{4}(2I_0 - I_H - I_L)\\
&> 0,
\end{aligned}
$$

since $I_0 > \frac{1}{2}(I_H + I_L)$.

Hence, the investment-to-price sensitivity in the presence of the feedback effect is greater than that in the case of no information production. ∎

PROOF OF IMPLICATION 1:

Plugging $\theta = \frac{\eta}{2A}\left(I_H(1-q) + I_L q - \frac{2c}{\eta}\right)$ into $\mathcal{V}_F(q,\theta)$ yields that maximizing $\left[1 - \frac{\delta'}{(1-2q)}\right]\mathcal{V}_F(q,\theta)$ is equivalent to maximizing $F(q,x) = \left[1 - \frac{\delta'}{(1-2q)}\right]\left[-\Delta q^3 + (2I_H - I_L - B)q^2 - \left(\frac{3}{2}I_H - \frac{1}{2}I_L - B\right)q + \frac{I_H}{2} + \frac{V_0 B}{\Delta\eta}\right]$, where $B = \frac{4A}{\eta}$, and $\delta' = \frac{\delta}{\eta}$. Denote $f(q,x) = \frac{\partial F}{\partial q}$, where x refers to the parameter I_H, I_L, c, or A. Then we have $\frac{\partial f}{\partial x} + \frac{\partial f}{\partial q}\frac{\partial q}{\partial x} = 0$. Since at the maximum q^*, we must have $\frac{\partial f}{\partial q} < 0$, the sign of $\frac{\partial q}{\partial x}$ is the same as the sign of $\frac{\partial f}{\partial x}$. Note, $\frac{\partial f}{\partial c} = \frac{\partial}{\partial q}\left(\frac{\partial F}{\partial c}\right) = \frac{2}{\eta}\left[\frac{2\delta'}{(1-2q)^2}\left(\frac{1}{2} - q + q^2\right) + \left[1 - \frac{\delta'}{(1-2q)}\right](1-2q)\right] > 0$. Therefore, q^* and β^* are both increasing in c. ∎

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