A Missing Link in the Risk-Incentive Tradeoff *

Qiang Kang †
University of Miami

Qiao Liu ‡
University of Hong Kong

This Draft: May 2005

Abstract

We investigate the role of information-based trading in affecting the risk-incentive relation. We analytically decompose the risk-incentive relation into two *offsetting* components. Directly reducing incentive aside, a greater uncertainty increases the level of information-based trading which enhances incentives indirectly. Numerical analysis shows that the indirect effect is about 40-50% of the direct effect in size and contributes significantly to social welfare improvement. Empirical tests using probability of informed trading (PIN) and CEO compensation data show that a median level of information-based trading on average causes a 20% offset of the risk-incentive tradeoff and improves CEO incentives by 15-96%.

JEL Classification: D80, G14, G32, J33
Keywords: Risk-incentive tradeoff, information-based trading, pay-performance sensitivity, PIN measure

*We thank Chong-En Bai, Xianming Zhou, and seminar participants at University of Hong Kong for helpful comments. An earlier draft was completed while Kang was affiliated with University of Hong Kong, whose hospitality is gratefully acknowledged. We thank Clara Vega and Rong Qi for sharing with us programming codes and offering computational suggestions. We appreciate the financial support from University of Hong Kong and University of Miami (Kang) and the RGC Earmarked Research Grant HKU 7128/01H (Liu). This research is also substantially supported by a grant from the University Grants Committee of the Hong Kong Special Administrative Region, China (Project No. AOE/H-05/99). All errors remain our own responsibility.

†**Corresponding author.** Mailing address: Finance Department, University of Miami, P.O. Box 248094, Coral Gables, FL 33124-6552. Phone: (305)284-8286. Fax: (305)284-4800. E-mail: q.kang@miami.edu.

‡Faculty of Business and Economics, University of Hong Kong. Phone: (852)2859-1059. Fax: (852)2548-1152. E-mail:qliu@hku.hk.

A Missing Link in the Risk-Incentive Tradeoff

Abstract

We investigate the role of information-based trading in affecting the risk-incentive relation. We analytically decompose the risk-incentive relation into two *offsetting* components. Directly reducing incentive aside, a greater uncertainty increases the level of information-based trading, which consequently enhances incentives. Numerical analysis shows that this indirect effect is about 20-40% of the direct effect in size and contributes significantly to social welfare improvement. Empirical tests using probability of informed trading (PIN) and CEO compensation data show that a median level of risk-related information-based trading on average causes a 38% offset of the risk-incentive tradeoff and improves CEO incentives by 16-52%.

JEL Classification: D80, G14, G32, J33

Keywords: Risk-incentive tradeoff, information-based trading, pay-performance sensitivity, PIN measure

1 Introduction

A standard principal-agent model predicts a negative relation between risk and incentives (Holmstrom 1979, and Holmstrom and Milgrom 1987). Uncertainty of an economy adds observation errors to agents' performance measures and dampens agents' incentives to act in the principal's best interest. The principal is less likely to use an incentive pay scheme in a more uncertain environment than in a less uncertain environment. However, evidence is weak in supporting the prediction.[1]

Directly reducing incentives aside, uncertainty may affect incentive provision through other channels. Prendergast (2002) argues that the uncertainty of environment has a positive impact on incentive provisions through the allocation of responsibility to employees. Raith (2003) posits that incentives might be positively related to firm risk because changes in competition, due to free entry and exit in the industry, alter the value of cost reduction and the variance of firms' profits in the same direction. In this paper, we propose another indirect effect that is missing from the incentive literature, that is, information enhancement due to information-based stock trading driven by uncertainty. A greater uncertainty attracts more informed stock traders and motivates more information-based trading than a lower uncertainty does. As a result, a stock price contains more informational content, which a principal can use to induce more effort from his agent. We characterize this indirect effect analytically and quantify its economic significance both numerically and empirically.

We develop a parsimonious model that combines an optimal contracting process with a stock trading process. Our model, although sharing many aspects of Holmstrom and Tirole's (1993) model, clearly demonstrates the impact of differential levels of information-based stock trading on the risk-incentive relation. In our model, the informational content in the stock price is endogenously determined and depends only on market characteristics such as risk, liquidity, precision of private signals, and reservation value of becoming an informed trader. We analytically decompose the equilibrium impact of risk on incentives into two offsetting effects: one measures the standard risk-incentive tradeoff given a certain level of information-based trading; and the

[1] For example, incentive pay schemes are widely used by new-economy firms, whose risks are arguably high (Ittner, Lambert and Larcker, 2003). Empirically, the executive compensation literature yields mixed results on the risk-incentive relation. Aggarwal and Samwick (1999) and Jin (2002) report a significantly negative relation between CEO incentives and risks. Core and Guay (1999, 2002) document a significantly positive relation. Garen (1994) and Yermack (1996) find no significant correlation.

other reflects the incentive enhancement due to an increasing level of information-based trading driven by uncertainty. Although the incentive enhancement effect is strictly dominated and the overall risk-incentive relation remains negative, the incentive enhancement effect partially offsets the risk-incentive tradeoff and flattens the risk-incentive curve (see Figure 1). As an illustration, compare firms A and B in Figure 1, which have different levels of information-based stock trading. Although facing a greater uncertainty, firm B retains a higher level of managerial incentives than firm A, thanks to a larger amount of information-based trading in firm B stocks.

We conduct a numerical analysis to evaluate the economic magnitude of the incentive enhancement effect. We calibrate parameter values of the model based on real-world executive compensation data. The incentive enhancement effect, though strictly dominated, contribute significantly to cross-sectional differences in pay-performance sensitivities. Numerical results show that the incentive enhancement effect offsets the incentive reduction effect of risks by 20-40%, and that the offset gains strength as the fundamental uncertainty rises. We also find that the optimal managerial incentive increases monotonically as the stock liquidity improves, and that the optimal managerial incentive displays a U-shaped response to either the reservation value of becoming an informed trader or the noisiness of private signals.

We test the main prediction of the model by using the CEO compensation data drawn from Compustat's ExecuComp database. We use probability of informed trading (PIN), developed in Easley, Kiefer and O'Hara (1996, 1997), as a proxy for the amount of information-based stock trading. The PIN measure calculated from the TAQ database involves only trading data and captures the amount of (private) information incorporated into stock prices. If the incentive enhancement effect does exist and play a significant role, we expect the firms with larger PIN measures to have less steeply downward-sloped risk-incentive curves because the incentive enhancement effect partially offsets the negative risk-incentive relation. The empirical evidence lends support to our model prediction. For a firm with a median level of information-based stock trading, the percentage offset of the incentive enhancement effect against the risk-incentive tradeoff averages at about 20 percent over the sample period 1994-2001. We further decompose the PIN measure into the risk-related and non-risk-related components, and we find that the information-based trading has both a positive level effect and a positive slope effect on CEO incentives. On the one hand, a median level of *non-risk-related* information-based trading increases the level of CEO incentives by \$1.823, per \$1,000 increase in the shareholder value. On the other hand, for a firm at the median level of *risk-related* information-based trading, the percentage offset of the incentive enhancement effect against the incentive-reduction effect averages at about 38 percent over 1994-2001. Every one percent increase in the level of risk-related information-based stock trading offsets the risk-incentive tradeoff by 0.624 percent.

Our empirical results also illustrate the economic significance of the information enhancement effect on the level of CEO incentives. We find that, for a firm of median characteristics, the CEO incentive, measured by pay-performance sensitivity (PPS), improves by 16.44 percent to 51.58 percent when the information-based stock trading increases from the median level to the maximum level. The increases in CEO incentives depend on the level of uncertainty facing the firm. The larger the underlying uncertainty, the greater the impact of information-based trading on CEO incentives.

This paper has two implications for the literature. First, we illustrate, both theoretically and empirically, the impact of information-based stock trading on managerial incentives and the risk-incentive relation, which is missing from the incentive literature. Identifying this missing link helps to better understand the contracting environment. The missing link potentially provides one explanation for the empirical ambiguity in testing the risk-incentive relation as well. When conducting cross-section tests, pooling the risk-incentive relations of firms with differential levels of information-based trading might lead to a model mis-specification problem. This is particularly a concern since many empirical analyses focus on testing comparative static predictions of agency theory and examine cross-section relations.

Second, we propose another channel through which stock market efficiency improves economic efficiency. Dow and Gorton (1997) emphasize stock market's information role in guiding managers' efficient investment decisions. We focus on stock market's information role in structuring managers' incentives. Our numerical analysis shows that, although the link between the two efficiencies is indirect, the magnitude of the social welfare loss without an efficient stock market is large and increases dramatically with the uncertainty of the economy.

The remainder of the paper proceeds as follows. Section 2 presents the model to decompose the risk-incentive relation into two offsetting effects. Section 3 numerically demonstrates the economic significance of the incentive enhancement effect. Section 4 discusses empirical evidence. Section 5 offers social welfare analysis. Section 6 concludes.

2 The Model

In this section, we introduce a parsimonious model that links information-based stock trading with an optimal incentive contracting process. We use the model only to demonstrate the impact of information-based trading on the risk-incentive relation and to motivate our numerical and empirical research.

2.1 Economy

We begin with a single-period model with two points of time, indexed t=0, 1. The period is further divided into several stages. The model unfolds as follows:

At the initial point of time 0, a publicly held firm is established and shares are issued on the firm's future cash flow. The terminal payoff of the firm at time 1 is: $\widetilde{r} = e + \delta$. Here e is the earning determined by managerial actions, and δ is a noise term, representing factors outside the manager's control. We assume that δ is distributed normally with mean zero and variances V_δ.

At stage 1, the firm owner (the principal) hires one manager (the agent). The owner writes a compensation contract on two performance measures, the stock price P and the firm's terminal payoff $\widetilde{r}$:

$$W = a + bP + f\widetilde{r}, \tag{1}$$

where a represents the fixed salary, b and f capture the sensitivities of the manager's compensation relative to P and $\widetilde{r}$, respectively. The compensation contract in equation (1) follows a commonly adopted form in the literature (see, e.g., Holmstrom and Milgrom, 1987; Holmstrom and Tirole, 1993; and Baiman and Verrecchia, 1995). Given the compensation contract, the manager chooses an effort level $e \in [0, \infty)$, which is unobservable.

At stage 2, the stock market opens. A stock market investor can observe an informative but non-contractible signal on the firm's future value at a cost. She does not search for the costly private signal on δ unless her expected value of doing so exceeds her reservation value μ. The costly signal acquired by an informed investor i is $\delta + \epsilon_i$, where ϵ_i is i.i.d. with mean zero and variance V_ϵ. Informed trader i submits a market order that is linear in her signal, $\beta(\delta + \epsilon_i)$. Both informed and uninformed traders submit their orders to the market maker who cannot tell whether an order is from an informed trader or from an uninformed trader. We assume that the total liquidity demand (of uninformed traders) in the market is z and z is a normally distributed variable with mean zero and variance V_z. We also assume that there are an endogenous number, N, of informed investors in the stock market. The total order flow observed by the market maker is $\omega = N\beta\delta + \sum_{i=1}^{N}(\beta\epsilon_i) + z$. The competitive market maker, given the aggregate order flow ω, sets a price such that $P = E\left[\widetilde{r}|\omega\right]$.[2]

At time 1, the payoff is realized, the incentive contract is honored, and the firm is liquidated. The resulting liquidation proceeds are distributed between the manager and the principal.

All players but the manager in this economy are risk-neutral. The manager's preference is represented by a negative exponential utility function over her compensation W with the (absolute) risk aversion coefficient γ. Her cost of choosing the effort e is denoted as $C(e) = \frac{1}{2}ke^2$. The cost is measured in money and is independent of the manager's wealth. Given her choice of effort e, the manager's evaluation of the normally distributed income W can be represented in the certainty equivalent measure as follows:

$$U(W, e) = E(W) - \frac{\gamma}{2}Var(W) - C(e). \tag{2}$$

2.2 Equilibrium

Based on the model set-up, we solve a rational-expectation equilibrium in which the players in the real sector, i.e., the principal and the manager, use the information contained in the stock price and the realized payoff to make optimal decisions, and both the real sector and the stock market attain equilibrium.

[2] We use the firm's gross proceeds instead of the net proceeds in the pricing function so as to obtain analytically tractable solutions. Because in our model W is linear in both P and $\widetilde{r}$, factoring W in the pricing function does not change the information content of the stock price. The stock price derived from this pricing function is informationally equivalent to the price derived from the more general pricing function specification, $P = E\left[(\widetilde{r} - W)|\omega\right]$. Baiman and Verrecchia (1995) and Milbourn (2003) make the same arrangement.

We first solve the stock market equilibrium. With liquidity demand z, the total order flow observed by the market maker is $\omega = N\beta\delta + \sum_{i=1}^{N}(\beta\epsilon_i) + z$. The market maker sets a linear price schedule of the form $P = e + \lambda\omega$ (Kyle, 1985). Using standard techniques, we obtain the equilibrium value of λ as $\lambda = \ V_z^{-\frac{1}{2}} \ \Gamma^{\frac{1}{2}}$, where $\Gamma = \frac{NV_\delta^2(V_\delta+V_\epsilon)}{[(N+1)V_\delta+2V_\epsilon]^2}$. The expected profit of an informed trader is given by $ER = \frac{V_\delta(V_\delta+V_\epsilon)^{\frac{1}{2}}V_z^{\frac{1}{2}}}{N^{\frac{1}{2}}[(N+1)V_\delta+2V_\epsilon]}$. A potential trader searches for the private signal if and only if the expected profit from doing so exceeds her reservation value μ. Thus, the equilibrium number of informed traders N, is determined by

$$\frac{V_\delta(V_\delta+V_\epsilon)^{\frac{1}{2}}V_z^{\frac{1}{2}}}{N^{\frac{1}{2}}[(N+1)V_\delta+2V_\epsilon]} = \mu. \tag{3}$$

We then analyze the optimal contracting. Following Holmstrom and Tirole (1993), we transform the wage function into the following equivalent normalized form:

$$W = \hat{a} + bP + f\hat{r}, \tag{4}$$

where $\hat{a} = a + fe^*$, $\hat{r} = \widetilde{r} - e^*$, and e^* is the equilibrium effort level. Note that equation (4) is a linear transformation of equation (1) at the hypothesized equilibrium value. The contracting analysis becomes much analytically easier with the normalized wage equation, so we build our analysis on this transformed compensation function from this point onwards. One way to interpret equation (4) is that besides the stock price P, the principal observes another signal $\hat{r}$ and include the signal into the compensation contract. The zero-mean $\hat{r}$ (or rather $\widetilde{r}$) can be understood as the firm's reported earnings, on which the principal also relies to better detect the managerial effort.[3]

Using the standard agency-theory approach, we have:

Lemma 1 *In the rational-expectations equilibrium, the optimal compensation contract can be rewritten as*

$$W = \hat{a} + b(P - \frac{Cov(P,\delta)}{Var(\delta)}\hat{r}), \tag{5}$$

[3] In order to interpret $\widetilde{r}$ or $\hat{r}$ as reported accounting earnings, we have to assume that the manager truthfully reports earnings. Factoring the manager's incentive to misreport earnings only makes $\hat{r}$ noisier but does not change our results qualitatively because, by construction, $\hat{r}$ only plays the role of a signal.

with $f = -b\frac{Cov(P,\delta)}{Var(\delta)}$*. The optimal pay-performance sensitivity* b *is given by*

$$b = \frac{1}{1 + \gamma k Var(P)(1-\rho^2)}, \tag{6}$$

where $\rho \equiv Corr(P, \delta)$*. The optimal effort level* e^* *is given by*

$$e^* = \frac{b}{k}. \tag{7}$$

In equilibrium, f is negative because ρ is positive (see Lemma 3). The intuition is similar to the relative performance argument first put forward in Holmstrom (1979) and then expanded in Holmstrom and Milgrom (1987). By construction, $\hat{r}$ acts as one signal, in addition to the stock price P, to help the principal better extract the information about the managerial effort. If $\hat{r}$ is high then the principal knows that the exogenous shock is positive, and hence lower the agent's compensation. In a different framework to analyze the use of reported accounting earnings and stock price as a basis for managerial compensation, Baiman and Verrecchia (1995) obtain a similar result: the negative weight on reported earnings in the manager's contract is used to imperfectly extract the manager's actual effort level from the stock price.

Define $x \equiv P - \frac{Cov(\delta,P)}{Var(\delta)}\hat{r}$. We can view x as an aggregate performance index built on two performance measures, P and $\hat{r}$. The compensation scheme in our model is hence based on an aggregate measure that captures various aspects of a firm's performance.[4]

2.3 Properties of Equilibrium

Lemma 2 *The number of informed traders,* N*, increases as the uncertainty of the firm's cash flow,* V_δ*, increases.*

The intuition behind Lemma 2 is as follows. Each potential informed trader engages in a strategic activity in this environment. Given the other potential traders' actions, her expected profit from collecting the costly private signal and becoming an informed trader increases as the

[4]Executive compensation contracts in real world are oftentimes written on a variety of performance measures such as economics value added (EVA), return on invested capital (ROIC), total returns to shareholders (TRS), and etc. The aggregate measure we propose in equation (5) thus reflects the features of the incentive pay scheme in real world.

uncertainty of the firm's cash flow V_δ increases, which can been easily shown since $\frac{\partial ER}{\partial V_\delta}_{|N=n} > 0$. Other potential outsiders will follow the same strategy and choose to become informed. Thus, the equilibrium number of informed traders increases as the firm's risk, measured by the firm's cash flow variance V_δ, increases.

Lemma 3 *The correlation coefficient ρ is positive. Moreover, both ρ^2 and $Var(P)$ are increasing functions of the underlying uncertainty V_δ.*

Lemma 1, Lemma 2 and Lemma 3 imply that as the underlying uncertainty V_δ increases, two effects arise: directly increasing the variance of the stock price or decreasing managerial incentives, and increasing the informational content in the stock price which indirectly improves incentives. The overall impact depends on which effect dominates in equilibrium.

Proposition 1 *Define $Var(MP) \equiv Var(P)(1-\rho^2)$. The overall response of the optimal pay-performance sensitivity b to the change in the fundamental uncertainty V_δ is given by*

$$\frac{db}{dV_\delta} = \frac{-\gamma k}{\left[1+\gamma k Var\left(MP\right)\right]^2} \frac{dVar\left(MP\right)}{dV_\delta}, \tag{8}$$

where

$$\frac{dVar(MP)}{dV_\delta} = PC - IE, \tag{9}$$

with

$$PC = \frac{\partial Var(MP)}{\partial V_\delta} = \frac{N(N+1)V_\delta^3 + 6NV_\delta^2 V_\epsilon + 8NV_\delta V_\epsilon^2}{[(N+1)V_\delta + 2V_\epsilon]^3} > 0, \tag{10}$$

and

$$IE = \frac{\partial Var(MP)}{\partial N}\frac{dN}{dV_\delta} = \frac{V_\delta^2(V_\delta + 2V_\epsilon)[(N-1)\,V_\delta - 2V_\epsilon]}{[(N+1)V_\delta + 2V_\epsilon]^3}\frac{dN}{dV_\delta}. \tag{11}$$

$IE > 0$ if $N > \frac{V_\delta + 2V_\epsilon}{V_\delta}$. Moreover, the PC term strictly dominates the IE term, and $\frac{dVar(MP)}{dV_\delta} > 0$.

Proposition 1 shows that two offsetting effects arise out of a growing uncertainty. The PC term measures the direct effect of the increase in uncertainty on incentives for a fixed number of the informed traders. In contrast, the IE term reflects the effect of an increasing information-based stock trading resulting from a greater uncertainty. As the uncertainty rises, more potential traders collect information and trade on the information (Lemma 2). Through trading, more information will be incorporated into the stock price and the correlation between the stock price and the cash flow increases (Lemma 3). The IE term thus characterizes the indirect effect of an increasing information-based trading on incentives in response to a shock.

Combining Proposition 1 with Lemma 1, we obtain

Proposition 2 *As the cash flow uncertainty increases, both the optimal pay-performance sensitivity and the optimal effort level decrease. The magnitude of the decrease is smaller for firms with a high level of information-based stock trading (or a high IE effect) than firms with a low level of information-based stock trading (or a low IE effect).*

Proposition 2 implies a negative risk-incentive relation even after taking into account the IE effect. IE equals zero if N is a constant (i.e., no information-based trading driven by a rising uncertainty in the stock market). When IE is zero, the PC term alone, measuring the traditional risk-incentive tradeoff, captures the overall risk-incentive relation. In the presence of information-based stock trading, the IE effect due to a greater uncertainty reduces the magnitude of the risk-incentive tradeoff.

3 Numerical Illustrations

3.1 Parameter Calibrations

Exogenous parameters in this model consist of the absolute risk aversion coefficient γ, the parameter on manager's disutility of effort k, the cash flow variance V_δ, the signal noise variance V_ϵ, the liquidity order variance V_z, the total order flow variance V_ω, and the reservation utility of becoming an informed trader μ. We normalize V_ϵ, V_z and μ by the scale of V_δ and define $stn \equiv \frac{V_\epsilon}{V_\delta}$, $ztn \equiv \frac{V_z}{V_\delta}$ and $smu \equiv \frac{\mu}{V_\delta}$, respectively. Each "baseline value" for the exogenous parameters is denoted by a subscript 0. We choose the baseline values of parameters, along with values of some relevant variables, to characterize the real-world data. Table 1 reports these calibrated values.

In our model e and V_δ capture the mean and variance of a firm's payoff, respectively. We measure the payoff by the firm's market value. Based on a data set merging the CRSP, Compustat,

Table 1: Calibrated Parameter and Variable Values

Parameters/Variables	Values
$V_{\delta,0} \equiv Var(\widetilde{r})$	1260.16^2
γ_0	2
$stn_0 \equiv \frac{V_\epsilon}{V_\delta}$	10
V_ω	$13.91^2 * 12$
k_0	1.7473e-5
$smu_0 \equiv \frac{\mu}{V_\delta}$	1.2985e-4
$ztn_0 \equiv \frac{V_z}{V_\delta}$	2.5534e-4
$e \equiv E(\widetilde{r})$	4292.29
b_0	0.075
n_0	41.99

ExecuComp, and TAQ databases for the period 1993-2001 (see Table 2 for detailed summary statistics of the data), we set e to the sample mean of the firm market value, i.e., $e = 4292.29$. (Units are in one million 1992 constant dollars for monetary variables.) Note that this data set covers a wide range of firms, from firms with very small market values to firms with very large market values. The pooled cross-sectional variance of this set of firm-year observations is thus not a valid measure of the uncertainty about firm value faced by any individual firm. We instead use the cross-sectional average of the time-series variances of the individual firms' values. Consequently, $V_{\delta,0} = 1260.16^2$. The ratio stn measures the relative importance of the noise term in the informed trader's signal. There are no good empirical estimates of stn in the literature. We rely on the empirical asset pricing studies reporting that at a one-year horizon, various variables forecast stock market returns with a R^2 around 5%-20% (Cochrane, 2001). We calibrate stn such that the implied signal-to-noise ratio is consistent with this empirical finding. We thus let $stn_0 = 10$, implying that about 9.10% of the variation in stock returns is forecastable. We choose $\gamma_0 = 2$ (Haubrich, 1994). We use the trading volume as a proxy for the total order flow. In our sample the cross-sectional standard deviation of the trading volume on a monthly basis is 13.91 (million shares), so we set $V_\omega = 13.91^2 * 12 = 2321.86$.

We adopt the following multi-step approach to calibrate the values of the other parameters and the relevant variables as they do not have good empirical estimates.

Step 1. We choose one initial value of the pay-performance sensitivity, b_0. From equation (7) we calculate $k_0 = \frac{b_0}{e}$ given e.

Step 2. We show (in Appendix 1, Proof of Lemma 3) that

$$Var\left(MP\right) = \frac{NV_{\delta}^{2}\left(V_{\delta}+2V_{\epsilon}\right)}{\left[(N+1)V_{\delta}+2V_{\epsilon}\right]^{2}} = \frac{N\left(1+2stn\right)}{\left[(N+1)+2stn\right]^{2}}V_{\delta}. \tag{12}$$

Combining equation (6) with equation (12), we obtain

$$\frac{\frac{1}{b}-1}{\gamma k} = \frac{N\left(1+2stn\right)V_{\delta}}{(N+1+2stn)^{2}}. \tag{13}$$

Given b_0, γ, k_0, stn_0 and $V_{\delta,0}$, we solve for n_0 from equation (13).

Step 3. Using $\omega = N\beta\delta + \sum_{i=1}^{N}(\beta\epsilon_i) + z$, we derive

$$V_{\omega} = \frac{(N+1)\,V_{\delta}+2V_{\epsilon}}{V_{\delta}+V_{\epsilon}}V_{z}, \tag{14}$$

which yields

$$ztn \equiv \frac{V_z}{V_\delta} = \frac{V_{\delta}+V_{\epsilon}}{(N+1)\,V_{\delta}+2V_{\epsilon}}\frac{V_{\omega}}{V_{\delta}} = \frac{1+stn}{(N+1)+2stn}\frac{V_{\omega}}{V_{\delta}}. \tag{15}$$

We then obtain ztn_0.

Step 4. We rewrite equation (3) as

$$smu = \frac{(1+stn)^{\frac{1}{2}}\,(ztn)^{\frac{1}{2}}}{N^{\frac{1}{2}}\,(N+1+2stn)}, \tag{16}$$

from which we calculate smu_0.

Step 5. Given these calibrated parameter values, we recalculate $Var(MP)$ from equation (12), and then we calculate b from equation (6). We use step 5 to check for the convergence of the calibration. If the value of b calculated from step 5 is significantly different from the chosen initial value b_0, then we pick another initial value b_0 and repeat step 1 to step 5 until the two values are close to each other (with a difference less than 1e-10).

Using the above multi-step approach, we achieve convergence when we set $b_0 = 0.075$, representing a \$75 annual increase in a CEO's firm-related wealth (including option and stock holdings) per \$1,000 increase in the shareholder wealth (Jensen and Murphy, 1990). This value is close to the ordinary least square (OLS) regression estimates of PPS in the literature (see, e.g., Aggarwal and Samwick, 1999; Murphy, 1999). The parameter on the manager's disutility of effort, k_0, is calibrated to be $1.7473e-5$. As a result, the manager's disutility of choosing the effort is $C(e) = \frac{1}{2}ke^2 = 160.961$ units in certainty equivalent measure, which is 3.75% of the average market value of firms. The number of informed traders, n_0, is calibrated to be 41.99. The ratio of the reservation value of being an informed trader to the underlying cash flow variance, smu_0, is $1.2985e-4$, suggesting that the reservation value to become an informed trader is 206.195 units. This figure also implies that the profit of an informed trading is 206.195 units, accounting for 4.8% of the average market value of firms. Finally, we obtain the ratio $ztn_0 = 2.5534e-4$ or the variance of liquidity orders $V_z = 405.477$, suggesting that liquidity orders contribute to 17.46% of variations in the aggregate market orders.

3.2 Numerical Results I: Univariate Comparative Statistics

We examine the comparative statistics of b in response to changes in ztn, smu, stn, and V_δ respectively. Holding fixed values of the other exogenous parameters as given in Table 1, we let the parameter of interest, say ztn, increase from the baseline value up to 200% by increments of 1%. For each new level of ztn, we first use equation (3) (or equation (16)) to solve for the equilibrium number of informed traders N, then we combine equation (12) and equation (6) to calculate the optimal pay-performance sensitivity b. We repeat the same procedure for other parameters of interest, smu, stn, and V_δ, respectively.

3.2.1 Comparative Statistics: ztn

Figure 2, Panel A plots the responses of N (left) and b (right) to changes in ztn (or V_z since V_δ is fixed). As ztn increases, both N and b increase monotonically. N increases from 41.99 to 56.08 when ztn doubles, and further to 66.01 when ztn triples. Accordingly, b increases from 0.075 to 0.0833 and further to 0.0896. If we, like Holmstrom and Tirole (1993), use the variance of liquidity trading as a proxy for market liquidity, our numerical result is consistent with their conclusion that an increase in market liquidity motivates informed traders, improves the information content of the price and market monitoring, and consequently, enhances managerial incentives.

3.2.2 Comparative Statistics: *smu*

Figure 2, Panel B plots the responses of N (left) and b (right) to changes in smu (or μ since V_δ is fixed). N decreases monotonically with respect to smu, but b displays a U-shaped response. N decreases from 41.99 to 22.26 when smu doubles, and declines further to 14.60 when smu triples. b decreases monotonically from 0.075 to 0.067 when smu increases by up to 113%, and afterwards increases monotonically to 0.069 when smu triples. The U-shaped response of b to changes in smu is due to the inverse-U-shaped response of $Var(MP)$ to N: The term $\frac{\partial Var(MP)}{\partial N} > 0$ when $N < 1 + 2stn$ and $\frac{\partial Var(MP)}{\partial N} < 0$ otherwise.

3.2.3 Comparative Statistics: *stn*

Figure 2, Panel C plots the responses of N (left) and b (right) to changes in stn (or V_ϵ since V_δ is fixed). Neither N nor b responds monotonically to changes in stn. On the one hand, N displays an inverse-U-shaped response: N increases monotonically from 41.99 to 44.01 when stn increases from 10 to 20.5 and afterwards, N decreases monotonically to 43.22 when stn continues to increase up to 30. On the other hand, b displays a U-shaped response: b decreases monotonically from 0.075 to 0.067 when stn increases from 10 to 21.5 and then increases monotonically to 0.069 when stn increases up to 30. Here, an increase in stn implies that the noise term in the signal observable by the informed trader (at a cost) gains relative importance. The signal becomes noisier and contains less information about the fundamentals. Before the noise of the signal reaches the threshold level, which is characterized by $N > 3 + 2stn$,[5] more informed traders are attracted into the market because the profit of doing so increases with the noisiness. If the noise continues to build up and exceeds the threshold level, the signal becomes too noisy (i.e., $N < 3 + 2stn$) to attract informed traders, and instead, it crowds out informed traders.

The change in stn has two effects (direct and indirect) on $Var(MP)$ and, in turn, on b. On the one hand, $Var(MP)$ responds directly to an increase in stn. $Var(MP)$ increases with respect to stn as long as the signal is not too noisy ($N > 1 + 2stn$), and $Var(MP)$ deceases if the signal becomes too noisy. On the other hand, the increased stn affects indirectly $Var(MP)$ through N.

[5] Applying the implicit function theorem to equation (3), we obtain $\frac{dN}{dV_\epsilon} = \frac{N^{\frac{1}{2}} V_\delta (V_\delta + V_\epsilon)^{-\frac{1}{2}} V_z^{\frac{1}{2}} [(N-3)V_\delta - 2V_\epsilon]}{\mu[(3N+1)V_\delta + 2V_\epsilon][(N+1)V_\delta + 2V_\epsilon]} > 0$ if $N > 3 + 2\frac{V_\epsilon}{V_\delta}$.

As explained above, before the noisiness of the signal exceeds the threshold level (i.e., $N > 3+2stn$), N increases with stn, which in turn lowers $Var(MP)$ to improve the informational content of the price. Afterwards, the too noisy signal crowds out informed traders to reduce N, leading to a lower $Var(MP)$. Together, when $N > 3 + 2stn$ or the signal is not too noisy, the indirect effect of stn on $Var(MP)$ is negative, offsetting but dominated by the positive direct effect, leading to a higher $Var(MP)$ and hence a lower b; when $N < 1+2stn$ or the signal turns too noisy, the indirect effect of stn on $Var(MP)$ is again negative and reinforces the negative direct effect, leading to a lower $Var(MP)$ and subsequently a higher b.

3.2.4 Comparative Statistics: V_δ

The comparative statistics of b in response to changes in V_δ characterizes the risk-incentive relationship. We follow the above approach to calculate the equilibrium number of informed traders N and the optimal pay-performance sensitivity b. The marginal responses of N (i.e., the slopes of the response curve) as well as the two (offsetting) effects, PC and IE, are accordingly calculated.

Figure 3, Panel A plots the responses of the equilibrium number of informed traders N to the percentage increases in the underlying uncertainty V_δ. As predicted in Lemma 2, N rises monotonically, from the initial level of 41.99 to 49.56 when V_δ doubles and further to 53.18 when V_δ triples. Panel B outlines the downward-sloped but positive marginal responses of N, suggesting that N is an increasing and concave function of V_δ.

Figure 3, Panel C presents the the two (offsetting) effects, PC and IE, affiliated with the responses of $Var(MP)$ to changes in V_δ. As predicted in Proposition 1, both effects are positive and IE is smaller than PC. (IE is positive because $N > 1+2stn_0 = 21$ in this exercise). The ratio of IE over PC increases monotonically from the initial level of 15.19% to 28.49% when V_δ doubles and further to 35.03% when V_δ triples. The gap between the two effects narrows, suggesting that a stronger offset of the IE effect relative to the PC effect occurs as the underling uncertainty mounts.

Figure 4, Panel A displays the responses of the optimal pay-performance sensitivity b to the percentage increases in the uncertainty V_δ under two scenarios: $N = n_0$ (dashed line) and N changes according to equation (3) (solid line). When N changes, i.e., when both the PC and IE effects are present, b decreases monotonically with respect to V_δ because the PC effect dominates, consistent with Proposition 2. The value of b starts from 0.075 and drops to 0.057 when V_δ doubles and further to 0.052 when V_δ triples. In contrast, when $N = n_0$, the term $IE = 0$. There is no information enhancement effect from the stock market at all. The PC effect corresponds directly to the overall risk-incentive relation. Clearly, as V_δ increases, b monotonically decreases, reflecting the risk-incentive tradeoff predicted by the standard agency theory. Starting at 0.075, the value of b is 0.052 when V_δ doubles and is 0.044 when V_δ triples.

Compared to the case where N can change, the optimal pay-performance sensitivity with a constant N fixed at n_0 is uniformly smaller. Interestingly, the gap between the solid line and the dashed line keeps widening as the underlying uncertainty rises. It attests to the increasing relative importance of the information enhancement effect in inducing managerial incentives. The value of b with the information enhancement effect exceeds the value of b without the information enhancement effect by 10.05% and 17.60% when V_δ doubles and triples, respectively.

The gap between the solid and dashed lines reveals the offset of the information enhancement effect against the risk-incentive tradeoff. To quantify the offset, we compute the difference between the decline in b with a changing N and the decline in b with a constant $N = n_0$ as a result of the increases in V_δ, and then divide the difference by the magnitude of the decline in b with a constant $N = n_0$ to obtain the percentage offset of the risk-incentive tradeoff. Figure 4, Panel B plots such percentage offsets. The percentage offsets monotonically increase at a decreasing pace with respect to the percentage increases in the underlying uncertainty. When V_δ rises by 1% from the initial value, the percentage offset is 15.35%. The percentage offset reaches 22.62% and 24.95% when V_δ doubles and triples, respectively.

3.3 Numerical Results II: Multivariate Comparative Statistics

We check the sensitivity of the risk-incentive relationship to different choices of the parameter values ztn, smu and stn, respectively. We retain values of the other parameters from Table 1.

3.3.1 Different Values of ztn

We respectively increase V_δ and ztn from their baseline values by 200% and 100% with an increment of 1% apiece. Figure 5, Panel A (left half) plots a three-dimensional responses of the optimal pay-performance sensitivity b against changes in ztn and V_δ. On one dimension, given any level of ztn, b is a decreasing function of the uncertainty, consistent with the risk-incentive-tradeoff prediction of Proposition 2 because IE is strictly dominated by PC. Along the other dimension, given any level of V_δ, b is an increasing function of the standardized ratio $ztn \equiv \frac{V_z}{V_\delta}$, indicating that b is an increasing function of the liquidity order variance V_z, consistent with the results we obtain from Section 3.2.1.

For a better illustration, we graph in the right half of Panel A the optimal pay-performance sensitivity b in response to percentage changes in V_δ with the minimum (dotted line), median (dashed line), and the maximum (solid line) values of ztn. Clearly, at any level of uncertainty, b with the minimum ztn is smaller than b with the medium ztn, which is further smaller than the maximum ztn. The difference in b between the minimum and the maximum ztn keeps increasing as the uncertainty increases. The value of b with the maximum ztn exceeds b with the minimum ztn by 11.11% at the initial level of uncertainty. The ratio rises to 17.79% and 20.01% when V_δ doubles and triples, respectively.

3.3.2 Different Values of *smu*

We let V_δ and smu increase from their baseline values by 200% and 100% respectively, with an increment of 1% each. Figure 5, Panel B plots a three-dimensional responses of the optimal pay-performance sensitivity b against changes in smu and V_δ. On one dimension, given any level of smu, b is a decreasing function of the uncertainty, consistent with the risk-incentive-tradeoff prediction of Proposition 2 because IE is strictly dominated by PC. Along the other dimension, given a level of V_δ, b monotonically decreases as the standardized ratio smu rises up to 100%. Consistent with the result from Section 3.2.2, an increasing smu yields a monotone decrease in N and, in turn, a steadily lower b as long as $N > 1 + 2stn$.

We graph in the right half of Panel B the optimal pay-performance sensitivity b in response to percentage changes in V_δ with the minimum (dotted line), median (dashed line) and the maximum (solid line) values of smu. Given a level of uncertainty, the minimum smu delivers the highest values of b, followed by the median smu and then by the maximum smu. The difference in b between the minimum and the maximum smu keeps increasing as the uncertainty increases. The value of b with the minimum smu exceeds the value with the maximum smu by 11.46% at the initial level of uncertainty. The ratio rises to 32.66% when V_δ doubles and to 40.15% when V_δ triples.

3.3.3 Different Values of stn

We let V_δ increase from the baseline value up to 200% by increments of 1%. We choose stn from 5 to 15 with an increment of 0.1 so that $stn_0 = 10$ is the median.

The left half of Figure 5, Panel C exhibits the response surface of b against changes in stn and V_δ. Given any value of stn, b is a decreasing function of the underlying uncertainty, consistent with the risk-incentive-tradeoff prediction of Proposition 2. On this dimension, the IE effect is always dominated by the PC effect. Along the other dimension, for a given level of V_δ, b monotonically decreases as the standardized ratio stn rises. Consistent with the result from Section 3.2.3, an increase in stn both directly and indirectly affects $Var(MP)$ and, consequently, b. As long as $N > 3 + 2stn$, which is true in this exercise, an increasing stn directly increases $Var(MP)$. At the same time, it also motivates more informed traders into the market which helps lower $Var(MP)$. The direct effect dominates the indirect effect, though. Overall, a higher stn brings about a higher $Var(MP)$ and a lower b.

We plot in the right half of Panel C the optimal pay-performance sensitivity b against percentage changes in V_δ given the minimum, median and the maximum values of stn: $stn = 5$ (dotted line), $stn = 10$ (the baseline value, dashed line), and $stn = 15$ (solid line). Each line is downward-sloped, demonstrating the tradeoff between risk and incentives. The dotted line is above the dashed line, which is further above the solid line. The value of b with $stn = 5$ is 35.70% higher than the value with $stn = 15$ at the initial level of uncertainty. The ratio rises to 61.09% when V_δ doubles and further to 67.61% when V_δ triples.

4 Empirical Analysis

Numerical results in Section 3 show that the IE effect due to the information-based stock trading driven by a greater uncertainty offsets about 20-40% of the PC effect. To study whether such economic significance is consistent with real-world data, we analyze in this section the impact of information-based stock trading on CEO incentives and the risk-incentive relation empirically.

4.1 Data and Variables

We obtain CEO compensation data from the ExecuComp database for the period 1992–2001. ExecuComp reports annual compensation flows as well as information related to changes in the value of stock and stock option holdings for the five most-paid executives, including the CEO, for firms appearing in either the S&P500 Index, S&P MidCap 400 Index, or the S&P SmallCap 600 Index. We obtain stock return data from the CRSP Monthly Stock File and accounting information from the Compustat Annual File. To measure the amount of information-based trading of a stock, we use intraday trading data extracted from the TAQ database to compute a firm's probability of informed trading (PIN) for a given year.

We measure incentives by pay-performance sensitivity, which we define as the dollar value change in the CEO's firm-specific wealth per $1,000 change in the shareholder value (Jensen and Murphy, 1990). We identify CEOs by the fields "BECAMECE", "CEOANN", and "LEFTOFC" in ExecuComp. Using only the field "CEOANN" causes a loss of many observations for the earlier periods of the sample (Milbourn, 2003). Although CEO compensation comprises several different layers[6], the stock-based incentive, i.e., the pay-performance sensitivity from stock and stock option portfolio revaluations, simply swamps the incentive from other compensation components and constitutes the overwhelming heterogeneity in the empirically estimated pay-performance sensitivity (Hall and Liebman, 1998; and Murphy, 1999). We thus use the stock-based pay-performance sensitivity (PPS) in our empirical analysis (see Appendix 2 for more details about how we compute PPS). Table 2 presents summary statistics of CEO incentive measure, PPS. The mean and median values of PPS are respectively $41.12 and $11.88 per $1,000 change in the shareholders' value. The PPS measure has a standard deviation of $76.47 with a maximum value of $994.45.

We use probability of informed trading (PIN) developed by Easley, Kiefer and O'Hara (1996,

[6]For example, the total current compensation (TCC) is the sum of salary and bonus. The total direct compensation (TDC) is the sum of total current compensation, other annual short-term compensation, payouts from long-term incentive plans, the Black-Scholes value of stock options granted, the value of restricted stocks granted, and all other long-term compensation. Both TCC and TDC measure the direct payment a CEO receives from his firm within one fiscal year. However, neither TCC nor TDC considers the indirect compensation that a CEO derives from a revaluation of stocks and stock options already granted to him in previous years.

1997) as a proxy for the amount of information-based trading of a stock. The literature has firmly established the PIN variable as a good measure of the amount of information-based stock trading in various settings.[7] PIN reflects how the mechanics of a trading process affects the informational content of a stock price. Compared to other variables measuring stock price informativeness, PIN tends to be an "exogenous" factor in the context of CEO incentives. We estimate PIN for the period 1993-2001 since the TAQ database starts data coverage from 1993 (see Appendix 3 for technical details about the construction and estimation of PIN). There are 8,456 firm-year observations after we merge the TAQ database with the ExecuComp database. Table 2 presents summary statistics of PIN. In our sample, the average PIN is 0.163 with a standard deviation of 0.051. The median value of PIN is 0.157. The maximum PIN is 0.797 with a minimum of zero. The sample property of our PIN estimates is consistent with the sample property identified in previous studies (see, e.g., Easley, Hvidkjaer, and O'Hara, 2002).

Following Aggarwal and Samwick (1999) and Jin (2002), we measure a firm's risk by the dollar return standard deviation (in millions of dollars), $STDV$. We compute $STDV$ of a given year as the annualized percentage standard deviation of the past five-year monthly stock returns multiplied by the beginning-of-year firm value. As shown in Table 2, the mean and median of $STDV$ are 1260.16 and 292.44, respectively. The standard deviation of $STDV$ is 4970.07. Its maximum and minimum are 186693.9 and 1.068, respectively. The sample firms have an average market value (in millions of dollars) of 4292.29 with a median market value of 864.98.

Table 2 presents summary statistics of several firm-specific control variables as well. We construct two institutional ownership variables to control for the monitoring effect suggested in Hartzell and Starks (2003). We define $TOTHLD$ as the total institutional share holdings in percentage of the total number of shares outstanding. We expect institutional investors to have greater influence if the shares are concentrated in the hands of larger investors. Like Hartzell and Starks (2003), we use the concentration of institutional ownership as a proxy for institutional influence. We define $CON5$ as the proportion of institutional investor ownership accounted for by the top five institutional investors in the firm. Table 2 shows that, on average, 56.47% of a firm's shares are owned by institutional investors, and 43.80% of the shares held by institutional investors

[7] See, e.g., Easley, Kiefer, and O'Hara (1996, 1997); Easley, Kiefer, O'Hara, and Paperman (1996); Easley, O'Hara, and Srinivas (1998); Easley, Hvidkjaer, and O'Hara (2002); and Vega (2004).

are controlled by the top five institutional investors. To measure a firm's growth opportunities, we calculate Tobin's Q as the ratio of the market value of assets to the book value of assets. We obtain the market value of assets 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). The average Tobin's q of the firms in our sample is 2.16 with a standard deviation of 2.75. Tobin's q ranges from 0.28 to 105.09 with a median value of 1.48.

Other control variables are CEO tenure, industry dummies, and year dummies. We calculate CEO tenure as the number of years the executive has been the CEO of this firm as of the compensation year in ExecuComp. The mean and median of the CEO tenure are 7.68 and 5.50 years, respectively. The maximum CEO tenure in our sample is 54.92 years. Finally, we construct 20 industry dummies based on the 2-digit SIC code from CRSP.

4.2 Hypothesis and Econometric Strategy

Our model predicts that two effects arises to an increase in the fundamental uncertainty. Directly reducing incentives aside, the rise in uncertainty (or risk) encourages information-based trading in the stock market, which increases the information content of the stock price and in turn, improves incentives. The incentive enhancement effect is outweighed by and partially offsets the incentive reduction effect. We hypothesize for our empirical testing that a higher level of information-based stock trading contributes to a larger offset against the risk-incentive tradeoff.

We empirically test the model prediction by regressing the incentive measure PPS on the measure of risk $STDV$, the interaction term of $STDV$ and the proxy for information-based stock trading PIN, and the control variables such as institutional holding $Tothld$, concentrated ownership $Con5$, growth opportunities $Tobinq$, CEO tenure $Tenure$, and industry and year dummies $Dummies$. The coefficient of $STDV$ reflects the direct effect of firm risk on CEO incentives and is expected to be negative. The coefficient of the interaction term captures the indirect effect of risk on CEO incentives through information-based stock trading. This coefficient is the parameter of interest and is expected to be positive based on our model prediction.

Following Aggarwal and Samwick (1999) and Jin (2002), we apply cumulative distribution functions (CDFs) to the explanatory variables such as $STDV$, PIN, $Tothld$, $Con5$, $Tobinq$, and

$tenure$. The CDF transformations help to smooth data and make the regression results economically more sensible than raw measures. By using CDFs, we can easily transform the estimated coefficient values into pay-performance sensitivities at any percentile of the distribution of the explanatory variables.

Because the CEO incentive measure PPS displays an apparent right skewness (Table 2), we follow the literature and estimate median regressions to control for the possible influence of outliers. We obtain standard errors of the estimates by using bootstrapping methods. The subject period of study is 1994-2001 as the sample period for PIN is 1993-2001 and we need one-year lag for such regressions.

4.3 Empirical Results

4.3.1 Initial Results

To gain a preliminary view of the incentive-enhancement effect empirically, we begin by estimating the following regression:

$$\begin{aligned} PPS_{i,t} &= \theta_0 + \theta_1 * CDF(STDV_{i,t}) + \theta_2 * CDF(STDV_{i,t}) * CDF(PIN_{i,t-1}) \\ &\quad + \theta_3 * CDF(Tothld_{i,t-1}) + \theta_4 * CDF(Con5_{i,t-1}) + \theta_5 * CDF(Tobinq_{i,t-1}) \\ &\quad + \theta_6 * CDF(Tenure_{i,t}) + \sum_{k \geq 7} \theta_k * Dummies_{i,t} + \varepsilon_{i,t}. \end{aligned} \tag{17}$$

Here, we implicitly assume that the amount of information-based trading is related only to the risk, and we do not separately control for the impact of information-based trading on CEO incentives in the regression. Because factors other than risk also affect the information-based stock trading and, in turn, CEO incentives, the specification in equation (17) may suffer from an omitted variable bias. We examine this issue in Section 4.3.2. Given equation (17), we expect that θ_1 is negative, θ_2 is positive, and θ_2 has a smaller magnitude than θ_1.

Equation (17) implies that the overall risk-incentive relation is equal to $\theta_1 + \theta_2 * CDF(PIN)$. The size of the offsetting effect is measured as $\frac{\theta_2 * CDF(PIN)}{\theta_1}$. We normalize the offsetting effect at the minimum level of information-based trading to zero. That is, $CDF(PIN) = 0$, so the overall risk-incentive relation is θ_1 and the offset is zero. If the information-based stock trading is at the maximum level, $CDF(PIN) = 1$, the overall risk-incentive relation is $\theta_1 + \theta_2$, and the size of an offset is $\frac{\theta_2}{\theta_1}$. For a median level of information-based stock trading, $CDF(PIN) = 0.5$, the overall risk-incentive relation is $\theta_1 + 0.5 * \theta_2$, and the size of an offset is $\frac{0.5*\theta_2}{\theta_1}$. With the coefficients, we can also interpret the economic significance of an offset via an elasticity measure, that is, a one percent increase in the level of information-based stock trading offsets the risk-incentive tradeoff by $\frac{\theta_2}{\theta_1}$ percent.

Table 3, Column 1 reports the pooled median regression results. The estimated coefficient on $STDV$, i.e. θ_1, is -16.168 with a standard error of 0.794 and is significant at the 1% level. This result supports our model prediction that the direct effect of firm risk is to reduce CEO incentives, also consistent with the standard agency theory prediction. The coefficient of the interaction term, θ_2, is 5.763 with a standard error of 1.041. The estimate of θ_2 is positive and significant at the 1% level, lending support to the model prediction that the information-based stock trading has an offsetting effect on the risk-incentive tradeoff. For a firm with a median level of information-based stock trading, the indirect incentive-enhancement effect offsets the direct incentive-reduction effect by $\frac{0.5*5.763}{16.168} = 17.82\%$. The parameter estimates on other control variables suggest that CEO incentives are negatively related to total institutional holdings and positively related to concentrated ownership, growth opportunities and CEO tenure, all of which are consistent with the findings of the literature.

As a robustness check, we estimate year-by-year median regressions on equation (17) (year dummies dropped) over the period 1994-2001.[8] We report the time-series averages of such year-by-year cross-sectional regression results in Table 3, Column 2. The parameter estimates from year-by-year regressions are similar to the parameter estimates from pooled regressions in both magnitude and statistical significance. All time-series averages of the parameter estimates are significant at the 1% level. The coefficient on the interaction term, θ_2, is positive, reflecting that the incentive enhancement effect of information-based stock trading (partially) offsets the incentive reduction

[8]We estimate year-by-year median regressions for three reasons. First, the year-by-year analysis helps to check whether the above empirical results are stable over time. Second, the U.S. stock market experienced a bubble in the late 1990s. The bubble burst in 2000, rendering many executives' options virtually worthless. The way in which we compute changes in value of stock option portfolios, and hence PPS, might create bias for firms with more out-of-money options, and for firms with options that are at-the-money or near-the-money. Comparing the results in different years is thus useful. Third, we might rationally suspect that a firm's incentive provision policies have changed in recent years, which may directly affect our results.

effect due to a rise in uncertainty. The time-series averages of θ_1 and θ_2 are respectively -16.227 and 6.555, suggesting that the size of the offset for a firm with a median level of information-based stock trading is 20.20%.

4.3.2 Main Results Based on Decomposed PIN

The specification in equation (17) implicitly assumes that the amount of information-based trading is related only to the risk. However, as discussed above, other factors, such as liquidity, noisiness of private signals, reservation value of becoming informed traders, and so on, also affect information-based trading and consequently CEO incentives. The empirical measure of information-based stock trading, PIN, may contain components which helps improve CEO incentives but are unrelated to risk. As a result, the coefficient, θ_2, on the interaction term in equation (17) is likely a biased estimate of the incentive-enhancement effect. We address this concern here.

We first decompose PIN into two components by cross-sectionally regressing PIN against $STDV$ and $STDV^2$ year-by-year. We include $STDV^2$ into the regression to capture the potentially non-linear relation between PIN and $STDV$. We calculate from the regressions the fitted values (not including the intercept of the regression), $PINF$, and the residuals (including the intercept), $PINR$. The two terms $PINF$ and $PINR$ respectively measure the components related and unrelated to the risk $STDV$. While controlling for the impact of the non-risk-related component on CEO incentives, we examine the incentive-enhancement effect of the risk-related component as follows:

$$
\begin{aligned}
PPS_{i,t} \quad = \quad & \theta_0 + \theta_1 * CDF(STDV_{i,t}) + \theta_2 * CDF(STDV_{i,t}) * CDF(PINF_{i,t-1}) \\
& + \theta_r * CDF(PINR_{i,t-1}) + \theta_3 * CDF(Tothld_{i,t-1}) + \theta_4 * CDF(Con5_{i,t-1}) \\
& + \theta_5 * CDF(Tobinq_{i,t-1}) + \theta_6 * CDF(Tenure_{i,t}) + \sum_{k \geq 7} \theta_k * Dummies_{i,t} + \varepsilon_{i,t}. \quad (18)
\end{aligned}
$$

Because $PINF$, by construction, is a mapping of $STDV$, we do not include $PINF$ as a separate control variable in equation (18) to avoid the multi-colinearity problem. Instead, we interact $PINF$, the risk-related component of PIN, with $STDV$ to characterize the impact of information-based trading driven purely by an increase in the fundamental uncertainty on the risk-incentive relation.

Our model predicts that θ_1 is negative, θ_2 is positive, and θ_2 has a smaller magnitude than θ_1. We do not have a clear prediction about the sign of θ_r, the coefficient on $PINR$, a priori. A significantly negative θ_1 and a significantly positive θ_2 point to the offset against risk-incentive tradeoff from the risk-related component of information-based stock trading.

Table 4, Column 1 reports the results of the pooled median regression on equation (18). Notably, all the coefficient estimates are significant at the 1% level. Same as above, CEO incentives are negatively related to total institutional holdings and positively related to concentrated ownership, growth opportunities and CEO tenure. The corresponding coefficients, θ_3, θ_4, θ_5, and θ_6, are respectively estimated as -5.155, 5.531, 8.671, and 14.816. Their magnitudes are very close to their counterparts from Table 3, where they are respectively -5.527, 5.782, 9.107, and 14.715. The intercept, θ_0, is 4.226. The coefficient on $CDF(PINR)$, θ_r, is 3.645 with a standard error of 0.571, suggesting that the non-risk-related component of information-based stock trading increases the level of CEO incentives. The coefficient on risk, θ_1, is estimated to be -13.909 with a standard error of 0.757, illustrating the incentive reduction effect of risk. The coefficient on the interaction term, θ_2, is 8.674 with a standard error of 1.497, suggesting that the risk-related component of information-based stock trading influences CEO incentives positively and offsets the risk-incentive tradeoff partially. For a firm with a median level of risk-related component of information-based stock trading, the indirect incentive-enhancement effect offsets the direct incentive-reduction effect by $\frac{0.5*8.674}{13.909} = 31.18\%$. Graphically, the slope of a risk-incentive curve is reduced by 31.18%. Using the elasticity measure, we infer that every one percent increase in the level of information-based stock trading offsets the risk-incentive tradeoff by 0.624 percent.

Compared to their counterparts in Table 3, the estimates of θ_1 and θ_2, have quite different magnitudes. θ_1 and θ_2 are respectively -13.909 and 8.674 in Table 4, and they are respectively -16.168 and 5.763 in Table 3. As expected, the decomposition of PIN yields a much stronger offset against the incentive reduction. Clearly, decomposing the PIN measure into risk-related and non-risk-related components helps better characterize the information enhancement effect of information-based trading and renders an empirically stronger offset against the risk-incentive tradeoff.

The two positive coefficient estimates affiliated with the two PIN components demonstrate that the information-based trading positively affects incentives by increasing the level of incentives (the level effect) as well as by reducing the slope of risk-incentive relation (the slope effect). The level effect is attributable mainly to the non-risk-related component of information-based trading, and the slope effect attributable to the risk-related component of information-based trading. The slope effect depicts the non-linear impact of risk on incentives as well: directly reducing incentives aside, an increase in the fundamental uncertainty indirectly induces incentives and (partially) offsets the incentive reduction by encouraging informed-based trading in the market and improving the informational content of the stock price.

The effect of information-based stock trading on CEO incentives increases with the level of uncertainty. For any level of risk and risk-related information-based trading, fixing all the other CDF values at 0.5, we compute PPS as $17.98 - CDF(STDV) * (13.909 - 8.674 * CDF(PINF))$. For a firm with the median level of risk, when the risk-related information-based trading increases from the median level to the maximum level, PPS increases from \$13.194 to \$15.363, up by \$2.169 or 16.44%, per \$1,000 increase in the shareholder value. For a firm with the maximum level of risk, when the risk-related information-based trading increases from the median level to the maximum level, PPS increases from \$8.408 to \$12.745, up by \$4.337 or 51.58%, per \$1,000 increase in the shareholder value. This result is consistent with our numerical and empirical analysis above, showing a growing influence of information-based stock trading on CEO incentives and risk-incentive tradeoff in response to a mounting uncertainty.

Table 3, Column 2 reports the time-series averages of year-by-year cross-sectional regressions on equation (18). Again, the parameter estimates from year-by-year regressions are similar to the parameter estimates from pooled regressions in both magnitude and statistical significance. All time-series averages of the parameter estimates are significant at the 1% level. CEO incentives are positively related to concentrated ownership, growth opportunities and CEO tenure and are negatively related to risk and total institutional holdings. The coefficient on the interaction term, θ_2, is positive, reflecting that the incentive enhancement effect of information-based stock trading and (partially) offsets the incentive reduction effect of the risk. The time-series averages of θ_1 and θ_2 are respectively -13.226 and 10.015, suggesting that the size of the offset for a firm with a median level of information-based stock trading is 37.86%. Based on the (unreported) detailed year-by-year regressions, we have two interesting findings: 1) the size of the offset averages at 41.48% for a firm with a median level of risk-related information-based stock trading over 1994-2001; and 2) such an offsetting effect due to the information-based stock trading tends to strengthen over time. The second finding is consistent with our numerical results. As the stock market has become more volatile in the past decade(s), ceteris paribus, the (private-)information-driven trading becomes more profitable and this attracts more stock traders to search for information, reinforcing the role of the stock market in producing/improving information, and consequently, enhancing CEO incentives.

In summary, our analytical, numerical, and empirical analysis above have underlined the importance of the information-based stock trading to CEO incentives and the risk-incentive relation. The results suggest that failure to control for differential levels of information-based stock trading in a cross-section empirical study might lead to a serious model mis-specification problem.

5 Welfare Analysis

Our model sheds light on the connection between stock market efficiency and economic efficiency. We view stock market efficiency in terms of information production as well as information improvement from the stock market, and economic efficiency in terms of social welfare improvement. In the model, the principal uses the information produced in the stock market to induce managerial efforts. The more efficient the stock market is, the higher is the managerial incentive, which consequently improves social welfare.

Dow and Gorton (1997) show that the stock market helps to improve economic efficiency through its role in guiding investment decisions. We focus on the stock market's role in improving the stock price's informational content which can be used by the principal to induce managerial incentives. We conduct the following numerical analysis to illustrate the economic significance of this alternative channel.

From Section 2, at equilibrium, the manager's ex-ante utility is fixed at $U_a = \overline{U}_a$, and the principal's ex-ante utility is $U_p = E(\tilde{r} - W) = \frac{b}{k} - \frac{b^2\gamma}{2} Var(P) - \frac{f^2\gamma}{2} Var(\delta) - \gamma bf Cov(\delta, P) - \frac{b^2}{2k} - \overline{U_a}$. (See proof of Lemma 1 in Appendix 1.) The social welfare is the sum of the principal's ex-ante utility and the manager's ex-ante utility:[9]

$$SW = \frac{b}{k} - \frac{b^2\gamma}{2}Var(P) - \frac{f^2\gamma}{2}Var(\delta) - \gamma bfCov(\delta, P) - \frac{b^2}{2k}$$
$$= \frac{b}{k} - \frac{b^2\gamma}{2}Var(P)(1-\rho^2) - \frac{b^2}{2k}. \quad (19)$$

The amount of information-based stock trading determines the level of information production and the corresponding information enhancement effect in the economy. We examine the following two scenarios:

1. $N = n_0$, where n_0 is the *initial* equilibrium number of informed traders in the stock market. This corresponds to the case where the stock market produces information, but the amount of produced information is fixed. This situation may also resemble the case where some legal or institutional rules are in place to prohibit any potential trader from becoming an informed trader except the n_0 existing informed traders.

2. N changes according to equation (3) as the cash flow uncertainty changes, which corresponds to the case where a greater uncertainty attracts more information-based stock trading.

Let SW_1 and SW_2 represent the levels of social welfare in Scenarios 1 and 2, respectively. We calculate SW_1 and SW_2 using the baseline values of the parameters in Table 1.

Figure 6, Panel A graphs the two social welfare levels against percentage increases in the underlying uncertainty. The dashed and solid lines stand for SW_1 and SW_2, respectively. Both SW_1 and SW_2 are strictly downward-sloped, indicative of a tradeoff between the social welfare and uncertainty for a given level of information production. The information enhancement effect is strictly dominated (Proposition 2), leading to an overall risk-incentive tradeoff as well as a negative risk-welfare relation. Strictly dominated as it is, the information enhancement effect contributes to a significant welfare improvement. In the figure, the SW_2 curve tops the SW_1 curve, and the gap widens as the uncertainty mounts. Starting from the same initial level, SW_2 exceeds SW_1 by 10.05% when V_δ doubles and by 17.60% when V_δ triples.

[9]Since informed traders, liquidity traders, and market-makers are all risk-neutral and the stock market is a zero-sum game in this economy, the net welfare out of the stock market is zero. Thus, the SW term defined in equation (19) is the social welfare for the entire economy including both the real and financial sectors.

To measure the social welfare improvement due to the information enhancement, we compute the difference between the decline in SW_2 and the decline in SW_1 as a result of the increases in V_δ, and then divide the difference by the magnitude of the decline in SW_1 to obtain the percentage offset of the risk-welfare tradeoff. Figure 6, Panel B plots the percentage offsets of the social welfare reduction against percentage increases in uncertainty V_δ. The offset becomes stronger and stronger as the underlying uncertainty builds up. When V_δ rises by 1% from the initial value, the offset is 15.35%. The offsets are respectively 22.62% and 24.95% when V_δ doubles and triples. Overall, the social welfare implications of an increasing level of information-based stock trading in response to a greater uncertainty are by all means significant.

6 Summary and Conclusions

We investigate the role of information-based stock trading in affecting the risk-incentive relation in this paper. We develop a parsimonious model that combines an optimal contracting process with a stock trading process. The informational content in stock price is endogenously determined and depends only on trading characteristics. We analytically decompose the equilibrium impact of risk on incentives into two offsetting effects: the direct effect measures the standard risk-incentive tradeoff given a level of information-based trading; and the indirect effect reflects incentive enhancement due to an increasing level of information-based trading driven by uncertainty. The information enhancement effect due to information-based stock trading is missing from the incentive literature.

We conduct a numerical analysis to evaluate the economic magnitude of the missing link. The information enhancement effect, though strictly dominated, contribute significantly to cross-section differences in pay-performance sensitivities. Numerical results show that the size of the information enhancement effect is around 20-40% of the size of the standard risk-incentive tradeoff when the level of fundamental uncertainty doubles. The offset of the information enhancement effect against the risk-incentive tradeoff gains in strength with respect to the mounting uncertainty. We find that the optimal managerial incentive increases monotonically as the market liquidity improves, and that the optimal managerial incentive displays a U-shaped response to either the reservation value of becoming an informed trader or the noisiness of private signals.

Using probability of informed trading (PIN) as a proxy for the amount of information-based trading, we test one main model implication with CEO compensation data. We not only obtain a statistical significance that strongly supports our model prediction, but we also identify an economic significance that matches the result from the numerical analysis. We find that a median level of information-based stock trading leads to an average 20 percent offset of the risk-incentive tradeoff over the sample period 1994-2001. By decomposing the PIN measure into the risk-related and non-risk-related components, we find that the information-based trading has both a positive level effect and a positive slope effect on CEO incentives. On the one hand, a median level of *non-risk-related* information-based trading increases the level of CEO incentives by \$1.823, per \$1,000 increase in the shareholder value. On the other hand, for a firm at the median level of *risk-related* information-based trading, the percentage offset of the incentive enhancement effect against the incentive-reduction effect averages at about 38 percent over 1994-2001. Every one percent increase in the level of risk-related information-based stock trading offsets the risk-incentive tradeoff by 0.624 percent.

Our empirical results also illustrate the economic significance of the information enhancement effect on the level of CEO incentives. We find that, for a firm of median characteristics, the CEO incentive, measured by pay-performance sensitivity (PPS), improves by 16.44 percent to 51.58 percent when the information-based stock trading increases from the median level to the maximum level. The increases in CEO incentives depend on the level of uncertainty facing the firm. The larger the underlying uncertainty, the greater the impact of information-based trading on CEO incentives.

Our model sheds light on the connection between stock market efficiency and economic efficiency. A well-functioning stock market not only produces information but also fine-tunes the information precision in response to a shock to the economy. Although the link between the two efficiencies is indirect, the magnitude of the social welfare loss without such a link is large and increases dramatically when the uncertainty of the economy rises.

Appendix 1: Proofs

Proof of Lemma 1: We set up the principal's problem as follows:

$$\begin{aligned} \max_{a,b,f,e} \quad & E(\widetilde{r} - W) \\ \text{s.t.} \quad & \max_{e} E(W) - \frac{\gamma}{2} Var(W) - c(e) \geq \overline{U}_a \end{aligned} \tag{A. 1}$$

where $\overline{U}_a$ is the reservation utility to the manager. Given the compensation contract $W = \hat{a} + bP + f\hat{r}$ (as specified in equation (4)), the manager solves the following problem:

$$\max_{e} \hat{a} + be - \frac{b^2\gamma}{2} Var(P) - \frac{f^2\gamma}{2} Var(\delta) - \gamma bf Cov(P, \delta) - \frac{ke^2}{2}. \tag{A. 2}$$

The first-order condition yields

$$b = ke. \tag{A. 3}$$

We therefore have equation (7). At equilibrium, the manager's individual rationality condition should be binding, which yields

$$\hat{a} = \overline{U}_a - be + \frac{b^2\gamma}{2} Var(P) + \frac{f^2\gamma}{2} Var(\delta) + \gamma bf Cov(P, \delta) + \frac{ke^2}{2}. \tag{A. 4}$$

With $W = \hat{a} + bP + f\hat{r}$, the principal's problem can be rewritten as

$$\begin{aligned} \max_{\hat{a},b,f} \quad & (1 - b)e - \hat{a} \\ \text{s.t.} \quad & b = ke \\ & \hat{a} = \overline{U}_a - be + \frac{b^2\gamma}{2} Var(P) + \frac{f^2\gamma}{2} Var(\delta) + \gamma bf Cov(P, \delta) + \frac{ke^2}{2} \end{aligned}$$

Substitute $\frac{b}{k}$ for e and equation (A. 4) for $\hat{a}$. The above problem is therefore simplified as

$$\max_{b,f} \frac{b}{k} - \frac{b^2\gamma}{2} Var(P) - \frac{f^2\gamma}{2} Var(\delta) - \gamma bf Cov(P, \delta) - \frac{b^2}{2k}. \tag{A. 5}$$

The first-order conditions yield

$$\frac{1}{k} - b\gamma Var(P) - f\gamma Cov(P, \delta) - \frac{b}{k} = 0, \tag{A. 6}$$

and

$$-\gamma f Var(\delta) - \gamma b Cov(P, \delta) = 0. \tag{A. 7}$$

We immediately obtain from equation (A. 7)

$$f = -b \frac{Cov(P, \delta)}{Var(\delta)}. \tag{A. 8}$$

Plugging $f = -b\frac{Cov(P,\delta)}{Var(\delta)}$ back into equation (A. 6), we obtain

$$b = \frac{1}{1+\gamma k VarP(1-\rho^2)}. \tag{A. 9}$$

Q.E.D.

Proof of Lemma 2: Using the implicit function theorem, we have:

$\frac{dN}{dV_\delta} = N^{\frac{1}{2}}\frac{V_\delta^2(V_\delta+V_\epsilon)^{-\frac{1}{2}}V_z^{\frac{1}{2}}+4\mu N^{\frac{1}{2}}V_\epsilon}{\mu[(3N+1)V_\delta+2V_\epsilon]V_\delta} = N\frac{(N+1)V_\delta^2+6V_\delta V_\epsilon+4V_\epsilon^2}{V_\delta(V_\delta+V_\epsilon)[(3N+1)V_\delta+2V_\epsilon]} > 0.$ **Q.E.D.**

Proof of Lemma 3: Because $\omega = N\beta\delta + \sum_{i=1}^{N}(\beta\epsilon_i) + z$, we obtain $V_\omega = \frac{(N+1)V_\delta+2V_\epsilon}{V_\delta+V_\epsilon}V_z$. Further, with $P = e + \lambda\omega$, we have $Var(P) = \lambda^2 V_\omega = \frac{NV_\delta^2}{(N+1)V_\delta+2V_\epsilon}$.

From the stock market equilibrium, we have $Cov(P,\delta) = \lambda Cov(\omega,\delta) = \lambda N\beta V_\delta = \frac{NV_\delta^2}{(N+1)V_\delta+2V_\epsilon} = Var(P)$. Then, $\rho^2 \equiv \frac{Cov^2(P,\delta)}{Var(P)V_\delta} = \frac{NV_\delta}{(N+1)V_\delta+2V_\epsilon}$. Thus, $\frac{d\rho^2}{dV_\delta} = \frac{V_\delta(V_\delta+2V_\epsilon)\frac{dN}{dV_\delta}+2NV_\epsilon}{[(N+1)V_\delta+2V_\epsilon]^2} > 0$ because $\frac{dN}{dV_\delta} > 0$ (see Lemma 2).

We then conclude that $Var(P) = \rho^2 V_\delta$, and clearly, $\frac{dVar(P)}{dV_\delta} > 0$ as $\frac{d\rho^2}{dV_\delta} > 0$. **Q.E.D.**

Proof of Proposition 1: Using the results from proof of Lemma 3 and applying the total differentials, we immediately obtain $\frac{dVar(MP)}{dV_\delta} \equiv \frac{dVar(P)(1-\rho^2)}{dV_\delta} = PC - IE$, where PC and IE are defined as in equation (10) and equation (11), respectively. To show that $\frac{dVar(MP)}{dV_\delta} > 0$, we need to show that $PC > IE$. That is,

$$N(N+1)V_\delta^3 + 6NV_\delta^2V_\epsilon + 8NV_\delta V_\epsilon^2 > V_\delta^2(V_\delta+2V_\epsilon)[(N-1)V_\delta - 2V_\epsilon]\frac{dN}{dV_\delta}. \tag{A. 10}$$

Or,

$$\begin{aligned} LHS &\equiv \left[N(N+1)V_\delta^3 + 6NV_\delta^2V_\epsilon + 8NV_\delta V_\epsilon^2\right][(V_\delta+V_\epsilon)(3N+1)V_\delta + 2V_\epsilon] > \\ RHS &\equiv NV_\delta(V_\delta+2V_\epsilon)[(N-1)V_\delta - 2V_\epsilon]\left[(N+1)V_\delta^2 + 6V_\delta V_\epsilon + 4V_\epsilon^2\right]. \end{aligned} \tag{A. 11}$$

This holds as the coefficient of each term in LHS is larger than that of its corresponding term in RHS. **Q.E.D.**

Appendix 2: The CEO Incentive Measure

We compute the change in value of a CEO's stock holdings for a given year as the beginning-of-year value of his stock holdings multiplied by the year's stock return. It is important to revalue the stock option portfolios. The ExecuComp database contains the values of unexercised exercisable and unexercisable in-the-money options, but the database measures only the intrinsic value of the option portfolios. We apply the Black-Scholes model modified with dividends to revaluate the stock option portfolios. We adopt Core and Guay's (1999) method to compute the hedge ratio delta (δ) of each option. We then multiply the option deltas by the change in the firm's market value (or change in shareholders' wealth), adjusting for the percentage of stock shares represented by the options, and then add the value from stock option exercise to obtain the change in value of the CEO's option holdings. We define the changes in shareholders' wealth over a given year as the firm's beginning-of-year market value times this year's stock return. We then formally define the stock-based pay-performance sensitivity (PPS) as follows:

$$PPS_{it} = \frac{(\triangle CEO's\ Holdings\ of\ Stock\ and\ Stock\ Options)_{it}}{(\triangle Shareholder's\ Wealth)_{it}}. \tag{A. 12}$$

Appendix 3: The PIN Measure

The PIN measure is based on the market microstructure model introduced in Easley and O'Hara (1992), where trades can come from liquidity traders or from informed traders. There are three types of players in the game, liquidity traders, informed traders, and market makers. The arrival rate of liquidity traders who submit buy orders is ϵ and that of liquidity traders who submit sell orders is also ϵ. Every day, the probability that an information event will occur is α, in which case the probability of bad news is δ and the probability of good news is $(1-\delta)$. If an information event occurs, the arrival rate of informed traders is μ. Informed traders submit a sell order if they get bad news and a buy order if they get good news. Thus, on a day without information events which happens with probability $(1-\alpha)$, the arrival rate of a buy order will be ϵ and the arrival rate of a sell order will also be ϵ. On a day with a bad information event (with probability $\alpha\delta$), the arrival rate of a buy order will be ϵ and the arrival rate of a sell order will be $\epsilon+\mu$. On a day with a good information event (with probability $\alpha(1-\delta)$), the arrival rate of a buy order will be $\epsilon+\mu$ and the arrival rate of a sell order will be ϵ. Let $\theta = (\epsilon, \alpha, \delta, \mu)$. The likelihood function for a single trading day is given by:

$$\begin{aligned} L(\theta|B,S) &= (1-\alpha)e^{-\epsilon}\frac{(\epsilon)^B}{B!}e^{-\epsilon}\frac{(\epsilon)^S}{S!} + \alpha\delta e^{-\epsilon}\frac{(\epsilon)^B}{B!}e^{-\epsilon+\mu}\frac{(\epsilon+\mu)^S}{S!} \\ &\quad +\alpha(1-\delta)e^{-\epsilon+\mu}\frac{(\epsilon+\mu)^B}{B!}e^{-\epsilon}\frac{(\epsilon)^S}{S!}, \end{aligned} \tag{A. 13}$$

where B is the number of buy orders and S is the number of sell orders in a single trading day. The trade direction is inferred from intraday data based on the algorithm proposed in Lee and Ready (1991).

Using the number of buy and sell orders in every trading day in a given year $M = (B_t, S_t)_{t=1}^T$ and assuming cross-trading day independence, we can estimate the parameters of the model

$(\epsilon_b, \epsilon_s, \alpha, \delta, \mu)$ by maximizing the following likelihood function:

$$L(\theta|M) = \prod_{t=1}^{t=T} L(\theta|B_t, S_t). \tag{A. 14}$$

Thus, we estimate the probability of informed trading PIN by dividing the estimated arrival rate of informed trades by the estimated arrival rate of all trades:

$$PIN = \frac{\alpha\mu}{\alpha\mu + 2\epsilon}. \tag{A. 15}$$

References

[1] Aggarwal, Rajesh K., and Andrew A. Samwick, 1999, The other side of the trade-off: The impact of risk on executive compensation, *Journal of Political Economy*, 107, 65-105.

[2] Baiman, Stanley, and Robert E. Verrecchia, 1995, Earnings and price-based compensation contracts in the presence of discretionary trading and incomplete contracting, *Journal of Accounting and Economics*, 20, 93-121.

[3] Black, Fischer, and Myron Scholes, 1973, The pricing of options and corporate liabilities, *Journal of Political Economy*, 81, 637-654.

[4] Cochrane, John H., 2001. Asset Pricing. Princeton University Press.

[5] Core, John, and Wayne Guay, 1999, The use of equity grants to manage optimal equity incentive levels, *Journal of Accounting and Economics*, 28, 151-184.

[6] Core, John, and Wayne Guay, 2002. The other side of the trade-off: The impact of risk on executive compensation: A revised comment. Working paper, University of Pennsylavania.

[7] Dow, James, and Gary Gorton, 1997, Stock market efficiency and economic efficiency: Is there a connection?, *Journal of Finance*, 52, 1087-1129.

[8] Easley, David, and Maureen O'Hara, 1992, Time and the process of security adjustment, *Journal of Finance*, 47, 577-607.

[9] Easley, David, Soeren Hvidkjaer, and Maureen O'Hara, 2002. Is information risk a determinant of asset returns? *Journal of Finance*, 57, 2185-2221.

[10] Easley, David, Nicholas Kiefer, and Maureen O'Hara, 1996. Cream-skimming or profit-sharing? The curious role of purchased order flow, *Journal of Finance*, 51, 811-833.

[11] Easley, David, Nicholas Kiefer, and Maureen O'Hara, 1997. The information content of the trading process, *Journal of Empirical Finance*, 4, 159-186.

[12] Easley, David, Nicholas Kiefer, Maureen O'Hara, and Joseph Paperman, 1996. Liquidity, information, and less-frequently traded stocks, *Journal of Finance*, 51, 1405-1436.

[13] Easley, David, Maureen O'Hara, and P.S. Srinivas, 1998. Option volumn and stock prices: Evidence on where informed traders trade, *Journal of Finance*, 53, 431-465.

[14] Garen, John, E., 1994, Executive compensation and principal-agent theory, *Journal of Political Economy*, 102, 1175-1199.

[15] Hall, Brian J., and Jeffrey B. Liebman, 1998. Are CEOs really paid like bureaucrats?. *Quarterly Journal of Economics*, 113, 653–691.

[16] Hartzell, Jay C., and Laura T. Starks, 2003. Insitutional investors and executive compensation. Journal of Finance 58, 2351-2374.

[17] Haubrich, Joseph G., 1994, Risk aversion, performance pay, and the principal-agent problem, *Journal of Political Economy*, 102, 258-276.

[18] Holmstrom, Bengt, 1979, Moral hazard and observability, *Bell Journal of Economics*, 10, 74-91.

[19] Holmstrom, Bengt, and Paul R. Milgrom, 1987, Aggregation and linearity in the provision of intertemporal incentives, *Econometrica*, 55, 303-328.

[20] Holmstrom, Bengt, and Jean Tirole, 1993, Market liquidity and performance monitoring, *Journal of Political Economy*, 101, 678-709.

[21] Ittner, Christopher D., Richard A. Lambert, and David F. Larcker, 2003, The structure and performance consequences of equity grants to employees of new economy firms, *Journal of Accounting and Economics*, 34, 89-127.

[22] Jensen Michael C., and Kevin J. Murphy, 1990, Performance pay and top-management incentives, *Journal of Political Economy*, 98, 225-262.

[23] Jin, Li, 2002, CEO compensation, diversification, and incentives, *Journal of Financial Economics*, 66, 29-63.

[24] Kyle, Albert S., 1985, Continuous auctions and insider trading, *Econometrica*, 57, 1315-1335.

[25] Lee, Charles M. and Mark J. Ready, 1991, Inferring trade direction from intraday data. *Journal of Finance*, 46, 733-746.

[26] Milbourn, Todd T., 2003. CEO reputation and stock-based compensation. *Journal of Financial Economics*, 68, 233-262.

[27] Murphy, Kevin J., 1999. Executive compensation. In: Orley Ashenfelter and David Card (Eds.), Handbook of Labor Economics, Vol 3, North Holland.

[28] Prendergast, Canice, 2002, The tenuous trade-off of risk and incentives, *Journal of Political Economy*, 110, 1071-1102.

[29] Raith, Michael, 2003, Competition, risk and managerial incentives, *American Economic Review*, 93, 1425-1436.

[30] Vega, Clara, 2004. Are investors overconfident? Working paper, University of Rochester.

[31] Yermack, David L., 1995, Do corporations award CEOs stock-options effectively? *Journal of Financial Economics*, 39, 237-269.

Table 2: Summary Statistics

We measure the stock-based pay-performance sensitivity (PPS) as the change in value of the CEO's stock and stock options holdings divided by the change in the firm's shareholder value. The change in value of stock holdings is computed as the beginning-of-year value of CEO's stock holdings multiplied by the current year's stock return. The change in the value of stock options equals the product of option deltas and the change in the firm's market value after adjusting for the share percentage represented by existing stock options. We calculate the change in the firm's shareholder as the percentage stock returns times the market capitalization of equity at last year-end (in millions of dollars). We use probability of informed trading (PIN) per Easley, Kiefer and O'Hara (1996, 1997) to measure the amount of information-based trading. We obtain the firm value ($MKTVAL$, in millions of dollars) as the product of fiscal year-end stock price and the total number of shares outstanding. We measure risk by a firm's standard deviation of shareholder dollar returns, $STDV$. We compute $STDV$ of a given year as the annualized percentage standard deviation of the past five-year monthly stock returns multiplied by the beginning-of-year firm value (in millions of dollars). Both $MKTVAL$ and $STDV$ are in 1992 constant dollars. We calculate the total institutional holding $Tothld$ as the total institutional share holdings scaled by the total number of shares outstanding. We compute the concentrated ownership ($Con5$) as the top-five institutional share holdings in percentage of the total institutional share holdings. We calculate Tobin's Q ($Tobinq$) as 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 (data25 times data 199) less the book value of common equity (data 60) and balance sheet deferred taxes (data 74). We compute $TENURE$ as the CEO's tenure as of year t. Nobs is the number of non-missing observations. All monetary variables are in 1992 constant dollars. The sample period for PIN is 1993-2001 since the PIN measure is calculated from the TAQ database which starts its data coverage from 1993. The sample periods for the other variables are 1992-2001.

Variables	Mean	Std Dev	Median	Min	Max	Nobs
Incentive (PPS)	41.119	76.475	11.881	4.80e-16	994.446	14,324
Information-based Trading (PIN)	0.163	0.051	0.157	0	0.797	8,456
Firm Value (MKTVAL,$M)	4,292.29	15,270.39	864.98	6.10e-3	427,220.8	17,369
Risk (STDV,$M)	1,260.16	4,970.07	292.44	1.068	186,693.9	16,862
Total Institutional Holding (Tothld,%)	56.472	20.187	58.048	0.027	99.937	14,602
Concentrated Ownership (Con5,%)	43.801	14.639	41.393	12.532	100	14,676
TOBIN's Q	2.159	2.747	1.480	0.279	105.090	17,307
TENURE	7.682	7.409	5.500	0.083	54.917	16,028

Table 3: Median Regression of CEO Incentives (PPS): 1994-2001

This table reports the pooled median regression results (Column 1) and the time-series average of year-by-year median regression results (Column 2) on the following model:

$$\begin{aligned} PPS_{i,t} &= \theta_0 + \theta_1 * CDF(STDV_{i,t}) + \theta_2 * CDF(STDV_{i,t}) * CDF(PIN_{i,t-1}) + \theta_3 * CDF(Tothld_{i,t-1}) \\ &\quad + \theta_4 * CDF(Con5_{i,t-1}) + \theta_5 * CDF(Tobinq_{i,t-1}) + \theta_6 * CDF(Tenure_{i,t}) + \sum_{k \geq 7} \theta_k * Dummies_{i,t} + \varepsilon_{i,t}. \end{aligned}$$

PPS, $STDV$, and PIN are proxies for CEO incentives, firm risks, and the amount of information-based stock trading, respectively. Control variables, $Tothld$, $Con5$, $Tobinq$, and $Tenure$ stand for total institutional holdings, concentrated ownership, Tobin's Q, and CEO tenure, respectively. $Dummies$ include both industry dummies and year dummies. We define CEO incentives, PPS, as the change in dollar value of the CEO's stock and stock option holdings per $1,000 change in the shareholder value. Table 2 details variable definitions. For brevity we do not report coefficient estimates of industry dummies and year dummies in the table. We report standard errors in parentheses. The standard errors in Columns 1 and 2 are calculated based on 20 bootstrap replications and the standard deviation of the time-series parameter estimates, respectively.

*, **, *** stand for statistical significance at the 10%, 5% and 1% levels, respectively.

	(1) Pooled regression	(2) Time-series Average: Year-by-year regression
Constant	8.343***	8.266***
	(1.020)	(0.512)
CDF(STDV$_{i,t}$)	-16.168***	-16.227***
	(0.794)	(0.908)
CDF(STDV$_{i,t}$) $* CDF(PIN_{i,t-1})$	5.763***	6.555***
	(1.041)	(1.621)
CDF(Tothld$_{i,t}$)	-5.527***	-5.675***
	(0.635)	(0.574)
CDF(Con5$_{i,t-1}$)	5.782***	6.530***
	(0.744)	(1.038)
CDF(Tobinq$_{i,t-1}$)	9.107***	10.067***
	(0.737)	(0.729)
CDF(tenure$_{i,t}$)	14.715***	14.671***
	(0.547)	(0.444)
Industry Dummies	yes	yes
Year Dummies	yes	no
Sample Size	6,503	813
Pseudo R^2	0.073	0.077

Table 4: Median Regression of CEO Incentives (PPS): Decomposed PINs, 1994-2001

This table reports the pooled median regression results (Column 1) and the time-series average of year-by-year median regression results (Column 2) on the following model:

$$
\begin{aligned}
PPS_{i,t} \;=\;& \theta_0 + \theta_1 * CDF(STDV_{i,t}) + \theta_2 * CDF(STDV_{i,t}) * CDF(PINF_{i,t-1}) + \theta_r * CDF(PINR_{i,t-1}) \\
&+ \theta_3 * CDF(Tothld_{i,t-1}) + \theta_4 * CDF(Con5_{i,t-1}) + \theta_5 * CDF(Tobinq_{i,t-1}) + \theta_6 * CDF(Tenure_{i,t}) \\
&+ \sum_{k\geq 7} \theta_k * Dummies_{i,t} + \varepsilon_{i,t}.
\end{aligned}
$$

PPS and $STDV$ are proxies for CEO incentive and firm risk, respectively. We use the PIN measure as a proxy for the amount of information-based stock trading. $PINF$ and $PINR$ are separately the fitted values (not including the intercept) and residuals (including the intercept) from year-by-year cross-sectional regressions of PIN against $STDV$ and $STDV^2$. Control variables, $Tothld$, $Con5$, $Tobinq$, and $Tenure$ stand for total institutional holdings, concentrated ownership, Tobin's Q, and CEO tenure, respectively. $Dummies$ include both industry dummies and year dummies. We define CEO incentives, PPS, as the change in dollar value of the CEO's stock and stock options holdings per $1,000 change in the shareholder value. Table 2 details variable definitions. For brevity we do not report coefficient estimates of industry dummies and year dummies in the table. We report standard errors in parentheses. The standard errors in Columns 1 and 2 are calculated based on 20 bootstrap replications and the standard deviation of the time-series parameter estimates, respectively.

*, **, *** stand for statistical significance at the 10%, 5% and 1% levels, respectively.

	(1) Pooled regression	(2) Time-series Average: Year-by-year regression
Constant	4.226***	4.346***
	(1.098)	(0.692)
CDF(STDV$_{i,t}$)	-13.909***	-13.226***
	(0.757)	(0.842)
CDF(STDV$_{i,t}$) $* CDF(PINF_{i,t-1})$	8.674***	10.015***
	(1.497)	(2.236)
CDF(PINR$_{i,t-1}$)	3.645***	3.948***
	(0.571)	(0.971)
CDF(Tothld$_{i,t}$)	-5.155***	-5.527***
	(0.624)	(0.664)
CDF(Con5$_{i,t-1}$)	5.531***	6.324***
	(0.722)	(1.034)
CDF(Tobinq$_{i,t-1}$)	8.671***	9.204***
	(0.729)	(0.723)
CDF(tenure$_{i,t}$)	14.816***	14.567***
	(0.540)	(0.520)
Industry Dummies	yes	yes
Year Dummies	yes	no
Sample Size	6,267	783
Pseudo R^2	0.075	0.080

Figure 1: Risk-Incentive Curves with High and Low Levels of Information-Based Stock Trading

This figure plots risk-incentive curves with different levels of information-based trading (and hence different levels of information production). The dashed and solid lines correspond to the high and low information-based stock trading, respectively.

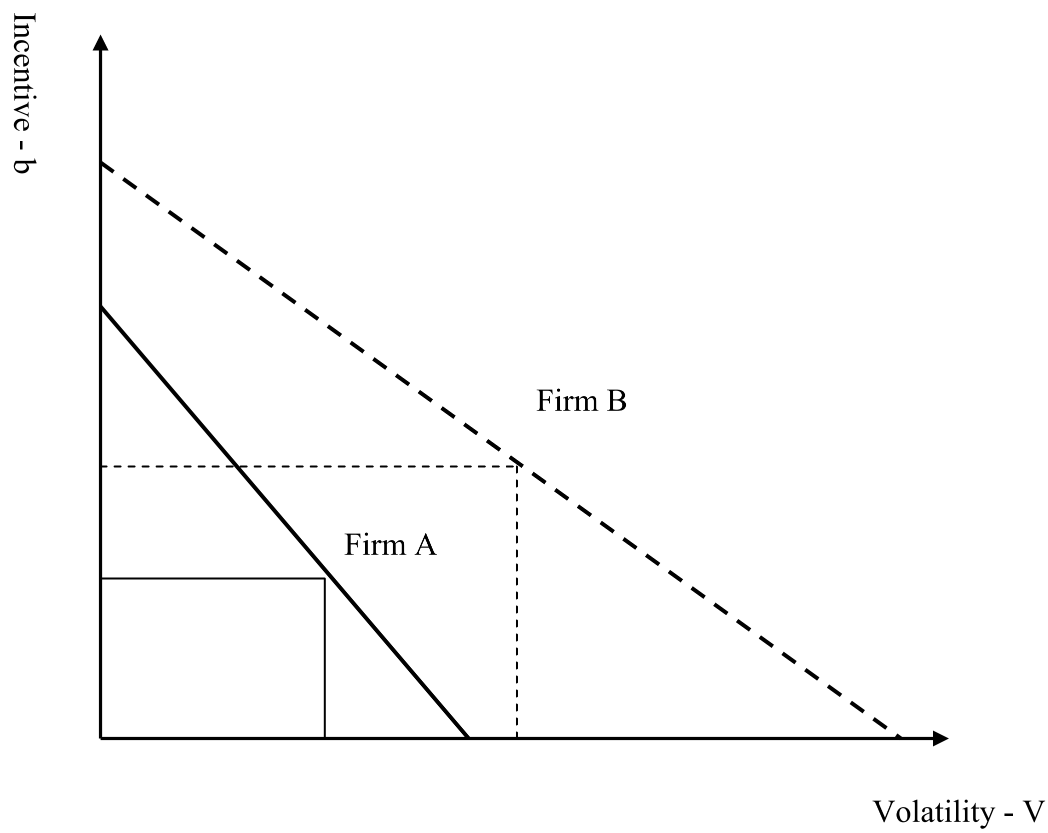
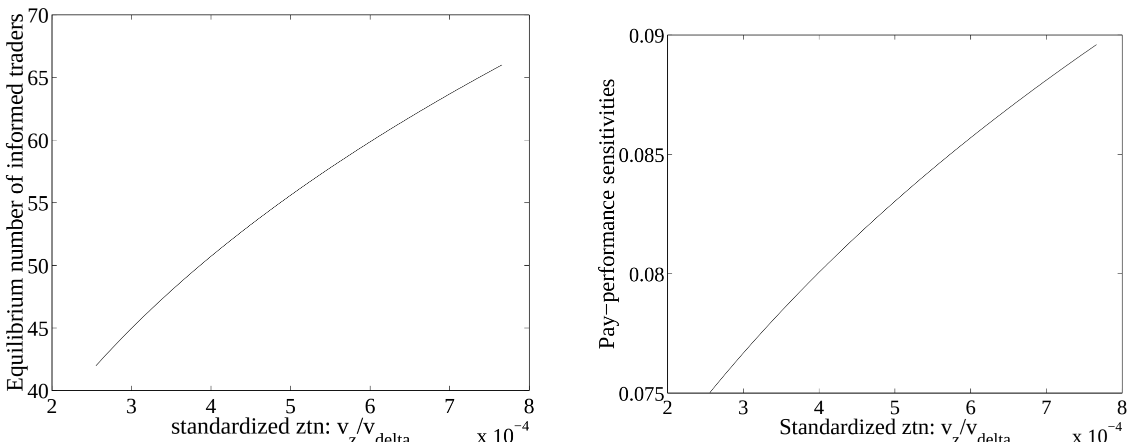


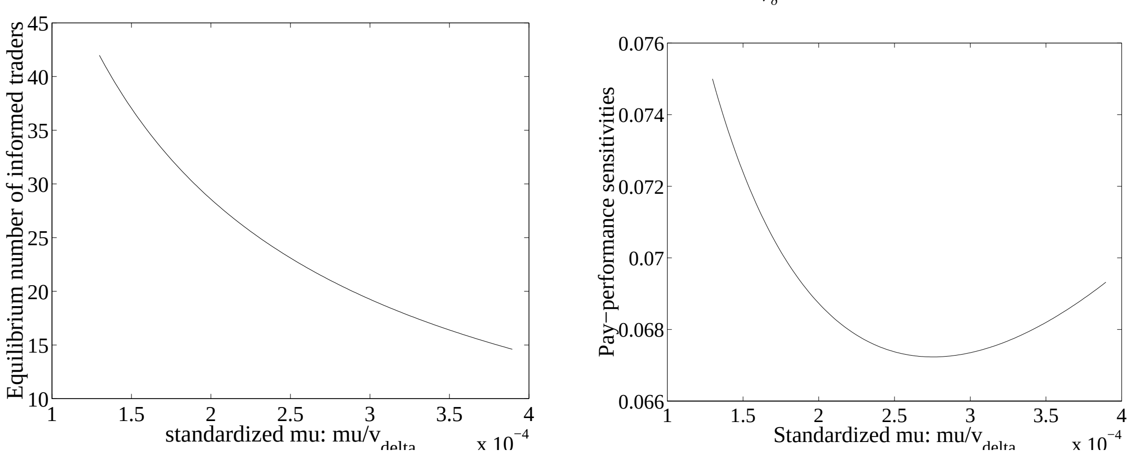
Figure 2: Comparative Statistics: Responses of N and b to Changes in ztn, smu, and stn

This figure plots the responses of the equilibrium number of informed traders, N, and the optimal pay-performance sensitivity, b, to different values of $ztn \equiv \frac{V_z}{V_\delta}$ (Panel A), $smu \equiv \frac{\mu}{V_\delta}$ (Panel B), and $stn \equiv \frac{V_\epsilon}{V_\delta}$ (Panel C), respectively.

Panel A. Comparative Statistics: $ztn \equiv \frac{V_z}{V_\delta}$



Panel B. Comparative Statistics: $smu \equiv \frac{\mu}{V_\delta}$



Panel C. Comparative Statistics: $stn \equiv \frac{V_\epsilon}{V_\delta}$

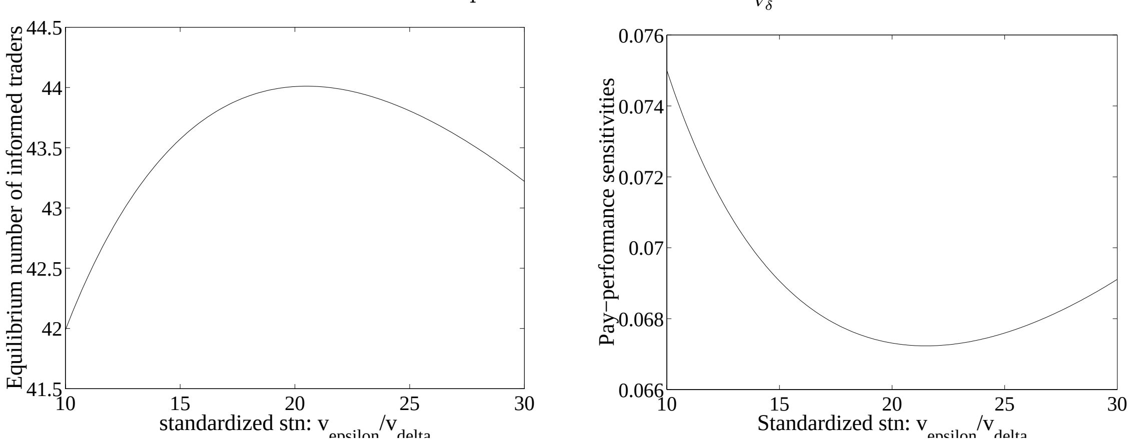


Figure 3: Responses of N and The Two Offsetting Effects: Baseline Values

This figure plots different levels of N (Panel A) and marginal changes in N (Panel B) as well as the two offsetting effects, PC and IE (Panel C), in response to percentage changes in the underlying uncertainty V_δ. The marginal changes are the total differentials evaluated at each corresponding level of uncertainty. In Panel C, the dashed and solid lines stand for the PC and IE effects, respectively.

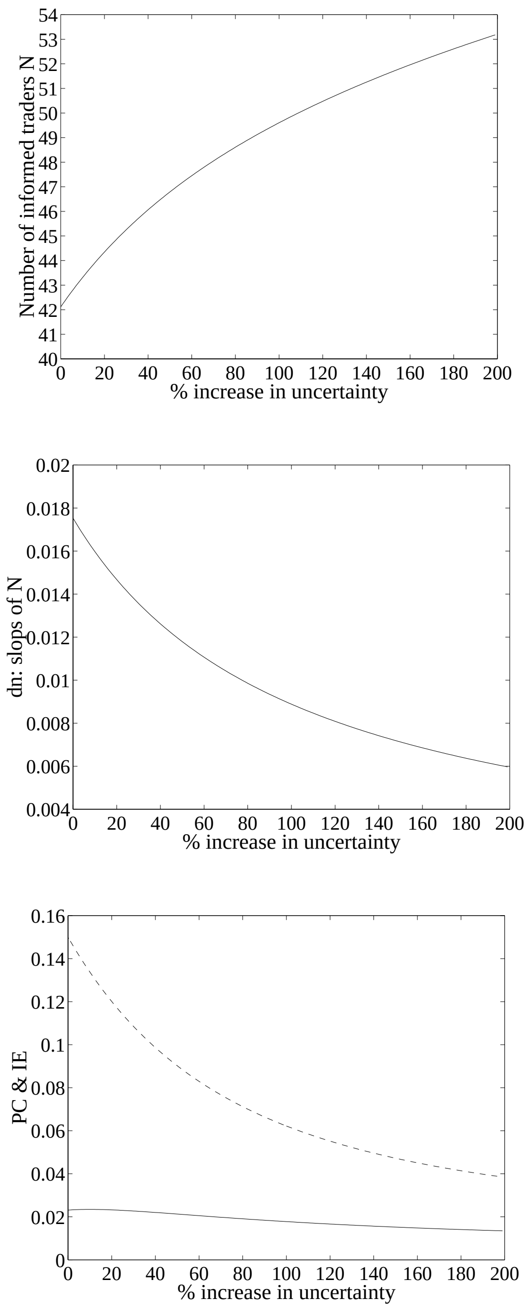
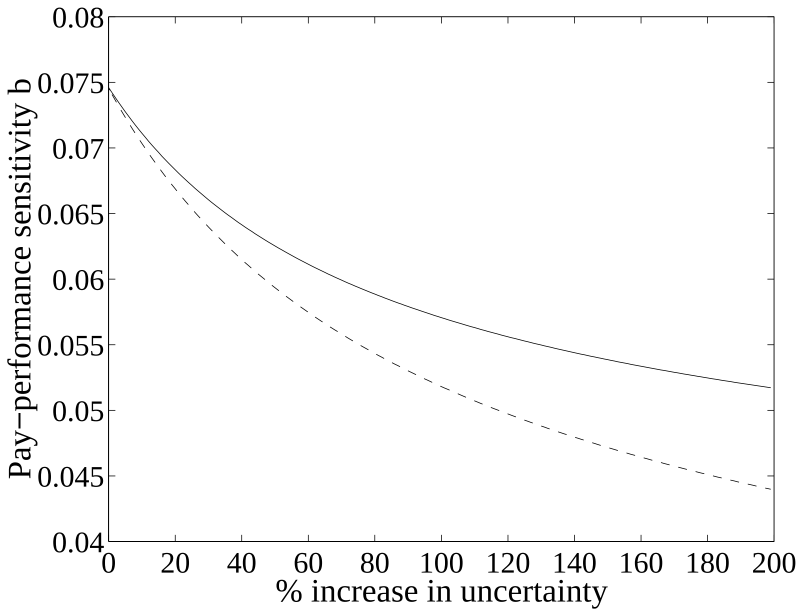


Figure 4: Responses of b: Baseline Values

Panel A plots the responses of the pay-performance sensitivity b against percentage increases in uncertainty V_δ. The dashed and solid lines represent the cases where $N = n_0$, and N changes according to equation (3), respectively. Panel B plots the percentage offsets of the risk-incentive tradeoff against percentage increases in uncertainty V_δ. We compute the difference between the decline in b with a changing N and the decline in b with a constant $N = n_0$ as a result of the increases in V_δ, and then divide the difference by the magnitude of the decline in b with a constant $N = n_0$ to obtain the percentage offset of the risk-incentive tradeoff.

Panel A. Responses of b to percentage increases in V_δ



Panel B. Percentage offsets of the risk-incentive tradeoff due to information enhancement

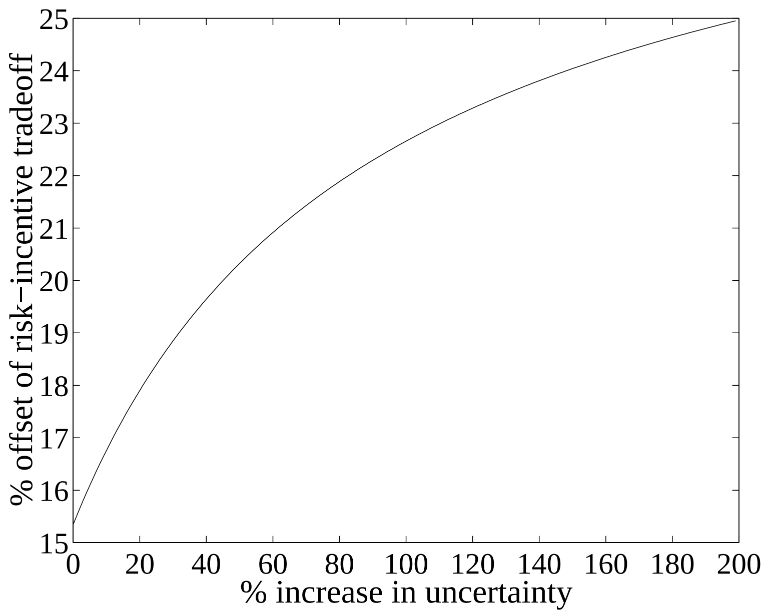
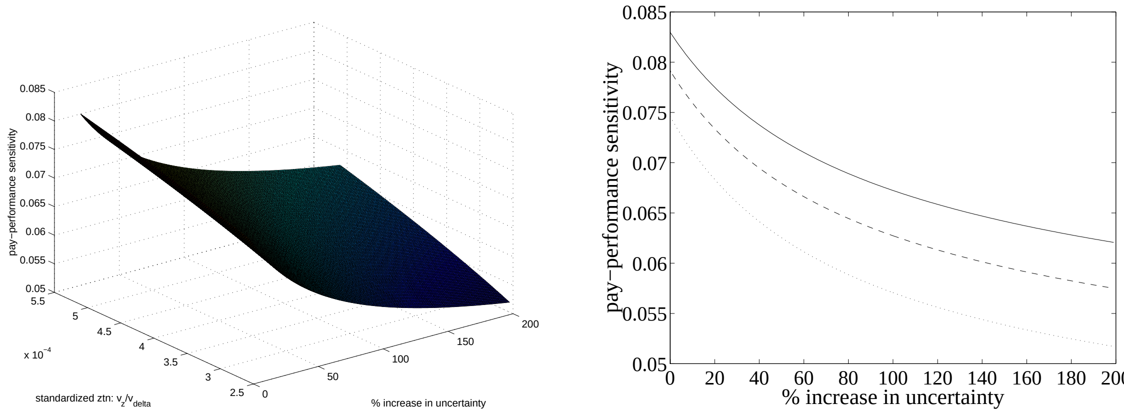


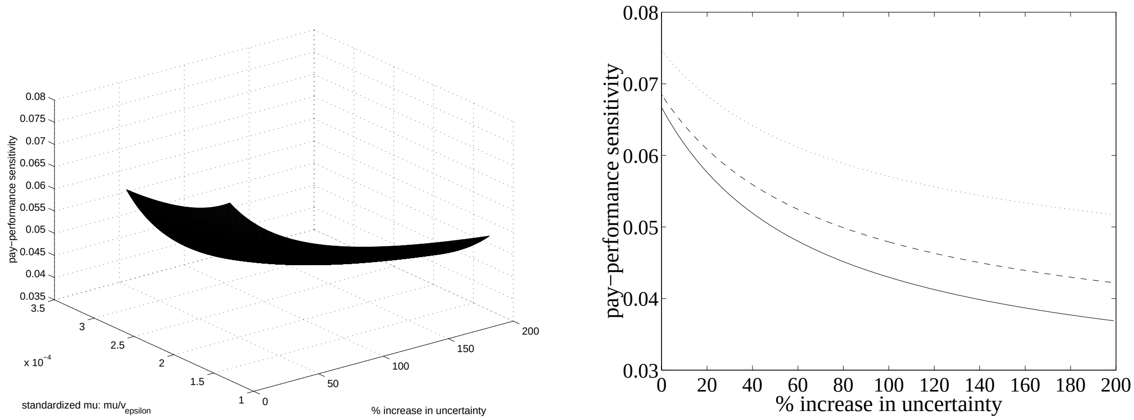
Figure 5: Response Surfaces of b to Joint Changes in V_δ with ztn, or smu or stn

This figure plots the response surfaces of b to the joint changes in V_δ with ztn (Panel A), or smu (Panel B), or stn (Panel C). The changes in V_δ range from 0 to 200%. The changes in ztn, smu and stn range from 0 to 100%, 0 to 100%, and 5 to 15, respectively. In Panel A, the left half plots the three-dimension response surface, and the right half the responses of b to percentage increases in V_δ with the minimum (the dotted line), median (the dashed line), and maximum ztn (the solid line), respectively. Similar in Panel B and Panel C.

Panel A. Response surfaces: V_δ and $ztn \equiv \frac{V_z}{V_\delta}$



Panel B. Response surfaces: V_δ and $smu \equiv \frac{\mu}{V_\delta}$



Panel C. Response surfaces: V_δ and $stn \equiv \frac{V_\epsilon}{V_\delta}$

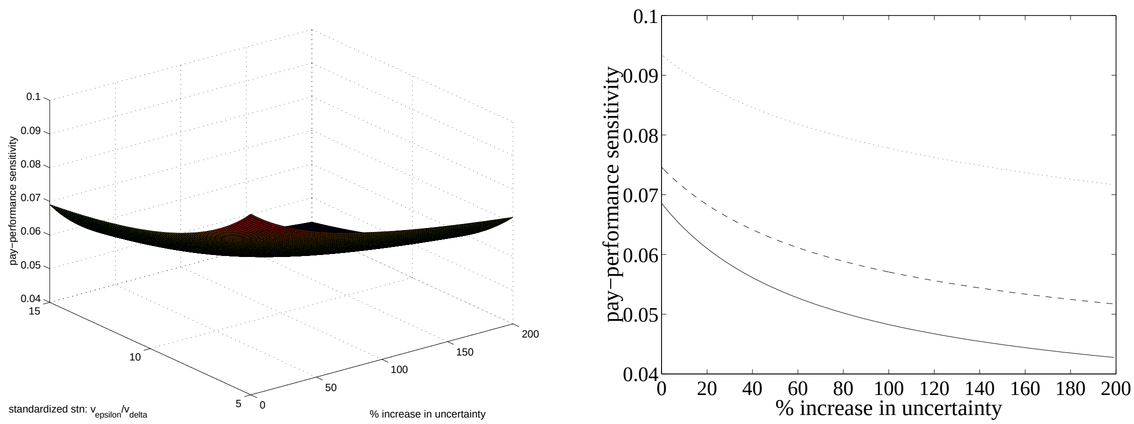
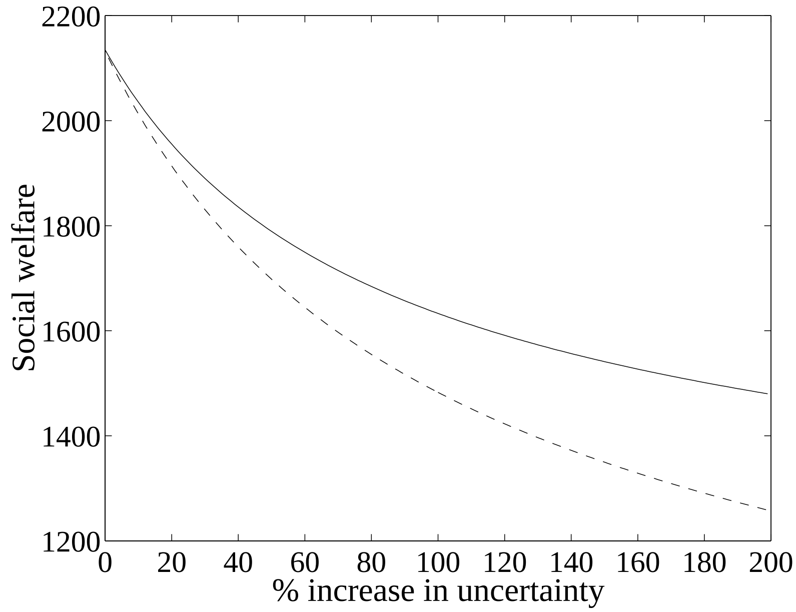


Figure 6: Responses of Social Welfare: Baseline Values

Panel A plots different levels of social welfare in response to percentage changes in the underlying uncertainty V_δ. The dashed line (SW_1) and the solid line (SW_2) represent the social welfare responses for the cases $N = n_0$, and N changes according to equation (3), respectively. Panel B plots the percentage offsets of the social welfare reduction against percentage increases in uncertainty V_δ. We compute the difference between the decline in SW_2 and the decline in SW_1 as a result of the increases in V_δ, and then divide the difference by the magnitude of the decline in SW_1 to obtain the percentage offset of the risk-welfare tradeoff.

Panel A. Responses of SW to percentage increases in V_δ



Panel B. Percentage offsets of the risk-welfare tradeoff due to information enhancement