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by

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Three Essays in Finance

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Three Essays in Finance

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Three Essays in Finance

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Chapter 1 develops a model advancing a new rationale for high CEO pay - the board's incentive to signal confidence in the CEO's capabilities. The CEO creates value for the firm by stimulating investments from various stakeholders, such as the firm's workers, analysts, or financiers. However, the payoffs to these investments often depend on the CEO's ability, which is difficult for stakeholders to directly observe. The model considers one specific stakeholder interested in the board's assessment of the CEO's capabilities, an analyst who may produce information that will have little value if the CEO is subsequently terminated. Because the firm's board both has private information about the CEO's ability and sets his wage, high compensation can positively influence the analyst's belief about the CEO's ability,

thereby increasing her incentives to collect information and improve the firm's decision making. The model thus predicts that signaling the CEO's capabilities is self-fulfilling: because stakeholders infer that a well-paid CEO has higher ability, they increase their investments, justifying the cost of the CEO's compensation. Chapter 2 presents broad empirical support for the main idea and assumptions used in the theory model presented in Chapter 1. It addresses trends in corporate governance, decreasing job security for CEOs, the role of analysts as stakeholders, and various signaling mechanisms boards may use to enhance the CEO's credibility. Chapter 3 explores how varying degrees of trader anonymity in financial markets impacts trading behavior and market characteristics. A surprising result emerges. Informed traders are not always better off with their identities protected, i.e., they may prefer to transact in relatively transparent markets. The reason is that in more transparent markets, the visibility of the informed trader's behavior creates an incentive for him to "bluff" the market maker, sometimes trading against his information. But because the market maker understands this incentive, prices are less sensitive to order flow. Thus, more transparent markets may in fact exhibit higher levels of liquidity than more anonymous markets, conferring higher levels of expected profits to informed traders.

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Chapter 1

Can High Compensation Improve a Firm's Access to Information?

1.1 Introduction

An important function of financial markets is to provide firms with timely, accurate information that allows them to make better decisions. For example, firms can use stock prices to better monitor and compensate managers (Holmstrom and Tirole, (1999)) or to improve their investment efficiency (Dow and Gorton (1997), Subrahmanyam and Titman (1999)).[1] Empirical evidence confirms that such feedback from prices to firm behavior is not merely theoretical. Luo (2005) finds, for example, that stock price reactions to merger announcements impact the decision of whether to complete the merger. Giammarino et al. (2004) argue that managers learn about their firm's prospects from observing price reactions to seasoned equity offerings, withdrawing the offering when the reception is poor. Several papers examine price sensitivities of investment, including Durnev, Morck, and Yeung (2004) and Chen, Goldstein, and Jiang (forthcoming). Each of these studies suggests that the incorporation of private information into prices can benefit firms.

However, collecting information about the firm can be risky, especially if it is

[1] Other relevant papers include Dow and Rahi (2003), Goldstein and Guembel (2005), and Dow, Goldstein, and Guembel (2007).

long-lived. When a firm alters strategy or replaces key top management, for example, previously collected information may be rendered stale, especially when it relates to an assessment of a specific manager's capabilities, or when a chosen strategy is likely to differ from that chosen by a potential successor. Empirical evidence including Weisbach (1995), Denis and Denis (1995), Clayton, Hartzell, and Rosemburg (2001), and Bertrand and Schoar (2003) confirms that CEOs play meaningful roles in their firm's strategies implying that turnover, especially forced replacement, will generally be associated with significant strategic changes – changes that would likely impact the value of long-lived information previously collected about the firm.

This reasoning suggests that stable management can be as asset, increasing the *ex ante* incentives of analysts, hedge funds, or portfolio managers to produce long-lived information pertaining to a management team's capabilities. Because the board is ultimately responsible for replacing the CEO, it also implies that the board has an incentive to appear confident in the CEO's long-term capabilities. This paper develops a signaling model in which the board does exactly this, using the CEO's compensation strategically to promote him as a viable and stable leader.

In the model, the firm has a long-lived risky project whose productivity depends on top management (think about the firm starting a new line of business that exploits the CEO's specialized skills). After the project begins, an investor may collect a costly private signal about the project's probability of success. By later trading on this signal, the investor is compensated for her information gathering costs, but also permits the firm to benefit from her efforts. To the extent that the firm can infer the investor's signal from prices, it can adjust its investment accordingly, scaling up (down) in the event that positive (negative) information is inferred.

However, although the firm's project is long-lived, the CEO's tenure may not be. In particular, the board holds the option to replace the incumbent if it encounters a more talented replacement. Importantly, the likelihood of this depends on the incumbent CEO's ability, which is *privately* known by the board.[2] This information

[2] The assumption that the board holds a private signal about the CEO's ability is reasonable, but need not be interpreted strictly. For example, the CEO may be hired largely because of his networks and personal relationships, human-capital assets that create value for the firm. Although these assets need not stem directly from the CEO's ability, they play a similar role in the analysis in that the board is not only likely to have an information advantage over the market in assessing their value to the firm, but is also likely to consider this assessment when making any termination decision.

is of particular interest to the investor, who is reluctant to collect a manager-specific signal about a management team who may soon be replaced.

The motivation for signaling arises from the fact that although the investor cannot directly observe the CEO's ability, she does observe his compensation, which provides information about the board's assessment of him. Because more talented CEOs are more productive, they can bargain with the board for a higher wage. However, more talented CEOs are also less likely to be terminated (a choice endogenized in the model), simply because the board is less likely to encounter a more talented potential replacement. The investor is therefore more likely to produce long-term information about a highly compensated CEO because she infers him to be of higher ability, and thus more likely to be retained for an extended period of time.

The link between compensation, longevity, and information production means that boards may have incentives to *rationally* overpay their CEOs, balancing the cost of overpayment against the benefit of stimulating the investor to produce long-term information. This paper thus presents a novel explanation for high CEO pay, one motivated by the observation that although the board's assessment of the CEO is likely to be important for investors, credibly communicating this information may be difficult. When investors infer the CEO's ability from his wage, even firms with comparatively less talented CEOs will pay "superstar" wages, hoping to stimulate the production of long-lived information normally reserved for exceptional managers with long expected horizons.

Importantly, overpaying the CEO is a value-maximizing choice, in contrast to the 'managerial power' hypothesis in which weak boards are unable to prevent CEOs from extracting rents from shareholders (Bertrand and Mullainathan (2000), Bebchuk and Fried (2003, 2004)). Indeed, the presence of a strong board here is crucial – it is the board's ability and willingness to terminate the CEO that provides the original motivation to signal its confidence in his ability. Thus, although the model certainly does not imply that weak governance cannot generate exorbitant compensation, it does show that strong governance may not represent a quick fix. Although a tough board may prevent the CEO from setting his own pay, the threat of board activism may introduce a new set of problems, e.g., reducing the incentives of investors to produce long-lived information. This implies that the benefits of strict governance may have limits, generating an incentive for strong boards to downplay this potential for activism by showing support for the CEO.

Rather than entrench the manager (Almazan and Suarez (2003) or reduce the perception of the board's power (Adams and Ferreira, 2007), this paper shows that signaling the CEO's ability can have a similar effect on the market's investment in long-term information. Entrenching the manager with a long-term contract or generous severance may increase the CEO's tenure (leaving aside whether such commitments are credible), but are also likely to worsen any existing CEO agency problems. Besides being subject to neither concern, the CEO's compensation is highly publicized, ensuring that a wide range of long-term investors have access to a succinct measure that reflects the board's assessment of the CEO's ability. Finally, it is also worth mentioning that although the board in the model fully anticipates the effect of overpaying the CEO, such foresight is not required for the signal to be effective. A board that *mistakenly* views its CEO as highly capable and pays him as such, for example, will still stimulate the production of long-term information from investors. In other words, if a board (even wrongly) believes that its CEO is worth his wage, then this belief may become self-fulfulling. For this reason, a board's overconfidence in its ability to evaluate and select talent may further contribute to the effectiveness of the signal.

Although the model deals specifically with information production, a similar interpretation would likely extend to other parties with a stake in the firm's long-term strategy. For example, the firm's workers are often asked to make human capital investments that depend on the strategy endorsed by a CEO. Like long-term investors, workers may be concerned that management turnover may reduce the value of their investments, making the board's assessment of top management an important consideration for workers. Even if the board doesn't replace him immediately, a CEO lacking the board's confidence may encounter resistance from the board, damaging his credibility with the firm's workers and other stakeholders whose input is crucial for the firm's success.

The model explores three factors that affect the board's incentive to signal. The first is the investor's cost of producing information. When information becomes more difficult to collect, the investor becomes more selective about the firms she covers, producing information only about firms with low probabilities of board interference. Thus, an increase in the cost of collecting information increases the minimum CEO compensation required to induce the investor to produce information, implying that when information collection is costly, few firms find it worthwhile to overpay their CEOs. A second factor I explore is the CEO's bargaining power in wage negotiations with the board. When the CEO has high bargaining power (perhaps because he manages a firm in an industry requires rare and specialized skills), he can negotiate a larger fraction of the surplus he creates. But because a CEO's wage will never exceed the entire surplus, there is less scope for strategic overpayment when a CEO's bargaining power (and share of the surplus) is high. The final effect pertains to the degree to which the investor's information is CEO-specific. I find that when the investor's cost of gathering information is low, information that is less CEO-specific increases the fraction of boards that strategically overpay.

Finally, the model suggests that strategic overpayment is likely to be important when CEOs play large roles in determining their firms strategies. For example, CEOs likely have comparatively large impacts on the strategies of young firms or those in industries depending heavily on human capital investments such as technology, software, or service. In addition, the extent to which the firm depends on stock prices to guide its investment also affects its incentive to encourage the production of information from investors. Baker, Stein, and Wurgler (2003) show that price-investment sensitivities of financially constrained firms are higher, and Chen, Goldstein, and Jiang (forthcoming) show that firms whose stocks contain more private information incorporate this information into their investment decisions. The results of these studies suggest a connection between compensation, information production, and investment-price sensitivities that is readily testable.

The model depends explicitly on feedback from the information contained in stock prices to real investment decisions by the firm, a mechanism featured in Leland (1992), Holmstrom and Tirole (1999), Dow and Gorton (1997), Subrahmanyam and Titman (1999), Dow and Rahi (2003), and Dow, Goldstein, and Guembel (2007). One contribution of my paper is the specific channel through which the firm encourages the investor to collect information, trade on it, and thereby increase the informativeness of prices. It also contributes to an extensive literature on the determinants of CEO compensation, including theories based on tournaments (e.g., Rosen (1981)), agency (e.g., Holmstrom (1979)), and direct productivity (e.g., Gabaix and Landier (2008)). [3] Although my model does not consider an agency problems by the CEO, Holmstrom and Tirole (1999) suggests that the model's intuition would

[3]See Murphy (1999) for an extensive review.

still apply. To the extent that the investor's information allows the firm to better infer managerial misbehavior, the firm can provide more efficient incentives, implying that the board may desire to attract the attention of long-term investors.

The paper is organized as follows. Section 1.2 defines the model's economic environment, including the players, the decisions they face, and their respective payoffs. Section 1.3 explores the CEO's compensation under a variety of informational assumptions. First, in subsection 1.3.1, I establish a benchmark – the CEO's wage with no analysts. I then explore in section 1.3.2 the CEO's compensation after introducing an analyst who, by producing information, allows the firm to improve its investment decisions. Even when the CEO's ability is common knowledge (to the board and analyst), a 'superstar' effect arises where the compensation of a top CEO is markedly higher than a less talented counterpart. Finally, in subsection 1.3.3, I allow the board to know more about the CEO's ability than the analyst. I develop the model's main result in this subsection, where the board uses compensation strategically to signal the CEO's ability I conclude in section 1.4.

1.2 The Model

Consider a four-date model $t = 0, 1, 2, 3$, involving the following players: an all-equity firm, its board, its CEO, and an investor in its stock. The firm's cash flows are:

$$\pi(S, \alpha) = \alpha + (1 + \tilde{\Delta})\, S - c(S), \tag{1.1}$$

where α is the talent of the firm's CEO, S is the firm's capital stock, and $\tilde{\Delta}$ is a *CEO-specific* shock to the productivity of the firm's assets.[4] The firm cannot directly observe $\tilde{\Delta}$, which can take either high (+1) or low (-1) values with equal probability. Additionally, the firm faces a cost of implementing its technology, $c(S) = \frac{S^2}{2}$. The game proceeds as follows:

- At $t = 0$, the board privately learns the ability of its incumbent CEO, $\alpha_0 \in [0, 1]$ and offers him a publicly observable wage, $C(\alpha_0)$.

[4] The model's results are not sensitive to this particular specification, which is chosen for tractability. For example, allowing the CEO's talent to impact the productivity of the firm's assets, e.g., $\pi(S, \alpha) = \alpha\,(1 + \tilde{\Delta})\, S - c(S)$ does not change either the results or intuition.

- At $t = 1$, the investor may collect a signal about $\tilde{\Delta}$. Collecting this information costs $k > 0$.
- At $t = 2$, the board interviews and learns the ability of a potential replacement CEO, $\alpha_2 \in [0, 1]$. At this time, the firm may replace the incumbent CEO. The investor's signal about $\tilde{\Delta}$ is less informative if the CEO is replaced.
- At $t = 3$, the firm's stock is traded and the firm invests. If the investor has collected a signal, she will trade on it and (in expectation) increase the informativeness of the firm's stock price. The firm invests after observing its stock price and realizes a final payoff.

The game is summarized in the following timeline.

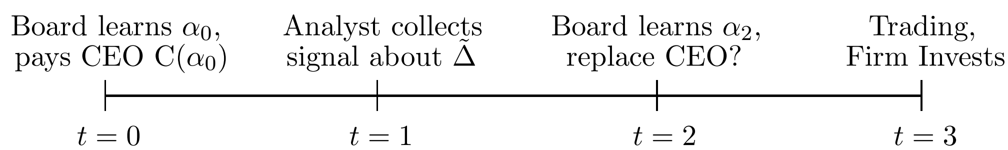

Figure 1.1: Timeline

1.2.1 Trading and Investment, *t=3*

The ultimate goal of the board is to maximize firm value, which in this case occurs by increasing the information content of the firm's stock price, thereby allowing the firm to invest more efficiently. However, the price informativeness of the firm's $t = 3$ stock price depends on prior events: 1) whether the analyst has acquired a private signal about $\tilde{\Delta}$ at $t = 1$, and 2) whether the firm has experienced a CEO turnover at $t = 2$ which would reduce the quality of the analyst's signal. Without loss of generality, suppose that the analyst has collected a signal that with probability β is perfectly correlated with $\tilde{\Delta}$, and with probability $1 - \beta$ is uninformative. $\beta = 0$ thus corresponds to either a completely uninformative signal or an analyst that has chosen not to produce information.

If the analyst does not to investigate, the firm's stock price cannot reflect any information about $\tilde{\Delta}$, so that the firm will optimize expression (1.1) taking $E[\tilde{\Delta}] = 0$, giving $S^* = 1$ and expected cash flows equal to $\alpha + \frac{1}{2}$. However, if the analyst's collects an informative signal ($\beta > 0$), and if the firm can infer this information, it will adjust S upward (downward) by β if the analyst receives a positive (negative) signal about $\tilde{\Delta}$. Because the firm expects the analyst to receive positive and negative signals with equal probability, its expected cash flow with information is $\alpha + \frac{1}{2}\frac{(1+\beta)^2}{2} + \frac{1}{2}\frac{(-1+\beta)^2}{2} = \alpha + \frac{1+\beta^2}{2}$. Comparing this expected cash flow to that with no information of $\alpha + \frac{1}{2}$, the firm would therefore pay up to

$$\frac{1+\beta^2}{2} - \frac{1}{2} = \frac{\beta^2}{2} \tag{1.2}$$

for the analyst's signal about $\tilde{\Delta}$, allowing it to scale its investment accordingly.

The firm can infer the analyst's signal by observing its stock price which, because the analyst will trade on her information, more accurately reflects the firm's fundamentals. The trading game is a highly stylized Kyle (1985) setting. There are three parties: 1) a single informed analyst who submits a unit buy or sell order, $x \in \{-1, +1\}$, 2) a cohort of noise traders with aggregate demand u, which is i.i.d. discrete uniform $[-1, +1]$, i.e., $u = -1$, 0, or +1 with equal probability, and 3) a risk-neutral, competitive market maker. The market maker, observing only the aggregate order flow, $z = u + x$, sets the price equal to the expected value of the firm's terminal cash flows.

The set of possible order flows is $z \in \{-2, -1, 0, +1, +2\}$, of which $z \in \{+1, +2\}$ reveal that the analyst has received a positive signal. To see this, note that because the analyst's cost of gathering information is sunk, she always trades after receiving her signal, so that aggregate order flows always reflect either a unit buy or sell from the analyst. Because $z = +1$ and $z = +2$ are only possible if the analyst's demand is $x = +1$, the market maker can infer that the analyst's signal about the firm's profitability shock is positive. By similar reasoning, $z = -1$ or $z = -2$ indicate that the analyst's signal is negative. Only $z = 0$ is uninformative. The set of possible prices is:

$$P(z) = \begin{cases} \alpha + \frac{(1-\beta)^2}{2} & \text{if} \quad z \leq -1 \\ \alpha + \frac{(1+\beta)^2}{2} & \text{if} \quad z \geq +1 \\ \alpha + \frac{1}{2} & \text{if} \quad z = 0. \end{cases} \tag{1.3}$$

Each of these prices reflects the market maker's rational expectations with respect to the quality of the analyst's information, her trading strategy, and to the firm's investment policy. That is, if the market maker knows that the firm will use the information contained in prices to invest more efficiently, prices will reflect that eventuality. For example, if $z = -1$, the market maker anticipates that the firm will infer that the analyst's signal is negative, will choose $S = 1 - \beta$, and (substituting into equation (1.1)) will generate an expected cash flow of $\alpha + \frac{(1-\beta)^2}{2}$.

1.2.2 Termination, *t=2*

Prior to investing at $t = 3$ but after the analyst's decision at $t = 1$ to collect CEO-specific information about $\tilde{\Delta}$, the board has the opportunity to replace the incumbent CEO. This timing assumption is intended to capture the idea that when a CEO is terminated, the board must consider the impact of past investments by the firm's stakeholders, and the likely impact CEO turnover has on the payoffs to these investments. The board compares the firm's value with the incumbent CEO (along with the payoffs of any CEO-specific investments) to that with the replacement, and selects the CEO that maximizes firm value. The board faces no agency costs of replacing the CEO.

At $t = 0$, the board privately learns the ability of its CEO, α_0, which is drawn from $U[0,1]$. At $t=2$, the firm interviews a potential replacement CEO and learns his ability α_2, also drawn (independently of α_0) from $U[0,1]$. If the ability of the potential replacement is sufficiently high, the firm terminates the incumbent CEO and hires the replacement. Denote as $\alpha_2^*(\alpha_0)$ the replacement's ability level which causes the firm to replace its incumbent CEO, i.e., for all $\alpha_2 \geq \alpha_2^*(\alpha_0)$, the firm terminates an incumbent CEO with skill α_0. The firm's termination rule $\alpha_2^*(\alpha_0)$ is endogenously determined. The main case of interest is when there is asymmetric information between the board and the analyst, i.e., when the analyst does not observe the realization of α_0. However, the analysis below also considers the benchmark case of no information asymmetry regarding α_0.

1.2.3 Information Collection, *t=1*

The analyst's signal is CEO-specific. Examples of such CEO-specific information would be developing a relationship with the firm's CEO and management team and forming an opinion of its competence, investigating the historical performance of projects under the CEO's tenure, or evaluating a strategy likely to be altered if the CEO is replaced. In each of these cases, both the analyst's information quality and expected trading profits become less valuable if the CEO is terminated at $t=2$, so that she prefers to avoid collecting information about a CEO who appears likely to be replaced. To formalize the CEO-specificity of the analyst's signal, if the CEO is not terminated at $t=2$, the analyst's has perfect information about $\tilde{\Delta}$, i.e., $\beta=1$. If the CEO is terminated, $\beta=p$, where $0<p<1$. When the analyst receives her signal, she does not know whether her signal is informative or not.

The analyst benefits from her information by trading the firm's stock at $t=3$. If prices fully reflect the analyst's private information ($z \neq 0$), the analyst's trading profits are equal to zero. Instead, the analyst profits from *un*informative prices, those in which neither the market maker nor the firm can infer the analyst's signal. To characterize the expected profits from trading, consider an analyst who receives a positive signal. Because she will submit a buy order, the range of possible order flows are $z \in \{0,+1,+2\}$. With probability $\frac{1}{3}$, $z=0$, affording the analyst a profit of $\frac{1+2\beta}{2}-\frac{1}{2}=\beta$. The analyst's expected profits are thus equal to $\frac{\beta}{3}$. The analyst's expected profits will be the same if she instead receives a negative signal. In this case, the analyst sells the stock short, securing profits of $\frac{1}{2}-\frac{1-2\beta}{2}=\beta$. Note that this event also occurs with probability $\frac{1}{3}$. Therefore, the analyst's expected trading profits, net of her costs of gathering information are $\frac{\beta}{3} - k$.

Recalling that $\beta = 1$ if the CEO is retained, it is obvious from that if $k \geq \frac{1}{3}$, the analyst will never collect information, regardless of the probability the CEO is replaced. Likewise, if $k \leq \frac{p}{3}$, the analyst will always collect information, even for a firm that is certain to fire and replace its CEO. I therefore focus on the interesting case in which $\frac{p}{3} < k < \frac{1}{3}$, so that the analyst's decision to collect information depends on her expectation of the likelihood that the CEO is replaced.

1.2.4 Compensation, *t=0*

The board moves first at $t = 0$. After learning the CEO's ability, α_0, it offers him a publicly observable wage $C(\alpha_0)$, which is modeled as a bargaining game between the board and CEO. To define the payoffs to each party in the $t = 0$ wage negotiation, I make the following assumptions. First, the CEO has a reservation wage normalized to zero, but has some bargaining power with his firm during the wage negotiations at $t = 0$ denoted by $\psi \in [0, 1]$. The CEO's bargaining power specifies what fraction of the CEO's marginal contribution to firm value he is able to capture in his compensation. Second, I simplify the exposition by assuming that the firm has all the bargaining power during $t = 2$ should it hire a replacement.[5] The second assumption quantifies the firm's threat point, or the continuation value for the firm if negotiations with its CEO are not successful. Finally, I assume that the CEO's wage is settled at $t = 0$, and is publicly observable.

1.3 Equilibrium

I analyze the wage bargaining outcomes and termination rules under three different information environments. As a benchmark case, in subsection 1.3.1, I first characterize the compensation schedule if the analyst provides no information to the firm about its investment opportunities. Next, in subsection 1.3.2, I analyze the outcomes when the analyst provides valuable information about the firm's assets, but assume that the incumbent CEO's talent, α_0, is *common knowledge* at $t = 0$. Finally, in subsection 1.3.3, I consider the case when the board is more informed

[5]Altering this assumption does not change the qualitative nature of the results.

about his ability than the analyst. In this situation, the analyst infers the CEO's expected tenure from his compensation at $t = 0$, creating an incentive for firms to use compensation strategically to signal the CEO's talent.

1.3.1 Uninformative Analysts

Consider first the result of wage bargaining when the analyst's investigation provides no information to the firm about the productivity shock, i.e. $\beta = 0$. Because analysts are assumed to provide the firm with no information about the profitability shock affecting its assets, the firm will solve expression (3.1) with $E[\tilde{\Delta}] = 0$, resulting in an expected cash flow of $E[\alpha_2] + \frac{1}{2}$. If wage negotiations fail, the firm expects to hire a replacement at $t = 2$ with average ability $E[\alpha_2] = \frac{1}{2}$.

If however, negotiations are successful, the incumbent CEO accepts employment at $t = 0$. Although the firm's investment policy is not altered by the success or failure of $t = 0$ wage negotiations, the managerial component of firm value is clearly improved by the presence of an incumbent CEO. Because the CEO contributes α_0 to firm value, the firm will replace the incumbent CEO if the talent of the replacement exceeds that of the incumbent, or if $\alpha_2 \geq \alpha_0$. Given a termination cutoff $\alpha_2^*(\alpha_0) = \alpha_0$, the expected value of the managerial component of the firm's assets is given by:

$$Pr(\alpha_2 \leq \alpha_2^*(\alpha_0))\alpha_0 + Pr(\alpha_2 \geq \alpha_1^*(\alpha_0))E[\alpha_2|\alpha_2 \geq \alpha_2^*(\alpha_0)] \tag{1.4}$$

$$= \alpha_2^*(\alpha_0)\alpha_0 + (1 - \alpha_2^*(\alpha_0))\frac{(1 + \alpha_2^*(\alpha_0))}{2} \tag{1.5}$$

$$= \frac{1 + \alpha_0^2}{2}. \tag{1.6}$$

Expression (1.6) reveals that a CEO of talent α_0 affords his firm the option to be selective at $t = 2$, increasing the value of the firm by $\frac{\alpha_0^2}{2}$. The improvement in firm value is subject to bargaining. The CEO's $t = 0$ wage is ψ times the surplus his presence at the firm generates, $C(\alpha_0) = \psi\,\frac{\alpha_0^2}{2}$.

1.3.2 Informative Analysts, Observable CEO Talent

If, however, the analyst's investigation is informative, then a high-ability CEO is valued for an additional reason beyond his ability to directly enhance the firm's cash flows. A highly skilled CEO likely to enjoy a long tenure increases the incentive for the analyst to collect long-lived CEO-specific information. Relative to the no-analyst benchmark, this alters both the probability that the CEO is replaced as well as his compensation.

Trading and Investment, *t=3*

Assuming that the analyst has investigated at $t = 1$ (the benefit is trivially zero otherwise), the value of her information depends only on whether the incumbent CEO is still employed at $t = 3$. Expression (1.2) quantifies the average improvement in investment efficiency resulting from the analyst's signal. Because the analyst's information declines by $1 - p$ if the CEO is terminated at $t = 2$, the firm therefore expects to sacrifice $\frac{(1-p)^2}{3}$ if it replaces its CEO at $t = 2$.

Termination, *t=2*

This implies a stricter $t = 2$ termination rule, one that accounts for the lost value of the analyst's information:

$$\alpha_2^*(\alpha_0) = \alpha_0 + \frac{(1 - p^2)}{3}. \tag{1.7}$$

The first term is identical to the no-analyst benchmark case, showing that replacement occurs only if the replacement CEO is more talented than the incumbent. The second term in expression (1.7) shows that because CEO-specific information is destroyed during termination, the likelihood that the CEO is replaced is reduced. The probability that the CEO is replaced increases with p. Low values of p mean that the analyst's information is highly CEO-specific, depreciating rapidly in the event of replacement. Consequently, when p declines, retaining the CEO is more attractive, all else equal.

Expression (1.7) also implies a critical value, α^c, above which no CEO will be replaced. Given that α_2 is distributed on the unit interval, if expression (1.7) cannot be satisfied when $\alpha_2^* = 1$, then it will be impossible for a more skilled replacement CEO to provide enough direct benefit to offset the accompanying loss in investment efficiency. Any incumbent CEO with skill of at least $\alpha^c = 1 - \frac{(1-p^2)}{3}$ is assured of being retained for the investment period.[6]

Information Collection, *t=1*

Consider now the analyst's problem of choosing whether to collect information about a firm employing an incumbent CEO with talent α_0. As indicated above, if $\alpha_0 \geq \alpha^C$, the analyst will investigate and produce information because the CEO will certainly be retained. If $\alpha_0 < \alpha^C$, there is some probability that the CEO will be replaced, so the analyst may or may not produce information. The analyst's investigation decision is determined by comparing her cost of gathering information, k, to her expected trading profits,

$$\frac{p}{3}(1 - \alpha_1^*(\alpha_0)) + \frac{1}{3}(\alpha_1^*(\alpha_0)). \tag{1.8}$$

Setting expression (1.8) equal to k characterizes $\hat{\alpha}$, the minimum managerial skill level for which the analyst will investigate,

$$\hat{\alpha} = \frac{3\,k - p}{1 - p} + \frac{p^2 - 1}{3}. \tag{1.9}$$

Given the previous assumption that $k < \frac{1}{3}$, it follows directly that $\hat{\alpha} < \alpha^C$. Thus, for $\hat{\alpha} \leq \alpha_0 \leq \alpha^C$, the analyst produces information even though with some probability the firm replaces its CEO. Figure 1.2 summarizes what actions the board and analyst take for these ability cutoffs.

As in the last subsection, I focus on the interesting case in which the analyst's decision to collect information depends on her expectation of whether the CEO

[6]This cutoff is an artifact of a bounded distribution for abilities. If instead the CEO's skill had unbounded positive support, more talented CEOs would be less likely to be terminated, without there being a bound above which termination would never occur. This cutoff value is neither important for the model, nor a focus of the results.

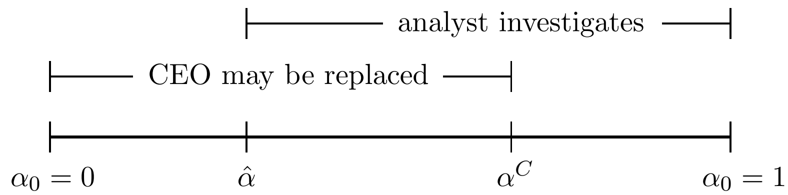

Figure 1.2: Board and Analyst Actions as Functions of CEO Talent

will be retained or not.[7] Without such an assumption, the analyst will produce information for all firms, so that there is no motivation to signal the CEO's ability.

Compensation, *t=0*

The CEO's compensation in the region where $\alpha_0 < \hat{\alpha}$, corresponds to the no-analyst case already discussed in the previous subsection, in which $C(\alpha_0) = \psi \frac{\alpha_0^2}{2}$. It is straightforward to show that in the rightmost region of Figure 1.2 ($\alpha^C \leq \alpha_0$), the CEO will never be replaced and receives compensation $C(\alpha_0) = \psi\,(\alpha_0 - \frac{1}{6})$.[8]

Most interesting is the middle region, $\hat{\alpha} \leq \alpha_0 \leq \alpha^C$, where the CEO creates an expected surplus of:

$$(1 - \alpha_2^*(\alpha_0)) \left[E(\alpha_2 | \alpha_2 \geq \alpha_2^*(\alpha_0) + \frac{p^2}{3} \right] + \alpha_2^*(\alpha_0) \left[\alpha_0 + \frac{1}{3} \right] - \frac{1}{2}. \qquad (1.10)$$

The first term corresponds to the case in which the CEO is terminated. captures the fact that replacing an incumbent CEO is associated with both a cost and a benefit. Although the firm enjoys the rents associated with a more talented CEO, its stock price is less informative, reducing its investment efficiency. The

[7] Formally, this assumption is $\frac{1+2p-p^2+p^3}{9} < k$, which is stronger than $\frac{p}{3} < k$, the corresponding assumption in the previous subsection. The reason a stronger assumption is needed is because the analyst's investigation increases the incumbent CEO's value to the firm, which in turn reduces the probability that he is terminated.

[8] Knowing that the CEO will never be replaced, the firm expects to reap the full value of the analyst's information, $\frac{1}{3}$. The expected improvement in firm value then, is $\alpha_0 - \frac{1}{2} + \frac{1}{3}$. The first two terms represent the expected direct improvement due to the CEO's talent, and the third term represents the value created through improved investment efficiency. The CEO's compensation when $\alpha_0 \geq \alpha$ is therefore $C(\alpha_0) = \psi\,(\alpha_0 - \frac{1}{6})$.

reverse is true if the firm retains its CEO, shown in the second term. Substituting and simplifying, the CEO's fraction of the surplus is

$$C(\alpha_0) = \psi \left[\frac{\alpha_0^2}{2} + \frac{p^2\ (1-\alpha_0) + \alpha_0}{3} + \frac{\left(1-p^2\right)^2}{18} \right]. \tag{1.11}$$

The first term in expression (1.11) is the value the incumbent CEO adds by affording the firm the option to be more selective in its replacement choice, as in the previous subsection. The second and third terms capture the value created by the analyst's information, which allows the firm to invest more efficiently in the production period.

Discussion

Figure 1.3 below graphs the CEO's $t = 0$ compensation, $C(\alpha_0)$, for $\alpha_0 \leq \alpha^C$. The solid line shows the CEO's compensation as a function of his ability, α_0, when ability is observable. The dashed line, shown for comparison, is the CEO's compensation in the no-analyst case.

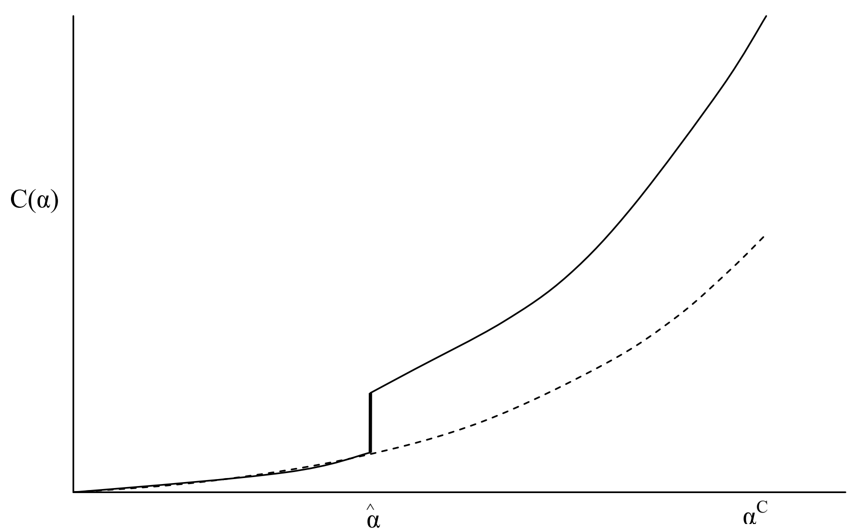

Figure 1.3: Compensation as a Function of CEO Talent

Two observations stand out in Figure 1.3. The first is the discontinuity at $\hat{\alpha}$, representing a discrete improvement conferred to the firm when the analyst initiates coverage. The second is that the slope of the compensation schedule increase faster with CEO-specific information (dark line) than without (dashed line). In other words, firms employing CEOs of different abilities place different values on the analyst's information. Because the analyst's information is more valuable if the firms retains its incumbent, a firm employing a high-ability CEO expects to realize the full benefit of the analysts's information. This leads to a compensation schedule that increases more sharply with α_0 than in the no-analyst case.

The remaining comparative statics of $C(\alpha_0)$ are intuitively sensible. Compensation becomes more expensive with ψ, a straightforward result of the CEO's bargaining power in wage negotiations. Additionally, the CEO's wage is higher if the analyst's information is less CEO-specific, i.e., when p increases.[9] This results from the firm being able to invest more efficiently even if it replaces its CEO. Interestingly, an increase in p improves firm value by more for firms with poorly talented CEOs than those with richly talented CEOs. The reason is that p captures how much information is lost in the event that the CEO is replaced. For firms that are relatively certain to retain their CEOs, this is not particularly important.

1.3.3 Unobservable CEO Talent

Until now, when the CEO's ability has been observable, bargaining alone has determined his compensation. When the board knows more about the CEO's talent than does the analyst, this is no longer the case. Because the analyst uses the CEO's compensation to infer his expected tenure, the board can use CEO compensation strategically to influence the analyst's beliefs about CEO talent. I now show that under some circumstances, the board offers the CEO a higher wage than bargaining alone would indicate.

To understand why the bargaining outcome displayed in Figure 1.3 can no longer be an equilibrium if the analyst cannot directly observe the CEO's talent, consider the incentives of a firm employing a CEO with talent α_0 slightly below $\hat{\alpha}$.

[9] The sign of the derivative of expression (1.11) is not obviously positive as claimed. However, recall that expression (1.11) refers only to the compensation offered in the region between $\hat{\alpha}$ and α^C. The derivative of expression (1.11) with respect to p is positive if and only if $p^2 \geq 3\alpha_0 - 2$. However, since $\alpha_0 \leq \alpha^C = 1 - \frac{(1-p^2)}{3}$, $\frac{\partial C(\alpha_0)}{\partial p} \geq 0$.

If it pays $\psi\,\alpha_0^2$ (the dashed line), it reveals itself as below the talent threshold for the analyst to investigate. It could, however, spur the analyst to produce information by paying $C(\hat{\alpha})$, as defined in expression (1.11) and shown in Figure 1.3. By paying the CEO as though he were more talented than he actually is, the board causes the analyst to overestimate the CEO's expected tenure, causing him to overinvest in collecting information.

As long as $\psi < 1$, so that the firm enjoys some portion of the improvement in firm value associated with the initiation of analyst coverage, a firm sufficiently close to $\hat{\alpha}$ will always find it optimal to pay the inflated compensation. However as α_0 decreases from $\hat{\alpha}$, two things occur. First, the firm becomes less valuable, meaning that to attract analyst coverage, the CEO must be paid a higher fraction of the firm's value. Second, since CEOs with low talent are likely to be terminated, the analyst's information becomes less valuable, reducing the board's incentive to signal. In equilibrium, the firm will be indifferent between paying its CEO $\psi\,\frac{\alpha_0^2}{2}$, thereby revealing his talent as below $\hat{\alpha}$, and paying a compensation that attracts the investigation of the analyst.

Characterizing the Equilibrium

I solve for and characterize a pure strategy equilibrium of the resulting signaling game. Definition 1 below characterizes the equilibrium concept I use for the remainder of the paper.

Definition 1 *A pure strategy perfect Bayesian equilibrium is a compensation schedule offered by the firm $C^*(\alpha_0) : [0,1] \to \Re^+$ and an information gathering strategy by the analyst $I^*(C^*(\alpha_0)) : \Re^+ \to \{0,1\}$ such that: i) given $I^*(C^*(\alpha_0))$, the expected firm value for a firm paying its CEO $C^*(\alpha_0)$, $V(C^*(\alpha_0))$, is at least as large as $V(C(\alpha_0))$ for any other compensation schedule $C(\alpha_0) \neq C^*(\alpha_0)$, and ii) given $C^*(\alpha_0)$, the analyst collects information ($I = 1$) and trades if his expected trading profits, conditional on $C^*(\alpha_0)$, at least offset his costs of gathering private information.*

Relative to the compensation schedule when the CEO's talent is observable (Figure 1.3), the compensation schedule with unobservable talent reflects the incentive of firms with poorly talented CEOs to not reveal this information to analysts. Unlike Figure 1.3, in which compensation maps one-to-one to CEO talent, the incentive of firms with poorly talented CEOs to influence the analyst's beliefs implies a range of talent levels $[\alpha_M, \alpha_P]$ that all pay the same compensation, such that the analyst cannot perfectly infer the CEO's expected tenure. Recalling that the analyst breaks even at $\hat{\alpha}$ under full information, but enjoys strictly positive (negative) expected profits for talent levels above (below) $\hat{\alpha}$, it must be the case that the $\alpha_M < \hat{\alpha} < \alpha_P$.

The cutoffs α_M and α_P depend respectively on the optimal strategies of the firm and analyst. In equilibrium, a firm employing a CEO with talent α_M will be indifferent between: 1) paying $C(\alpha_P)$ and reaping the benefit of the analyst's information, and 2) paying $\psi \frac{\alpha_M^2}{2}$, but foregoing the benefit of the analyst's investigation. In equilibrium, the benefit of the analyst's information for the firm with marginal CEO skill α_M,

$$\frac{p^2\ (1-\alpha_M)+\alpha_M}{3}+\frac{\left(1-p^2\right)^2}{18}, \tag{1.12}$$

must equal the additional compensation such a firm must offer,

$$\psi\,[\frac{\alpha_P^2}{2}+\frac{p^2\ (1-\alpha_P)+\alpha_P}{3}+\frac{\left(1-p^2\right)^2}{18}]-\psi\,\frac{\alpha_M^2}{2}. \tag{1.13}$$

Equating expressions (1.12) and (1.13) does not pin down the values of α_M and α_P. For this, it is necessary to consider the analyst's participation constraint. Because the analyst will lose money in expectation for $\alpha_M \leq \alpha_0 \leq \hat{\alpha}$, these expected losses must be offset by trading profits for the interval $\hat{\alpha} \leq \alpha_0 \leq \alpha_P$. The analyst's participation constraint over $\alpha_M \leq \alpha_0 \leq \alpha_P$ is:

$$\frac{1}{3}\cdot\overbrace{(\frac{(1-p^2)}{3}+\frac{\alpha_M+\alpha_P}{2})}^{Expected\ Pr(Incumbent\ retained)}+\frac{p}{3}\cdot\overbrace{(1-\frac{(1-p^2)}{3}-\frac{\alpha_M+\alpha_P}{2})}^{Expected\ Pr(Incumbent\ replaced)}\geq k. \tag{1.14}$$

Because the analyst's beliefs will be correct in equilibrium, expression (1.14) reveals that the analyst's beliefs about α_P and α_M influence the equilibrium values of these cutoffs. Specifically, because firms correctly anticipate how the compensation they offer their CEOs will influence the analyst's behavior, the analyst's beliefs about α_P and α_M will influence firms' compensation decisions.

I focus on the signaling equilibrium in which the analyst's costs of collecting information exactly offset his expected profits over the signaling region. For example, there exist equilibria in which expression (1.14) does not hold with equality, ones in which the analyst's expected profits are positive over the interval $\alpha_M \leq \alpha_0 \leq \alpha_P$. All of these equilibria involves signaling the CEO's ability via overpayment. I focus on the equilibrium in which the analyst breaks even for tractability and relatively easy analysis of comparative statics. Setting expression (1.14) with equality and simplifying, we have

$$\frac{\alpha_M + \alpha_P}{2} = \frac{3\,k - p}{1 - p} + \frac{-1 + p^2}{3} = \hat{\alpha}. \tag{1.15}$$

Equating (1.12) and (1.13) and substituting equation (1.15) pins down the values of α_M and α_P, completing the signaling equilibrium compensation schedule.

Proposition 1 *There exists a unique signaling equilibrium in pure strategies to the game with unobservable CEO talent in which a strictly positive set of firms employing a CEO with talent $\alpha_M \leq \alpha_0 \leq \alpha_P$ where $\alpha_M < \alpha_P$ pay the same compensation $C(\alpha_P) = \psi\,[\frac{\alpha_P^2}{2} + \frac{p^2\,(1-\alpha_P)+\alpha_P}{3} + \frac{\left(1-p^2\right)^2}{18}]$, and in which the analyst breaks even over $\alpha_M \leq \alpha_0 \leq \alpha_P$. If $\alpha_0 < \alpha_M$ or $\alpha_0 > \alpha_P$, the firm pays the same compensation as it would were CEO talent observable (displayed to Figure 1.3). The analyst collects information for all firms that pay at least $C(\alpha_P)$, and does not gather information otherwise.*

Proof: Suppose $\alpha_0 < \alpha_M$. At $\alpha_0 = \alpha_M$, the benefit of the analyst's information to shareholders (expression (1.12)) is exactly offset by the cost (expression (1.13)). Since the benefit strictly increases with α_0 and the cost strictly decreases with α_0, any firm employing a CEO with talent below α_M is made strictly worse by paying any compensation above $\psi\,\frac{\alpha_0^2}{2}$.

Suppose $\alpha_0 > \alpha_P$. Since all firms in this region will already generate information collection by analysts, there is no motivation to attempt to influence the *analyst's beliefs about the CEO's talent. Compensation in this region is determined by bargaining, as in the case when CEO talent is observable.*

Suppose $\alpha_M \leq \alpha_0 \leq \alpha_P$. *Paying any compensation less than* $C(\alpha_P)$ *would result in the analyst not collecting information for the firm, which is strictly dominated by paying* $C(\alpha_P)$ *for any firm employing a CEO with talent of at least* α_M. *Paying any compensation greater than* $C(\alpha_P)$ *transfers wealth to the CEO without any accompanying benefit.*

Q.E.D.

The signaling equilibrium described above is one in which some boards promote their CEOs as 'superstars,' even if they are not. Figure 1.4 plots the equilibrium compensation schedule for all three scenarios: no analyst, observable CEO talent, and unobservable CEO talent. To gain some intuition regarding the shape of Figure 1.4, consider that any firm with the incentive to signal its CEO's talent (i.e., any firm whose CEO's talent is below $\hat{\alpha}$) must pay at least $C(\hat{\alpha}) = \psi\,[\frac{\hat{\alpha}^2}{2} + \frac{p^2\,(1-\hat{\alpha})+\hat{\alpha}}{3} + \frac{\left(1-p^2\right)^2}{18}]$, because the analyst will not collect information for talent levels below this threshold.

However, $C(\hat{\alpha})$ may contain no mass in equilibrium, because the analyst's expected profits with any compensation pooling at $C(\hat{\alpha})$ will be strictly negative.[10] If the analyst plays a pure strategy, then his expected profits must at least offset his costs of gathering information for every compensation level for which he collects information. Thus, any compensation level where pooling includes CEOs below $\hat{\alpha}$ (for which the analyst's expected trading profits are negative) must also include CEOs with talent above $\hat{\alpha}$ (for which the analyst's expected trading profits are positive).

The first important observation from Figure 1.4 is that relative to the case when talent is observable, the compensation is shifted upward for talent levels in the neighborhood of $\hat{\alpha}$. Specifically, between α_M and α_P, all firms pay the same compensation, which prevents the analyst from inferring either the talent of the CEO or the likelihood he is replaced. In effect, shareholders whose CEO is just below $\hat{\alpha}$ are sacrificing some of their bargaining power to the CEO during wage negotiations.

[10] Recall that the analyst's expected profits are strictly decreasing in α_0.

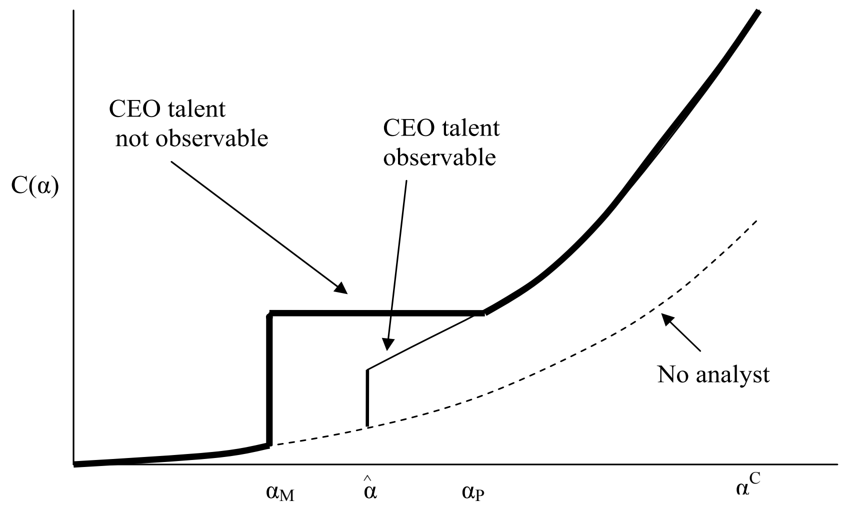

Figure 1.4: Compensation Schedule for All Three Cases

Although this means that wealth is transferred to the CEO, because the firm's stock price is more informative, the improved investment more than offsets this cost to shareholders. In addition, the analyst's expected profits are reduced. When CEO talent is observable, the analyst's expected net trading profits are strictly greater than zero for any talent level strictly above $\hat{\alpha}$. With unobservable CEO talent, his expected profits are exactly zero for $\alpha_M \geq \alpha_0 \geq \alpha_P$, and are again strictly positive above α_P. Since $\alpha_P > \hat{\alpha}$, the analyst's expected profits are strictly lower when he must use compensation to infer the expected tenure of the CEO.

Comparative Statics

In this subsection, I examine how the equilibrium fraction of firms that strategically overpay their managers is affected by variation in the analyst's information collection cost (k), the manager's bargaining power in wage negotiation (ψ), and the CEO-specificity of the analyst's signal (p). If more firms find strategic overpayment worthwhile, the horizontal portion of Figure 1.4 will be both longer (along the α_0 axis) and higher (along the $C(\alpha_0)$ axis). As the fraction of overpaying firms decreases to zero, Figure 1.4 collapses to Figure 1.3, where the CEO's talent is observable.

Proposition 2 *Firms whose CEOs have talent* $\alpha_0 \in [\alpha_m, \alpha_P]$ *overpay relative to the bargaining solution. The fraction of such firms,* $\alpha_P - \alpha_M$*: i) increases as the analyst's cost of collecting information,* k*, decreases, ii) increases as the CEO's bargaining power,* ψ*, decreases, and iii) may either increase or decrease as the analyst's information becomes more CEO-specific.*

Analyst's Cost of Gathering Information. When k increases, the analyst demands higher expected profits to compensate him for his increased cost of gathering information. Because the analyst's expected profits increase with α_0, an increase in k causes the analyst to become more selective about the firms he covers, i.e., shifting $\hat{\alpha}$ to the right and producing information for firms with very talented CEOs who are unlikely to be replaced. Such an increase in $\hat{\alpha}$ has the unambiguous effect of decreasing the fraction of firms that signal via overpayment. The reason for this is due to the convexity of the CEO compensation schedule, as seen in Figures 1.3 and 1.4.[11] Even though the benefit of signaling also increases with the CEO's talent, the fact that "superstar" CEOs are compensated so generously means that it is increasingly costly to signal as $\hat{\alpha}$ shifts to the right. In other words, an increase in k will increase both $\hat{\alpha}$ and α_M to the right, but because the cost of signaling increases faster than the associated benefit, α_M shifts by more than $\hat{\alpha}$. This results in fewer firms signaling when the analyst's information is expensive to collect.

CEO Bargaining Power. A related effect is found with respect to the CEO's bargaining power in wage negotiation (ψ), although the reasons differ significantly. Inspection of expression (1.15) reveals that $\hat{\alpha}$ does not depend on ψ, which is sensible given that the analyst's expected trading profits depend only the CEO's expected tenure and the characteristics of the analyst's information. Thus, an increase in ψ does not impact the analyst's break-even CEO talent level. It does, however, increase the relative cost required to mimic the compensation offered to more talented CEOs (i.e., in Figure 1.3, an increase in ψ would shift the entire compensation schedule up by a factor). The convexity of the compensation schedule

[11] Recall that this convexity arises through the optionality associated with hiring an incumbent CEO (see subsection 1.3.1 for more discussion).

means that an increase in ψ increases the cost of strategic overpayment, but confers no additional benefit.

In the limit when ψ increases to one, the width of the horizontal line in Figure 1.4, representing the fraction of firms engaging in strategic overpayment, decreases to zero. This is intuitively sensible. Strategic overpayment amounts to the board sacrificing more than the bargaining solution would prescribe. If a highly talented CEO is able to capture the entire surplus his presence creates, then strategic overpayment by firms with a less talented CEO would be strictly dominated. Because the value created by a less talented CEO is strictly less than the value created by a more talented CEO, overpayment would always destroy more value than it would create.

CEO-specificity of the Analyst's Information. Finally, consider how an increase in p, the inverse of the CEO-specificity of the analyst's information, affects the equilibrium. Examination of expression (1.11) reveals that although an increase in p is valuable to all firms (since stock prices will be more informative in case the CEO is replaced), it is more valuable to firms employing CEOs with low talent. This implies that the benefit of strategic overpayment given in expression (1.12) increases with p faster than does the cost required to attract analyst attention given in expression (1.13). All else equal, this would increase the fraction of strategically overpaying firms.

However, there is another effect that may either reinforce or diminish this effect. As noted above, if $\hat{\alpha}$ decreases, then this decreases the signaling cost required to attract the analyst's attention. In this case, an increase in p both increases the benefit and decreases the cost of strategic overpayment, which will increase the number of firms that pool at $C(\alpha_P)$. On the other hand, if p increases $\hat{\alpha}$ by enough such that the increased cost sufficiently offsets the increased benefit, fewer firms will overpay their CEOs in equilibrium. Inspection of expression (1.9) reveals that for sufficiently low values of k, $\frac{\partial\hat{\alpha}}{\partial p} < 0$, so that increases in p increase the fraction of strategically overpaying firms. For higher values of k, the impact of p is ambiguous.[12]

[12] The specific value is $k = \frac{3-2\,(-1+p)^2\,p}{9}$.

Empirical Implications

In trying to identify situations in which strategic overpayment may play a meaningful role in determining CEO compensation, it is useful to revisit the key assumptions of the model. Of particular significance is the assumption that the analysts is reluctant to produce information that has little value if the CEO is terminated, implying that a firm likely to terminate its CEO may not have access to high quality external information about its projects. When is this likely to be a concern for an analyst?

Clearly, timing is of first-order importance. In industries where projects are short-lived, the analyst's ability to profit from his information is less dependent on the CEO having a long tenure. Instead, signaling is comparatively more important when the analyst's information has time to depreciate if the CEO is replaced, leading him to be more discriminating about the firms he investigates. A second factor that influences signaling is how much influence a CEO has in determining his firm's strategy. In quickly-evolving and flexible industries, for example, different CEOs are likely to have different "visions" for their respective firms, leading them to pursue different operating plans. It is these situations where an analyst, having investigated the strategy advanced by a previous CEO, may not be able to apply his information to the strategy advanced by the replacement.

Also worthy of discussion is the assumption that the board knows more about the CEO's talent than does the market. Given the board's direct and repeated interaction with the CEO, taking this assumption literally is probably reasonable, especially for young CEOs with little track record for the market to evaluate. This does not, however, mean that signaling cannot play a role with more seasoned managers. Although the market can learn about the general ability of experienced CEOs by observing their performance over time, a CEO's "fit" or firm-specific skills are likely to both evolve over time as well as be more difficult to infer. For example, how a CEO deals with internal strife within his management team likely plays a large role in his job security. This and similar issues imply that the board's assessment of the CEO can play an important role, although the effect may be magnified for younger managers.

The primary implication of strategic overpayment is that higher levels of CEO compensation should result in more information being produced about the firm's prospects. Second, strategic overpayment clearly increases the average wage within an industry, as seen in Figure 1.4. Third, and more importantly from the analyst's perspective, signaling weakens the link between CEO compensation and his probability of being terminated. In contrast to Figure 1.3, where a CEO's compensation directly reflects his expected tenure, strategic overpayment means that even a board with a low opinion of its CEO may find the increase in stock price efficiency worth the signaling cost. This implies that in the strategic overpayment equilibrium, the CEO's compensation should be a less powerful predictor of his tenure.

Extensions

Size. In my model, firms are identical in size. However, as is documented empirically and shown theoretically in Gabaix and Landier (2006), size is an important determinant of CEO pay. Incorporating this feature into my current framework is straightforward, and delivers the standard prediction that larger firms more generously compensate their top executives. In Gabaix and Landier (2006), size interacts directly with the CEO's skill, so that the marginal impact of ability is higher for larger firms. The implication in my model is similar. Larger firms invest more intensively, increasing the value of the analyst's information and making highly talented CEOs very valuable and well compensated. Since the analyst's information is more valuable to large firms, they would also have a higher incentive to signal. All else equal, this would increase the fraction of firms that would find strategic overpayment of the CEO attractive.

However, a rigorous treatment of size in the context of my model would require altering the assumption of constant liquidity among firms of different sizes. Because larger firms have more liquid stocks, the analyst's incentive to gather information is higher, which would reduce a firm's incentive to signal. Thus, while the larger scale of firms means that the incentive to attract analyst attention is increased, it is unclear whether signaling would play a larger or smaller role in CEO compensation at big firms.

Financial Flexibility. Firms benefit from the analyst's information through more efficient investment. Allowing for financing constraints in the model would deliver the prediction that less flexible firms are less likely to engage in strategic overpayment. The intuition is that if a firm does not have the investment flexibility to take advantage of the analyst's information, then there is little motivation to signal via compensation. This would imply that highly leveraged firms, whose operating plans are constrained by their financial inflexibility, may be less inclined to signal their CEO's ability. There are, however, other reasons why highly leveraged firms may pay their CEOs less, perhaps most importantly because a history of poor performance may have resulted in the firm's excessive leverage.

Governance. Boards are not weak or strong in my model, but may intentionally "sacrifice" some of their bargaining power to the CEO by paying him a higher wage than the bargaining solution would indicate. Core, Holthausen, and Larcker (1999) shows that a board's structure, which likely provides information about the CEO's relative bargaining power, impacts compensation.[13] A direct interpretation of my model is that a sacrifice of such bargaining power, to the extent that it results in a heightened perception of the CEO's ability or job security, can be beneficial.

A less direct but related interpretation of the model is that a board may have an incentive to understate its willingness to terminate the CEO. Powerful boards with the ability and willingness to fire the CEO in the wake of poor performance may, for the reasons detailed in the model, reduce the incentives of analysts and other stakeholders to make investments that depend on the CEO's tenure. This interpretation would require that weak boards both pay their CEOs more handsomely and be less likely to terminate him. It would also require that more powerful boards downplay to the market their willingness to discipline the CEO. While this line of reasoning is unlikely to be of first order importance, it nevertheless highlights a potential benefit of appearing weakly governed, which may play a role in determining CEO compensation.

Other Stakeholders. The model primarily addresses the interaction between the firm and analyst community, but its interpretation may extend to other of the firm's relationships as well. For example, workers are often expected to make investments in skills and knowledge that depend upon a particular strategy embraced by the firm's top management. If these investments in human capital do not pay off immediately, then the investments of workers may depend on their perceptions of the CEO's support from the board and shareholders. The same may be

[13]Board structure refers to such characteristics as its size, the fraction of seats held by outsiders, and whether the CEO is the chairman.

said for others with an interest in the firm's long-term viability, such as suppliers or customers.

1.4 Conclusion

I develop a model in which the board may find it optimal to overstate its support of the CEO. Because the analyst is likely to produce better quality information if the CEO is supported by the board, the firm benefits from a perception that its CEO's job is safe. To the extent that compensation communicates the board's support of the CEO, the board may therefore have the incentive to overpay the CEO. The model applies to situations in which the analyst's benefit from collecting information is diminished if the CEO is replaced. This is likely to be the case in industries where projects do not pay off quickly, as well as those in which CEOs play a large role in determining the strategies of their respective firms. The model shows that more firms engage in signaling when the CEO's bargaining power is low, and when the analyst's cost of collecting information is small.

Implicit in the model is that the board can only signal its support of the CEO through his compensation, although there are certainly other ways in which this support can be conveyed.[14] My model focuses on compensation for two main reasons. First, unlike the structure of the CEO's severance agreement, the "independence" of the board's directors, or other evidence providing information about the CEO's likelihood of being replaced, the CEO's compensation is easily observable. Second, the CEO's compensation is determined after an extensive evaluation process, and is therefore likely to reflect the board's private information about the CEO's talent or specific "fit" with the firm, and therefore contribution to firm value. Since a board is likely to remain supportive of a CEO it views as more talented, the CEO's compensation likely provides analysts with insight into the board's likelihood of replacing its CEO.

Finally, although the model specifically addresses CEO termination and the impact this possibility has on the analyst's incentives to collect information, the

[14]For example, Gillan, Hartzell, and Parrino (2006) present evidence that CEO employment contracts are highly variable with respect to the definition of termination for "just cause." In extreme cases, termination for cause would only occur if the CEO were indicted on a felony that harmed the company.

board's actions need not be this extreme for the model's implications to hold. For example, if the board simply interferes with or alters the CEO's strategy after the analyst has collected information, then the analyst's *ex ante* incentives to collect information may be reduced. To the extent that compensation reflects a CEO's bargaining power in wage negotiations, it may also reflect the CEO's ability to resist interference from the board, which may lead to better information production from analysts.

Chapter 2

Empirical Evidence on the CEO's Tenure, Impact on Firm Strategy, and Relationship with the Board

2.1 Introduction

The main result of the model developed in Chapter 1 pertains to the firm's governance, specifically the optimal (perceived) balance of power between the firm's board and CEO. However, the story indirectly involves several additional players, and makes important assumptions about their behavior, preferences, and payoffs. This purpose of this chapter is to further develop the model's intuition by discussing several of these key parties and assumptions, and when possible, presenting supportive empirical evidence.

One of the model's important assumptions is that CEO turnover represents a legitimate threat to stakeholders, because any ensuing strategic changes may reduce the value of strategic-specific investments. This connection is crucial for the model - unless some aspects of the firm's competitive strategy are altered by new management, CEOs are merely figureheads with little power to influence stakeholder investments. Empirical evidence strongly suggests the contrary, i.e., that CEOs *do* in fact play large roles in guiding their firms' strategies. For example, stock price volatility significantly increases around CEO turnover, an effect more pronounced when the CEO is replaced by someone outside the organization. Real investments and operating efficiency are also affected by regime change, supporting the assumption that CEOs appear to heavily influence the direction of their firms. Section 2.2 summarizes empirical work on this area.

However, top executives must be replaced often enough so that the potential for termination is an important consideration for analysts and the firm's other stakeholders when making their investment decisions. Section 2.3 addresses this question directly, first providing empirical evidence that the CEO is an increasingly risky position, and then presenting reasons for this trend including more stringent corporate governance, the changing nature of responsibilities, and a more efficient labor market.

Although the model's intuition applies to any of the firm's stakeholders, the model specifically addresses the problem of an investor attempting to decide whether to collect costly CEO-specific information about the firm. Section 2.4 explores in more detail one type of investor - a stock analyst. Analyst coverage can certainly benefit the firm directly, for instance by increasing the firm's long-term credibility with the investment community, increasing its access to financing. There are various indirect benefits as well, such as when the firm uses information produced by analysts to improve its decision making. Section 2.4 also presents evidence that the value of the analyst's information is often tied to a particular firm or management team, so that the potential for regime change may impact the analyst's *ex ante* incentives to collect information.

Finally, Section 2.5 explores various ways that a board may communicate its confidence in the CEO, improving firm value by increasing his credibility with analysts and other stakeholders. First, I briefly discuss why commitment mechanisms such as long-term contracts and severance agreements may be effective, as well as describe their shortcomings. Following that is a discussion of how the board can use observable signals to communicate its confidence in the CEO's capabilities. Although other potential signals are discussed, I devote special attention to the role of the CEO's compensation as credible signal of the board's assessment of his capabilities. Section 2.6 concludes.

2.2 CEO and Firm Strategy

The CEO is a unique employee. In addition to being the most public figure in the firm, the CEO is generally expected to provide and articulate a strategic "vision" for the firm, i.e., a set of long-range plans and operational goals expected to define the firm's competitive strategy. For example, which markets the firm plans to target, how intensively it invests, or whether or not it acquires a rival are the types of high-level decisions likely to be influenced by the CEO's particular vision for the firm. That the CEO's strategy is well-understood is important, not only for those inside the firm, but also for parties outside the firm such as the firm's stakeholders and analyst community, parties that allow it to execute the strategy more effectively.

However, because the CEO's vision for his firm is often imperfect, it is not uncommon for firms to alter their strategies. While the CEO himself will sometimes revisit his initial strategy in light of new information, such changes – especially when the CEO's initial strategy was particularly high profile – are often initiated by the board against the CEO's wishes. The financial press is littered with examples where the CEO was either forced to abandon a major initiative such as a merger, or in extreme circumstances, was terminated by the board after the CEO's strategy failed to meet expectations. For example, "a strategy that appeared to pull the company in opposite directions" was explicitly cited as the reason former Compaq CEO Eckhard Pfeiffer was sacked by his board. Time will tell whether the well publicized strategy failures at Motorola will cost Ed Zander his position.[1]

To the extent that boards initiate strategy change by replacing CEOs, top executive turnover should be associated with measurable changes in, e.g., the firm's investment policy, efficiency, or other strategy-related characteristics. Denis and Denis (1995) study a sample of 721 CEO turnovers (83 forced) during the mid-1980s. They find that operating performance and investment policy is significantly altered when a CEO is replaced, an effect that is more pronounced in the event of a forced departure. In both normal and forced retirements, the median ratio of

[1]According to the Financial Times Online August 23, 2007, Nomura analyst said, "We think that Motorola has made a strategic blunder by giving up a long-term opportunity for short-term profits. If Motorola doesn't see a pick-up in the next two quarters, we may see a new CEO."

operating income before depreciation to total assets (OIBD/TA) improves. However, the effect of forced retirements is much larger, approximating the magnitude of efficiency improvement following management buyouts (Kaplan (1989)), leveraged recapitalizations (Denis and Denis (1993)), and proxy contests Mulherin and Poulsen (1994)).

Weisbach (1995) examines firms' investment decisions around CEO turnover. He finds that the probability of a firm divesting a poorly performing asset depends on whether the asset was acquired under the current or previous CEO's tenure. As asset inherited by the CEO is more likely to be sold than if purchased during his tenure, an effect that is invariant to the type of turnover, i.e., forced or voluntary. This result is consistent with similar evidence from Denis and Denis (1995), who find that industry-adjusted changes in total assets, employees, and capital expenditures are all significantly negative in the forced CEO turnover sample. Consistent with strategy changes being comparatively mild, the effect is less pronounced during regular, i.e., non-forced, retirements. Huson, Parrino, and Starks (2004) extend the work of Denis and Denis to consider how monitoring mechanisms such as institutional holdings or board composition influence performance changes around CEO turnover. Although their overall results confirm the findings of Denis and Denis (1995), they do not find that forced turnovers predict more drastic operating performance changes.

Bertrand and Schoar (2003) assess the importance of individual managers through a different empirical technique. Rather than analyze firm performance around CEO turnover, the authors show that a wide array of firm-level characteristics can be explained by CEO fixed-effects. Examining a data set spanning over 30 years (1969-1999), the authors are able to separately identify firm and CEO fixed effects by observing the behavior of specific managers across several firms. They find that CEO fixed-effects matter, particularly with regard to acquisition and divestiture decisions, interest coverage, and dividend policy. Moreover, the authors identify specific characteristics that may be responsible for driving the fixed effects, such as the CEO's birth cohort or educational background. Overall, the results of Bertrand and Schoar (2003) overwhelmingly suggest that CEOs matter for firm policy and strategy.

The strategy changes and efficiency improvements accompanying forced CEO turnover impact stock prices as well. Bonnier and Bruner (1989), Furtado and Rozeff (1987), and Weisbach (1988) all find significant price reactions surrounding

CEO changes. Denis and Denis (1995) find a positive effect only around forced turnover, while Warner, Watts, and Wruck (1988) find insignificant price reactions. While these results can be explained through efficiency improvements not necessarily linked to strategy changes, Clayton, Hartzell, and Rosenberg (2005) find that equity volatility increases around CEO turnover. This effect is most pronounced for forced turnover, a finding the authors interpret as "consistent with the view that forced departures imply a higher probability of large strategy changes."

In aggregate, this body of evidence suggests that selecting a replacement CEO is a complex task. The board must not only "be able to identify and attract superior replacement managers (Denis and Denis, 1995)," but must also anticipate the disruptions associated with transitioning management. Clearly, such disruptions can vary in severity, depending on how much the new CEO intends to alter the firm's competitive strategy and operations. CEOs hired from within are more likely to maintain the status quo, not only because they already possess experience under that regime, but also because internal promotions are likely not random. For example, a board pleased with the firm's overall strategy, but displeased with the CEO's behavior or ability to execute the strategy, may be apt to hire from within. On the other hand, a board wishing to implement more drastic changes may find external replacements more suitable.

2.3 Corporate Governance and CEO Job Security

The threat of dismissal is perhaps the most severe penalty a board can exact upon a poorly performing member of its management team. With the dramatic increase in performance-sensitive compensation for CEOs, it might be supposed that better incentive alignment between managers and shareholders would lead to less termination and longer tenure for top executives.[2] Instead, CEOs appear to face more turnover risk than ever. In fact, a growing body of empirical evidence now suggests that along with the notoriety and fortune often associated with leading a firm comes additional scrutiny, heightened accountability, and decreased job security.

[2]Frydman and Saks (2007) analyze long-term trends in CEO pay, finding that compensation has become more sensitive to firm performance. For example, cash bonuses tied to performance increased from less than 1 percent in the 1940s to more than 25 percent recently. Options have also grown in every decade since the 1950s, comprising about half of CEO pay in 2000.

The most recent large-scale study of CEO turnover is Kaplan and Minton (2006), which finds an annual turnover risk for CEOs of 14.9% during 1992-2005. Importantly, the study finds that CEOs are replaced more frequently in the latter part of the sample, increasingly from 12.7% per year during 1992-1997 to 16.5% during 1998-2005. These estimates of turnover are slightly higher than those found in previous periods.[3] Perhaps more importantly however, the timing of these turnovers suggests that boards are properly motivated; CEO termination is increasingly linked to performance, measured both at the firm and industry level. This finding contrasts with Huson, Parrino, and Starks (2001), which, in an earlier sample (1971-1994), finds no detectable trend in performance-turnover sensitivity. Kaplan and Minton (2006) interpret their more recent finding as evidence of increasingly effective governance, a welcome source of value creation in the wake of recent governance scandals.[4]

While CEO-firm separations are relatively easy to identify, a significant obstacle in quantifying termination risk, i.e., forced departures, is that the majority of CEO firings are not disclosed as such. The convention usually adopted begins with Parrino (1997), who classifies CEO turnover as forced if either: 1) the media (Parrino uses news mentions in the *Wall Street Journal*) recognizes it as such, or 2) the CEO leaves before age 60, but an explicit reason is not given, e.g., poor health, assuming another position, etc., or 3) retires suddenly (without at least 6 months notice). Using this classification, Parrino studies 977 CEO successions from 1969-1989, finding that 13% of departures were forced. Importantly, whether the replacement CEO is hired from outside the firm depends heavily on firm performance. When the CEO leaves voluntarily, over 90% of the replacements are insiders, compared to 50% if the CEO is forced out.

Although the trend of increasing termination risk for CEO is relatively well established, no clear consensus has emerged as to why this pattern exists. More effective corporate governance appears to be at least part of the answer, with boards becoming both smaller and more independent, presumably leading to better alignment of director and shareholder interests. Weisbach (1988) is the first to investigate the connection between board composition and termination risk. He finds that

[3]Khurana (2003) and Murphy and Zabonjik (2004) both report overall turnover rates of about 10% per year in the last three decades, increasing slightly in the 1990s. Parrino, Sias, and Starks (2004) find turnover rates of approximately 20%. Jensen, Murphy, and Wruck (2004) also finds modest increases in overall turnover risk in the 1990s compared to the previous two decades.

[4]See Karaoglu, Sandino, and Beatty (2006) for several examples.

boards dominated by those inside the firm (insiders) are less likely to terminate the CEO after poor performance.[5] Lehn, Patro, and Zhao (2003) document a dramatic decline in the fraction of corporate insiders sitting on boards. From 1980 - 2000, the fraction of inside directors decreased from 33% to 16%. Similarly, evidence suggests that boards are becoming smaller. These pieces of evidence suggest that modern CEOs are subject to greater discipline by directors, increasing the pressure of CEOs to perform.

A second factor owes to the changing nature of the CEO's job itself. For example, Gabaix and Landier (2007) document that firms have become much larger over time.[6] In their model, each firm's overall productivity depends on both its scale (size) and its CEO's ability, implying that the most able managers should manage the largest firms, where their contribution to value is highest. The main reason for rapid CEO compensation in the last three decades, the authors argue, is simply that firms have gotten much larger, increasing CEO productivity and compensation.

Though not the main focus of their paper, the extension to turnover is straightforward. If the rank ordering of firm size is not constant over time, then there will be (at least occasional) reshuffling among CEOs to preserve the match between executive talent and firm size. In the absence of hiring and firing frictions, CEOs are reshuffled whenever a firm overtakes or is overtaken by one of its counterparts. However, if firms face transition costs of replacing their CEOs, the threshold for replacement is increased (i.e., larger differences between incumbent and replacement CEO talent are required), so that replacements become somewhat less common.[7] An economy-wide increase in firm size, such as documented by Gabaix and Landier (2007), makes a clear prediction about the rate of CEO reshuffling. Because firms are larger, small shocks for example, in product demand, imply large differences for firm value. This is turn increases the importance of having a CEO whose talent matches the firm's size, so that CEO reshuffling should be more frequent when firms are, on average, larger.

Another example comes from Allayannis, Rountree, and Weston (2007), who document that because firms are going public earlier in their life cycles, modern

[5]Other related work includes Yermack (2004), who shows a negative relationship between severance packages and board independence. Core et al. (1999) and Lambert et al. (1993) show a similar relationship between board independence and on-the-job compensation.

[6]For example, the asset values of Fortune 500 firms have increased by a factor of 5 (500%).

[7]This is modeled explicitly in Hallman, Hartzell, and Parsons (2007).

CEOs are leading younger firms. The fact that young firms typically derive more of their value from growth options as opposed to asset-in-place imply high effective leverage (even in the absence of financial leverage). In addition, young firms are generally not diversified, further increasing the volatility and risk faced by employees with a stake in the firm's viability.[8] Because employment risk is closely linked to the firm's idiosyncratic volatility, managing a young firm imposes significant risk on its CEO, perhaps explaining part of the recent decrease in CEO tenure.

A third reason is that scrutiny of the CEO and board has greatly increased. The behavior and performance of both executives and directors has become very visible, being monitored through multiple channels, most notably shareholder advocacy groups and the media. Misbehavior or disappointing performance from the CEO is often immediately recognized, increasing the pressure for board members to take swift action.

Widespread media coverage of executive compensation dates back to at least 1971, when Forbes magazine began its annual survey. Since that time, numerous other outlets have compiled lists of the best paid American executives.[9] This time period is also characterized by the rise of shareholder advocacy groups, who act as external monitors of firm's management and board. If CEOs were ever afforded a measure of anonymity or privacy, it is clearly a historical relic. Shareholder rights groups and the media are directly responsible for exposing CEO fraud or impropriety in at least a few cases, and are probably indirect participants in the downfall of far more chief executives. Dyck, Morse, and Zingales (2007) find that the media is responsible for exposing roughly 14% cases of corporate fraud involving companies with assets over $750 million from 1996 - 2004. In addition to exposing illegalities or indiscretion, media coverage can have an effect on public perception of the CEO's ability or foresight, with potential real effects. Although data on this issue are scarce, casual empiricism suggests that negative publicity surrounding some recently dismissed CEOs (e.g., Carly Fiorina of Hewlett Packard) contributed to their downfalls.

A final reason why CEOs appear to be increasingly expendable is that firms may face lower costs of terminating and replacing poorly performing management.

[8] Indeed, the main point of Allayannis et. al (2007) is to relate the recent rise in idiosyncratic volatility to decreasing average firm age.

[9] The list of such surveys is very large, including the Wall Street Journal, Booz Allen, and The Chief Executive.

Hallman, Hartzell, and Parsons (2007) develop model in which the frequency of CEO replacement is inversely related to the direct frictions associated with transitioning between top executives.[10] Examples of these costs include: 1) detecting and documenting misbehavior, 2) finding and training a suitable replacement, 3) severance or termination benefits, or 4) defending itself in any legal associated disputes. Although time series data on these costs are generally not available, the argument above suggests that the increased activity of the media may reduce the board's costs of detecting or assessing poor performance. More efficient compensation mechanisms can play a similar role, increasing the board's ability to identify poor CEO-specific performance. For example, evaluating a CEO's performance net of his industry (or even aggregate market) performance removes noise from the evaluation process. Incorporating hedging or other derivatives into the CEO's compensation can have a similar effect.

Of course, just because boards can more accurately measure CEO ability or infer performance does not necessarily imply more frequent termination. With agency problems, more efficient monitoring technology will likely lead CEOs to alter their behavior. In the case of adverse selection, better screening tools and assessment of managerial ability may introduce a new class of agency problems, such as that studied by Zwiebel (1995). In his model, poorly skilled managers attempt to conceal this private information by increasing the risk of the firm's projects. Both of these suggest that even if boards have superior information about their managers skills and behavior, the effect on termination rates is unclear. However, it remains a likely possibility remains that changes in firm's termination and transition costs play a role in the increased frequency of forced CEO departure.

2.4 Analysts/Investors as Stakeholders

> "*To lead, a CEO must first define a unifying direction for the company which is inspirational for the organization. Choosing the right vision and expressing it with clarity is the first challenge of true leadership ... the vision statement should identify what is unique about your company; it should guide the activities of all employees; it should inspire them to*

[10]There are, of course, various indirect costs associated with replacing a CEO, including the focus of this review: large scale changes in strategic direction.

choose to work for your company and give their all; and it should be stated in such a way that you can measure progress and know when you have achieved your vision." – Consulting firm CEOmentors website, 2007.

The above quote suggests that individual success is largely meaningless for a CEO. Because his performance is measured at the firm level, the ability of a CEO to stimulate long-term investments from parties with a stake in the firm's future (in this example, the firm's workers) largely determines whether he and his strategy are considered successful or not. In many cases, the firm depends on input not only from its workforce, but from additional stakeholders as well - suppliers, customers, financiers, and analyst following.

The relative importance of each stakeholder class depends on a variety of factors, such as the firm's industry, age, or competitive position. For example, a fledgling software firm attempting to develop its initial products is far more likely to depend on human capital investments by its R&D team than is a mature airline, where customer-specific investments are probably more important. Reflecting the differing nature of the firm's relationship with each group, the ways that stakeholder investments benefit the firm also vary. The effects can be relatively direct, such as a supplier whose firm-specific technology investments afford the firm a cost advantage over its competitors, or indirect, such as a stock analyst who, by producing information useful for the firm, allows it to make better real decisions.

This section explores in more detail the idea of analysts having stakeholder-like payoffs, even though the analyst may not directly transact with the firm. Among their various responsibilities, analysts collect information about demand for a firm's products, evaluate the quality of its management, assess its competitive environment, and develop opinions about its long and short-term prospects. This information is valuable for the investment community, specifically in retail stock recommendations and valuation models by investment banks and private equity firms. However, the information can also feed back to benefit the firm itself.

For example, to the extent that information produced by analysts reduces asymmetries between the firm and capital markets, the firm may enjoy a lower cost of capital (Myers and Masluf, 1984). More efficient compensation is also an implication of more efficient stock prices causes by better information production by a speculator/analyst (Holmstrom and Tirole, 1993).[11] The information produced by analyst's can also improve the firm's real investment decisions, an idea explored by Dow, Goldstein, and Guembel (2007). Clearly however, not all information produced by analysts benefits the firm equally. For instance, inaccurate or redundant information would seem to confer modest benefit at best. Factors that affect an analyst's accuracy or willingness to provide bold forecasts are therefore likely to be of significant interest to firms.

The vast majority of literature studying information produced by analyst focuses on earnings forecasts.[12] Mikhail, Walther, and Willis (1997), Clement (1999), Jacob, Lys, and Nealse (1999), and Brown (2001) show that more experienced analysts provide more accurate earnings forecasts. This finding is perhaps unsurprising, given that more accurate analysts are likely to be retained by their firms. However, this result is also possible in the absence of ability selection over time. As analysts accrue experience, both their general and firm-specific knowledge increases, which likely improves forecast accuracy. Clement and Tse (2005) investigate the role of both types of experience (i.e., both general and firm-specific) on earnings forecasts, finding both predict accuracy and boldness.

While clearly related, there are important distinctions between an analyst's firm-specific and general experience. General experience is accrued across many firms over the analyst's career, allowing her to sharpen her general skills and knowledge of the industry in which she specializes. Firm-specific experience, in contrast, is more intimate. Over time, the analyst develops an assessment of a particular management team's competence, having learned its strengths and weaknesses through experience. With this knowledge, the analyst can better evaluate the firm's competitive strategy and position, combining both the feasibility of the strategy with knowledge of the management team's ability. In many cases, this knowledge may be highly idiosyncratic, for not only does the competence across CEOs and lower executives vary, but so do the strategies and visions espoused by each management team. Knowledge of a particular CEO's ability and strategy is not likely to be fully transferrable across firms, or even across management teams within the same

[11]In this model, the private information of a speculator becomes impounded in the firm's stock price, allowing the firm to more accurately identify whether the manager has misbehaved or not. The firm then provides more efficient compensation, increasing (decreasing) the manager's pay in states when proper (improper) behavior is most likely.

[12]Notable exceptions include recent work by Mayew et al. (2007).

organization.[13]

This reasoning suggests an important role for the firm's board. A board that thinks highly of its CEO and management team is more likely to lend its cooperation and support, likely generating a longer and more stable tenure for management. Because such cooperation and stability are likely important considerations for analysts asked to produce long-lived information about the firm's strategies, a board that appears committed to the CEO signals to analysts that it is safe to do the same. Although the importance of this dynamic between the board and analyst community may vary significantly across firms, the same argument applies to any party whose investments depend on the board's relationship with senior management. The benefits of keeping the CEO on a short lease are well advertised - this argument presents a justification for a board that is intentionally "softer" with its top executives.

2.5 How a Board Can Enhance the CEO's Credibility

The previous sections have laid the groundwork for the idea that tougher governance is not necessarily synonymous with better governance. However, what has not been discussed are the various avenues through which a board can enhance the CEO's credibility. This section explores two such devices: commitment mechanisms and signals. I conclude with a more detailed discussion of compensation as a particularly attractive signaling mechanism.

A board wishing to provide assurance to its shareholders, financiers, or stakeholders about the CEO's tenure can do so with a commitment device. For example, roughly one-half of Fortune 500 firms provide their top executives with explicit employment agreements. These contracts vary significantly in many aspects, including the term (often 3-5 years), renewal provisions, specifications of "just cause" for termination, severance arrangements, and non-compete clauses.[14] This flexibility allows the board, if it chooses, to increase the cost of replacing the CEO (for example, a particularly lengthy contract with a generous severance package triggered in the event that the CEO is terminated).

[13] See section 2.2 for more discussion about CEOs and the uniqueness of firm strategies.

[14] See Gillan, Hartzell, and Parrino (2007) for more details about descriptive contract features, as well as firm characteristics that influence the likelihood that a CEO is offered a contract.

The prevalence of employment contracts suggests distinct advantages of providing the CEO with such insurance. At least one rationale is to protect the CEO against factors beyond his control, such as a hostile takeover.[15] Providing such insurance to the manager may not only improve welfare through efficient risk shifting, but may also create value if such a contract lengthens the CEO's expected tenure. To the extent that payoffs of stakeholder investments are threatened by the CEO being terminated, a employment that mitigates this threat could add value to the firm. However, for a commitment device to achieve this goal, it must be effective. Whether an employment contract offered to a CEO has a meaningful impact on his tenure (or important characteristics about his tenure) determines whether stakeholders alter their strategies based on the presence or absence of such a device.

For at least two reasons, it is reasonable to suppose that such commitments may not, in reality, be credible impediments to replacing the CEO. The first is feasibility, i.e., whether contracts can be written with large enough penalties to have meaningful impacts on CEO tenure. The size of most public firms alone raises this question. Although executive compensation is often viewed as exorbitant, for all but the smallest firms, the CEO's pay is a trivial cost when viewed as a percentage of firm value. A second reason relates to personal costs facing directors should they fail to replace a poorly performing CEO. From the increased media scrutiny surrounding cases of so-called "captured" boards to recent shareholder class-action lawsuits naming board members themselves, it seems unreasonable to conclude that severance agreements could dissuade board members from replacing a poor CEO.

Supposing even that the board could credibly enter into a credible commitment with its CEO, what impact would this have on stakeholder investments? Clearly, if stakeholders care only about the CEO's tenure, and if a contract can be written precluding this possibility, then the problem is solved. However, in many cases, non-contractible actions such whether the board lends its cooperation and support to the CEO may significantly influence his credibility with stakeholders, ultimately determining whether he is successful or not. This 'advisory' role of the board is explored theoretically by Adams and Ferreira (2007), and is widely recognized by the financial press as a crucial ingredient of CEO success.[16] By withhold-

[15]Indeed, the majority of contracts contain "change of control" provisions, with payouts approximating those incurred should the CEO be terminated without just cause.

[16]For example, the agenda for *Found in Translation: A Toolkit for Chair Chief Executive Partnerships*, a presentation at a 2007 CEO symposium in Denmark includes topics on: 1) A CEO's

ing its advice, support, or cooperation from the CEO, the board can force strategy change, even in the absence of termination (of course, the rationing of support can often be a precursor to termination itself). However, because, e.g., cooperation is not verifiable, the role of commitment devices in enhancing the CEO's credibility is questionable.

A second mechanism that does not share this shortcoming is signaling. Rather than explicitly commit to a certain behavior (such as retaining the CEO after poor performance), the board takes an action to demonstrate its belief in the CEO's ability. Assuming that the signal is credible, the firm's stakeholders infer the board's assessment of the CEO, which in turn influences the willingness of these parties to invest in long-term relationship with the CEO and management team. To be credible, signals must be costly; otherwise, all boards would mimic the action, removing all information content of the 'signal.'[17] A second desirable feature of any signaling equilibrium is that the cost of signaling is higher for worse types, in this context, boards with lower opinions of their CEO's long-term viability.

Good candidate signals are therefore actions whose costs to the firm vary with the CEO's ability. Debt is one such possibility. Apart from the tax incentive, the most popular explanation for debt is its role in disciplining management (Jensen and Meckling, 1976), reducing free cash flow, and consequently, managerial discretion to pursue pet projects with private benefits. By this reasoning, suboptimally low leverage is costly to the firm, increasing the likelihood of wasteful (over)investment. However, the previous discussion of credibility implies that for highly talented managers, latitude can create substantial value for a firm. A highly talented manager with penchant for timely investing will, in the absence of agency considerations, create more value for his firm when unconstrained. Furthermore, stakeholders are more likely to invest in a CEO armed with the freedom to execute his preferred strategies. This suggests a signaling role for debt: firms with highly talented managers value the added flexibility more than do firms with comparatively less talented managers. Boards may therefore have an incentive to signal the manager's capabilities with

guide to making the most of your board, 2) Communicating the strategic vision together, and 3) Seeking early board involvement in strategy.

[17]Trivially, is the signal is not costly, there is an infinite number of equilibria involving both pure and mixed strategies for signaling, none of which allow for the stakeholder to refine its belief about the board's information.

seemingly suboptimally low debt levels.[18]

Another reasonable signal is the CEO's compensation. If managers of higher ability create more value for their firms, and if managers capture some of these value improvements in their wages, then compensation, like leverage, is likely to contain valuable information about the board's assessment of the CEO's capabilities. The implication for stakeholders is straightforward. Compensation conveys information about the CEO's ability, which likely impacts not only the CEO's tenure, but also the degree of cooperation and support the CEO is afforded by the board. This enhancement of the CEO's credibility increases stakeholder investments, and improves firm value.

The role of compensation as a signal provides a novel rationale for high CEO pay. In particularly, it suggests one reason why a board might intentionally soften its bargaining position in wage negotiations with the CEO, leading to rational overpayment of top executives. Although seemingly inefficient for shareholders, "excess" compensation paid to the CEO can communicate the board's belief in his abilities, and future willingness to support his policies. If the benefits associated with enhancing the CEO's credibility in this way outstrip the direct cost of the overpayment, then the board may find it optimal to do so.

2.6 Conclusion

Both the business press and academic literature give the distinct impression that shareholder interests are unambiguously better served by independent, tough boards. The merits of this argument are without question, especially in light of the numerous recent cases of fraud and scandal. When agency considerations are first order, the benefits of a strict board are apparent and significant. However, discipline is only one aspect of the CEO-director relationship - the board can also be a sounding board for the CEO's strategy ideas, can lend its expertise or relationships, or can offer advice. Its unique position also allows it to significantly alter the CEO's credibility with the firm's workers, providers of capital, analyst following, and customers. Because the board's assessment of the CEO's ability and performance has a meaningful impact on his tenure, parties with an interest in the firm's long-term viability

[18]An extensive literature documents the so-called 'low leverage' puzzle. Strebulaev and Yang (2006) document an even more extreme subset of firms that have *zero* debt.

also have an interest in the board's opinion of the CEO's performance. Thus, actions which speak to the board's opinion of the CEO can have wide implications for firm value.

Chapter 3

Does Anonymity Always Benefit Informed Traders?

3.1 Introduction

Traders have traditionally had little ability to influence the anonymity of their trades. However, this is no longer the case. An ever-expanding landscape of trading venues now offers considerable heterogeneity in the amount of anonymity traders are afforded, from platforms offering complete anonymity such as INET or Euronext to ones offering none, such as the Hong Kong or Austrialian Stock Exchanges.[1] Characteristics of traders also play a role in how much the market can infer about their identities. Now more than ever, informed traders are likely to be hedge funds or other relatively unregulated entities that not only escape disclosure requirements, but also have significant flexibility to disguise their identity with anonymizing strategies, e.g., breaking up large orders or routing through multiple brokers. Yet despite the increasingly important role of trader anonymity in financial markets, research has had little to say about its impact on market characteristics.

This paper is an attempt to improve our understanding of this issue, specifically considering how trader anonymity influences the optimal strategies of an in-

[1] In the latter two markets, broker identities are nearly always disclosed when the trade is initiated.

formed trader, his expected trading profits, and the resulting price dynamics. Our analysis yields some surprising results. First, we show that informed traders are not necessarily better off in anonymous markets, which would seem to confer higher expected profits via lower price impact of trading, i.e., Kyle's (1985) liquidity. In fact, we show that the relationship between anonymity protection and liquidity is not so straightforward. The direct effect is that less trader anonymity decreases liquidity, simply because informed trades are more frequently revealed as such, leading market makers to adjust prices.

However, there is an opposing indirect effect stemming from an informed trader's response to such an increase in the chance that his trade is revealed. The informed trader uses the increased visibility to his advantage, attempting to confuse the market maker by "bluffing" and trading against his information. This occurs when: 1) the stock is not badly mispriced (because trading against one's information is costly in proportion to the mispricing), and 2) when there is a high enough chance that the bluff is revealed to the market maker (otherwise the bluff is useless). Because the linkage between the informed trader's demand and his information is weakened, the market maker is more reluctant to adjusts prices in response to order flow, i.e., liquidity is increased.

This increased liquidity results in higher expected profits for the informed trader, but not directly - bluffing itself does not increase the trader's expected profits. Rather, it is the *possibility* that bluffing may be occurring that results in the increased liquidity associated with less anonymous markets. To better understand this, consider how bluffing helps a card player in a game of poker. When a player has poor cards in a given hand, she may bet more aggressively than her cards may warrant. Although she will almost certainly sustain a loss if her bluff is called during that round, her opponents learn that aggressive betting is not always backed up by good cards. Thus, they are more likely to challenge her betting in the future, which pays off tremendously when she has the cards to justify the aggressive bets. Likewise in a market where bluffing is known to occur, the market is deeper and price is less sensitive to order flow. The benefits to the informed trader of increased market depth are realized at times when the informed trader does not engage in manipulation (though an informed trader with different information might).

A second class of closely related implications speaks broadly to the impacts of bluffing on market stability and efficiency. Bluffing is destabilizing in that it moves prices away from fundamentals. Our findings suggest that this effect may be self-reinforcing. Previous research has shown that if liquidity traders have discretion over the timing or location of their trades, they will tend to avoid trading where or when liquidity is low or there exists a high proportion of informed traders.[2] This is because informed trader profits are financed by liquidity trader losses. Therefore, factors that increase informed trader profits will increase liquidity trader losses and tend to drive liquidity traders toward alternative trading venues.

Also of interest is the interaction between anonymity protection, bluffing, and information production. An informed trader is more likely to bluff when anonymity protection is low and when prices more accurately reflect fundamentals, i.e., the informational gap between the informed trader and market maker is narrow. This suggests that the relationship between information production and price efficiency isn't necessarily straightforward. When more information is produced (due, for example, to an increased number of analysts following a stock), prices will tend to be closer to fundamental value, all else equal. However, because prices are closer to fundamental value all else is not equal: informed traders have a greater incentive to trade against their and push prices away from fundamental value. Since bluffing is more likely in earlier periods when losses (or foregone gains) can be recovered, early information production may actually decrease *average* price efficiency. This temporary reduction in price efficiency is magnified when trader anonymity is poorly protected.

Our model is based on Kyle (1985), but differs in important ways that allow us to study varying degrees of trader anonymity. The most important departure is the introduction of a parameter ("informational trade transparency") that captures the chance that the informed trader's behavior is detected by the market maker. A single informed trader is endowed with a binary (e.g., bullish or bearish) signal of the liquidation value of a risky asset.[3] The informed trader is known to exist, but

[2] See, e.g., Admati and Pfleiderer (1988) and Chowdhry and Nanda (1991).

[3] Our assumption of a single informed trader is important, but need not be interpreted literally. Even if there exists multiple informed traders, each is likely to possess some degree of unique information. In this sense, the model may be viewed as studying the marginal component of an informed trader's order, that which is orthogonal to the information-based trade of other informed traders. Section 4 discusses the impact of multiple informed traders in more detail. Holden and Subrahmanyam (1992) study a multi-period Kyle (1985) model with multiple identically informed insiders. Foster and Viswanathan (1996) study a multi-period Kyle model with multiple differently informed insiders. Callahan (2004) studies a multi-period Kyle-type model with an unknown number of identically informed insiders. Dridi and Germain (2004) study a one period Kyle-type model

her information is private. There are three rounds of trade and in each round the informed trader can submit an order to buy or sell a single share (or not trade).[4] The market also includes a cohort of liquidity traders who trade for exogenous reasons and a risk-neutral competitive market maker. The aggregate liquidity trade in each round is independent and drawn from a discrete uniform distribution. The competitive market marker sets the market price in each trade round equal to the expected liquidation value of the asset, conditional on the observed aggregate order flow (and all previous trade). The model is solved by backward induction.

Our paper contributes to a small but growing literature on trader anonymity in financial markets. Foucault, Moinas, and Theissen (2007) show that anonymity influences how much information securities prices contain about future volatility. Simaan, Weaver, and Whitcomb (2003) study collusion among dealers. They argue that anonymous bid and ask quotes make it more difficult to maintain a collusive equilibrium, as offending dealers are not identified, and as such, cannot be retaliated against.[5] Garfinkel and Nimalendran (2003) examine the impact of informed trading on bid-ask spreads in markets that differ in anonymity.

Analysis of the informed trader's optimal strategy also overlaps with literature on bluffing, or "trade-based" manipulation (Allen and Gale (1992)). Back and Baruch (2004) study trading in both a Kyle (1985) and Glosten and Milgrom-type (1985) setting, arguing that bluffing can arise in either setting. Although bluffing is only one aspect of our analysis, the fact that it arises under alternative microstruture environments means that our particular assumptions are not crucial for appreciating the results. Huddart, Hughes, and Levine (2001) show that insiders have an incentive to "dissimulate" their orders following disclosure, with an intent similar to bluffing of reducing the link between order flow and information. Chakraborty and Yilmaz also study bluffing incentives in a Kyle-type (2004a) and Glosten-Milgrom (2004b) setting with finite discrete order flow and liquidation value. Other relevant papers include Fishman and Hagerty (1995), who study trade-based manipulation from uninformed traders and John and Narayanan (1997), who shows that even a

with multiple identically informed insiders with binary signals.

[4]The assumption of net unit demand is innocuous because we allow mixed strategies for the informed trader.

[5]This argument is broadly consistent with the findings of Benveniste, Marcus, and Wilhelm (1992), who note that floor brokers on the NYSE interact repeatedly with the same specialist, and are easily identified.

known informed trader may choose to manipulate the market.

3.1.1 Economic Environment

A single risky asset is traded in a market with three types of agents: a single risk-neutral informed trader, a competitive market maker, and noise traders. There are three successive rounds of trade. The asset pays a single cash flow $\tilde{v}$ after the final round of trade. Prior to trade $E[\tilde{v}] = p_0$. For simplicity, the discount rate between successive trade rounds is assumed to be zero. Prior to the market opening for trade an informed trader receives a binary signal $s \in \{l, h\}$ that is perfectly correlated with the asset payoff. Without loss of generality, we set $E[\tilde{v}|l] = 0$ and $E[\tilde{v}|h] = 1$. In each round of trade the informed trader can buy one share, sell one share, or not trade (i.e., sit out of the market). The informed trader's order flow in round n is denoted x_n. Therefore, $x_n \in \{-1, 0, +1\}$ for $n = 1, 2, 3$. x_n may be the outcome of a mixed trading strategy. We denote the informed trader's trading strategy in round n as $X_n(s; p_{n-1})$. The per trade round order flow from noise traders, denoted u_n, is i.i.d. discrete uniform $[-w, +w]$.[6] A competitive market maker observes the aggregate order flow in each round and sets price equal to the expected value of the asset. The aggregate order flow is denoted $z_n = x_n + u_n$ for $n = 1, 2, 3$ and the market price set by the market maker in each round is denoted p_n. We denote the market maker's pricing function in round n as $P_n(z_n; p_{n-1})$.[7]

This setting is the same as that of Kyle (1985), but with different distributional assumptions and a restriction on the informed trader's order size. Specifically, the informed trader's information is binary rather than continuous, the noise trader order flow is discrete uniform rather than normal, and the informed trader is restricted to buy or sell a single share (or sit out) rather than submit orders of arbitrary size. We do not argue that our assumptions are better (or worse) than those of Kyle. Simply, our modeling choices provide a tractible framework within which we can consider both linear and nonlinear equilibria. Manipulative trade strategies are by their very nature non-linear. The framework of Kyle allows for the solution

[6] All the results presented hold for $w > 3$. Some results need to be modified for $w \leq 3$. We don't present detailed results for $w \leq 3$.

[7] The informed trading strategy and pricing function are more properly denoted as $X_n(s, p_{n-1}, \ldots, p_0)$ and $P_n(z_n, \ldots, z_1, p_0)$. However, market efficiency dictates that prices follow a martingale which justifies the notation used in the text.

of linear equilibria, but nonlinear equilibria are intractable and therefore neither ruled out nor confirmed.[8] Overall, our assumptions equate to a discretization of the model. With a discrete-space model we can explore and solve for all equilibria. The discretization is the key departure; the specific discrete distributions chosen are less consequential. The model would be more tedious to solve, for example, if the informed trader were permitted to submit orders ranging from $-k$ to $+k$ shares, but the qualitative nature of the results would remain. Similarly, if the informed trader's information were, e.g., binomial rather than binary, the qualitative nature of our results would not change. We continue our discussion of the implications of our distributional assumptions in Section 4.

3.1.2 Definition of Equilibrium

An equilibrium for the model comprises an informed trader trade strategy, $X = (X_1, X_2, X_3)$, and a market maker pricing function, $P = (P_1, P_2, P_3)$ such that the informed trader maximizes her expected future profits:

$$\sum_{m=n}^{3} E\left[(\tilde{v} - p_m)x_m(X, P)|s, p_0, \ldots, p_{m-1}\right] \geq$$
$$\sum_{m=n}^{3} E\left[(\tilde{v} - p_m)x_m(X^*, P)|s, p_0, \ldots, p_{m-1}\right] \quad \forall\ X^* \neq X \text{ and } n = 1, 2, 3$$

and price equals the expected future asset payoff conditional on the observed order flow:

$$p_n = E[\tilde{v}|p_0, z_1, \ldots, z_{n-1}] \text{ for } n = 1, 2, 3.$$

3.1.3 Optimal Strategies

The model is solved by backward induction. The equilibrium is presented and discussed from the perspective of an informed trader with a high signal ($s = h$). Given this perspective, when the informed trader buys a share she is trading with her information and when an informed trader sells a share she is trading against her information. Throughout the paper, we define trade-based market manipulation as

[8]Nonlinear equilibria do not exist in a one-period Kyle model. In addition, Back (1992) proves that nonlinear equilibria do not exist in the continuous time Kyle setting.

trading against one's information, so that sitting out of the market and not trading is not construed as market manipulation. The following proposition presents an equilibrium to the 3-period model, a detailed proof of which is contained in the appendix.[9]

Proposition 3 *In the first round of trade, the informed trader's trading strategy $X_1(h; p_0)$ is a mixed strategy that depends on the initial price of the risky asset p_0. Specifically,*

$$X_1(h; p_0) = \begin{cases} -1 & \text{w.p.} \quad \phi_1^h(p_0) \\ 0 & \text{w.p.} \quad \theta_1^h(p_0) \\ +1 & \text{w.p.} \quad 1 - \phi_1^h(p_0) - \theta_1^h(p_0), \end{cases}$$

where the functional forms for $\phi_1^h(p_0)$ and $\theta_1^h(p_0)$ are given in the appendix. There exists a non-empty set of prices $p^{C3} < p_0 \leq 1$ for which $\phi_1^h(p_0) > 0$, i.e., for some prices the informed trader trades against her information with strictly positive probability. There exists a larger set of prices $p^{C1} < p_0 \leq 1$ where $p^{C1} < p^{C3}$ for which $\theta_1^h(p_0) > 0$, i.e., the informed trader does not trade with some probability during the first round.

In the second round of trade, the informed trader's trading strategy $X_2(h; p_1)$ is a mixed strategy that depends on the first period price of the risky asset p_1. Specifically,

$$X_2(h; p_1) = \begin{cases} 0 & \text{w.p.} \quad \theta_2^h(p_1) \\ +1 & \text{w.p.} \quad 1 - \theta_2^h(p_1), \end{cases}$$

where the functional form of $\theta_2^h(p_1)$ is given in the appendix. There exists a non-

[9] We prove existence, but not uniqueness, of the equilibrium. There exist, at least, additional equilibria that differ from the presented equilibrium in ways that are economically insignificant. For example, if the informed trader's information is fully reflected in market price prior to the last round of trade (as can happen), in later rounds the informed trader is indifferent between all feasible trading strategies as each and every one has zero expected profits.

empty set of prices for which the informed trader will sit out during the second round of trading.

In the third and final round of trade, the informed trader's trading strategy is the following pure strategy:

$$X_3(h; p_2) = 1$$

In all trading rounds $n = 1, 2, 3$, the market maker sets prices equal to the expected liquidation value of the asset, given the insider's trading strategy and total order flow:

$$P_n(z_n; p_{n-1}) = \begin{cases} \frac{\phi_n^h(p_{n-1}) \cdot p_{n-1}}{\phi_n^h(p_{n-1}) \cdot p_n + [1 - \theta_n^h(p_{n-1}) - \phi_n^h(p_{n-1})](1 - p_{n-1})} & \\ \text{for} & z_n = -w - 1, \\ \frac{[\theta_n^h(p_{n-1}) + \phi_n^h(p_{n-1})]p_{n-1}}{[\theta_n^h(p_{n-1}) + \phi_n^h(p_{n-1})]p_{n-1} + [1 - \phi_n^h(1 - p_{n-1})](1 - p_{n-1})} & \\ \text{for} & z_n = -w, \\ \frac{[1 - \phi_n^h(p_{n-1})]p_{n-1}}{[1 - \phi_n^h(p_{n-1})]p_{n-1} + [\theta_n^h(1 - p_{n-1}) + \phi_n^h(1 - p_{n-1})](1 - p_{n-1})} & \\ \text{for} & z_n = w, \\ \frac{[1 - \theta_n^h(p_{n-1}) - \phi_n^h(p_{n-1})]p_{n-1}}{[1 - \theta_n^h(p_{n-1}) - \phi_n^h(p_{n-1})]p_{n-1} + \phi_n^h(1 - p_{n-1}) \cdot (1 - p_{n-1})} & \\ \text{for} & z_n = w + 1, \\ p_{n-1}, & \\ \text{else.} & \end{cases}$$

3.2 Discussion

3.2.1 Optimal Strategies

During each round, the informed trader's optimal strategy is determined by comparing the relative costs and benefits associated with each of the available pure strategies. In the final round of trading, this comparison is straightforward: trading with one's information delivers a positive expected profit,[10] sitting out of the market

[10]The single exception is when $p_2 = 1$, in which case the informed trader's expected profits are zero.

and not trading on one's information results in zero profit, and trading against one's information yields an expected loss. Because there are no future rounds of trade in which to recoup a loss or otherwise benefit from not trading with one's information, it follows that in the last round of trade the informed trader will always trade with her information.

Her behavior differs in the second to last round. For some prices, the informed trader will follow a mixed strategy in which she sometimes trades with her information and sometimes does not trade. The informed trader will never trade against her information in the second to last period. To understand why an informed trader may not trade on her information, consider the costs and benefits of deviating away from a pure strategy in which the informed trader always trades with her information.

If the informed trader always trades with her information then the price the market maker sets after observing the aggregate order flow can take only three values. If aggregate order flow is sufficiently low, $z \in \{-w-1, -w\}$, the market maker knows the informed trader sold and sets $p_2 = 0$. Conversely, if order flow is sufficiently high, $z \in \{w+1, w\}$, the market maker knows the informed trader bought and sets $p_2 = 1$. Otherwise, the order flow contains no information about the direction of informed trade and the market maker maintains $p_2 = p_1$.[11] Therefore, with probability $\frac{2}{2w+1}$ the informed trader's information is revealed and she earns no current nor future profits. With probability $\frac{2w-1}{2w+1}$ however, $p_2 = p_1$, giving an informed trader profit of $(1-p_1)$ in the current period and an expected profit of $\frac{2w-1}{2w+1}(1-p_1)$ in the final period. For an informed trader with a high signal, the pure strategy of always trading with one's information yields an expected profit in the final two rounds of:

$$\overbrace{\left(\frac{2w-1}{2w+1}\right)(1-p_1)}^{\textit{second to last period}} + \underbrace{\left(\frac{2w-1}{2w+1}\right)^2(1-p_1)}_{\textit{last period}}. \tag{3.1}$$

[11]For this range of order flows, $-w+2 \leq z \leq w-2$, the market maker's posterior belief (that is, after seeing the aggregate order flow) about the nature of the informed trader's signal is unchanged. Consider, for example, if $z = -w+2$. Since the proposed equilibrium prescribes that the informed trader trades with his information, then $z = -w+2$ would have arisen from either $\{x = +1$ and $u = -w+1\}$ or $\{x = -1$ and $u = -w+3\}$. These events arise with probability p_1 and $1-p_1$ respectively, the market maker's beliefs prior to seeing the aggregate order flow.

Does the informed trader have an incentive to deviate from the pure strategy? Yes.

If the informed trader chooses not to trade during the second to last round she will forfeit her expected profits in that round (the first term in the above expression). In return, she lowers the expected price at which she will transact in the final round. Specifically, by not trading during the second to last period, the informed trader generates the following price distribution:[12] (1) $p_2 = \mathrm{E}[v|s]$ w.p. $\frac{1}{2w+1}$ (since $z = \pm(w+1)$ is now impossible), (2) $p_2 = p_1$ w.p. $\frac{2w-1}{2w+1}$ as before, and (3) $p_2 = 1-\mathrm{E}[v|s]$ w.p. $\frac{1}{2w+1}$. By not trading, there is now only a $\frac{1}{2w+1}$ chance that the market maker correctly infers the informed trader's information and there is an equal chance that the market maker incorrectly infers the informed trader's information (and sets the price completely wrong). Expected informed trader profits for the last period become

$$\left(\frac{2w-1}{2w+1}\right)\left(\frac{1}{2w+1}\right)+\left(\frac{2w-1}{2w+1}\right)^2(1-p_1), \tag{3.2}$$

where the first term is the benefit of having "tricked" the market maker by sitting out the market and not trading.[13]

Only the first terms of expressions (3.1) and (3.2) differ. The first term in (3.2) is positive and independent of price while the first term in (3.1) decreases in price. Therefore, it can *never* be an equilibrium for the informed trader to trade with his information for all prices. When price is sufficiently high, i.e., close to fundamental value, the informed trader has an incentive to not trade on her information and allow the price to 'drift' away from fundamentals prior to the final round of trade. An informed trader with a larger informational advantage, however, will follow the pure strategy of always trading with her information because the foregone profits from sitting out are too large relative to the benefit of a possibly

[12] Here we are holding the market maker's pricing function fixed. Of course, in equilibrium the market maker's pricing function will adapt to the mixed strategy of the informed trader. For now, we are simply demonstrating that the informed trader has an incentive to deviate from the pure strategy equilibrium.

[13] With probability $\frac{1}{2w+1}$, the second to last period's aggregate order flow is exactly $-w$, which causes the market maker to set $p_2 = 1-\mathrm{E}[v|h] = 0$. In the last period the informed trader will buy. With probability $\frac{2w-1}{2w+1}$ the aggregate order flow will not reveal the informed trader's order, giving her a profit of 1 in the last period. Combining these independent probabilities gives the first term of (3.2).

less efficient price in the last round of trade.

Sitting out the market and not trading on one's information, of course, is not manipulation. Sitting out the market is at least partially an artifact of having a discrete order size: there are prices for which the informed trader would prefer to trade a small fraction of a share rather than none at all. Nevertheless, the above intuition is very useful in understanding if, when, and why an informed trader will manipulate and trade against her information. Manipulation only happens in the first of three rounds of trade. In this case, the marginal benefit of trading against one's information is that the market maker may move price *away* from fundamental value, increasing future expected profits. The marginal cost is the difference in the current round between the expected profit from trading with one's information and the expected loss from trading against one's information. Like the 2-period case described in detail above, the marginal benefit is relatively constant in price while the marginal cost decreases in price (when the fundamental value is high). When prices are far from fundamentals therefore, it is never worthwhile to trade against one's information. When prices are close to fundamentals, the marginal benefit of manipulating can be made equal to the marginal cost by choosing the appropriate mixing probabilities of each strategy. The probability of trading against one's information increases in price. This probability, $\phi(p_0)$, is shown in Figure 3.1.

As the initial price, p_0, moves from 0 to 1, an informed trader with a high signal initially adopts a pure strategy of always trading with his information. When the price gets sufficiently high however, the informed trader begins to mix between trading with his information and not trading on his information (this probability, $\theta(p_0)$ is shown in Figure 3.2). As the initial price becomes higher still the informed trader mixes between all three elements of his strategy space: trading with his information, not trading on his information, and trading against his information. As shown in Figure 3.1, the likelihood of trading against his information increases with price. The likelihood of sitting out increases in price until the point when the informed trader begins to manipulate by trading against his information, at which point the likelihood of not trading on his information falls.

The *combined* probability of not trading on one's information, or trading against one's information, increases in price. The combined probability, $(\theta + \phi)$, is shown in Figure 3.3. Notice that these probabilities decrease in w. In this setting, one can interpret w, the noise trade distribution parameter, in two ways. First,

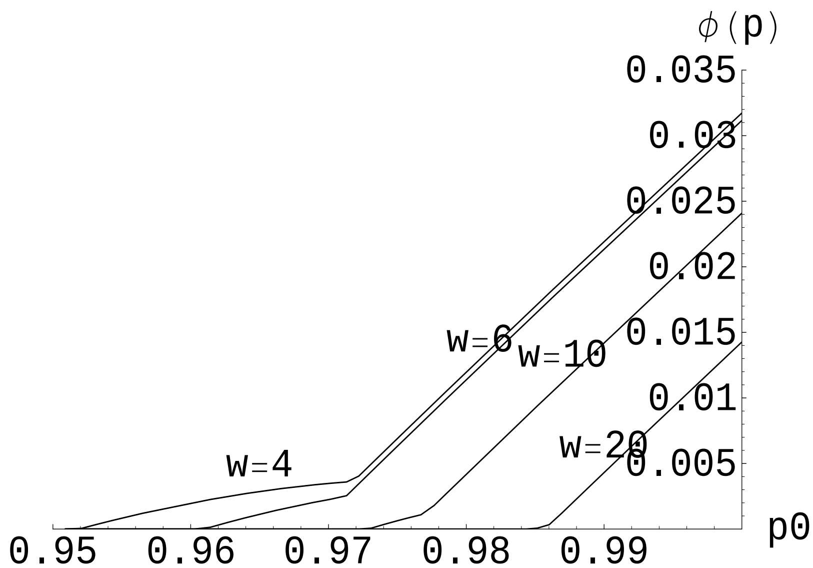

Figure 3.1: w-contours of $\phi(p_0)$ - Probability of Manipulative Trade

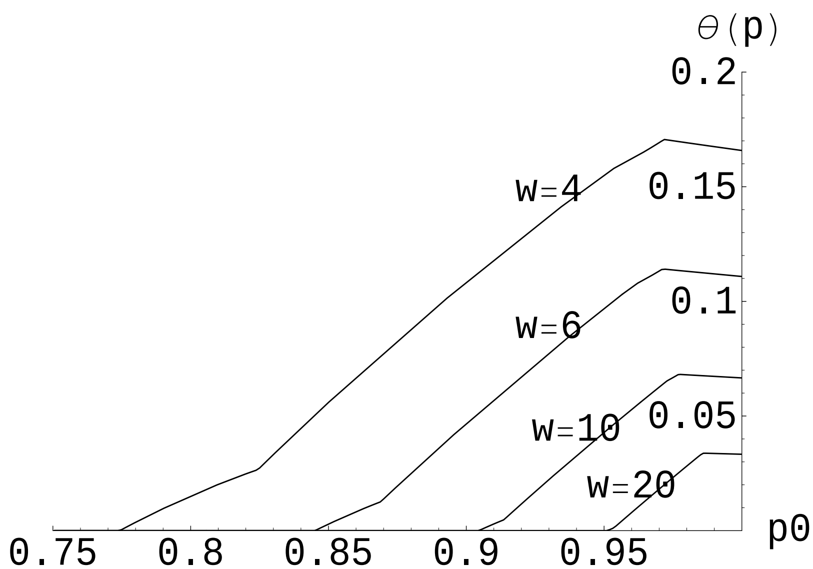

Figure 3.2: w-contours of $\theta(p_0)$ - Probability of No Trade

w is a measure of the amount of noise in the market during each trade round. Second, w is an inverse measure of the likelihood that the informed trader's order will be perfectly inferable from the aggregate order flow. This second interpretation is of particular interest because we are considering a setting in which the informed trader is not subject to mandatory disclosure. That is, the informed trader is not assumed to be an "insider." This interpretation of (the inverse of) w corresponds to what we refer to as *informational trade transparency*, namely the likelihood that informationally motivated trades are recognized as such.

A market with high informational trade transparency is able to extract more information from the order flow. For example, consider a market in which the market maker sees individual orders. This market would have a very high informational trade transparency if all informed traders had no non-information based motives for trade (e.g., liquidity) and were subject to mandatory disclosure rules. If informed traders had liquidity motives for trade in addition to their information-based motives, the market would have a lower informational trade transparency. Finally, if the informed traders were not required to disclose their trades the market would have an even lower informational trade transparency. In a market with no informational trade transparency no information could be inferred from the order flow. In our model, a large w proxies for a market with low informational trade transparency and a small w proxies for a market with high informational trade transparency.

Informed traders clearly prefer markets with lower informational trade transparency. In such markets informed traders can transact undetected and earn large profits. In such markets manipulation is also less likely. The benefit of trading against one's information is in moving prices away from fundamentals to increase future expected profits. In markets with low informational trade transparency the likelihood of an informed trader's order moving prices is lessened, so the incentives to manipulate are reduced. This raises an interesting tension. On the one hand, higher informational trade transparency increases market efficiency via a more direct link between informed order flow and market price adjustments. On the other hand, higher informational trade transparency increases the incentives for informed traders to manipulate prices by trading against their information such that the "informed" order flow becomes less informative. This point has been discussed by Fishman and Hagerty (1985) as it pertains to mandatory disclosure laws. We demonstrate that this is a general consideration that pertains to any aspect of the market mechanism

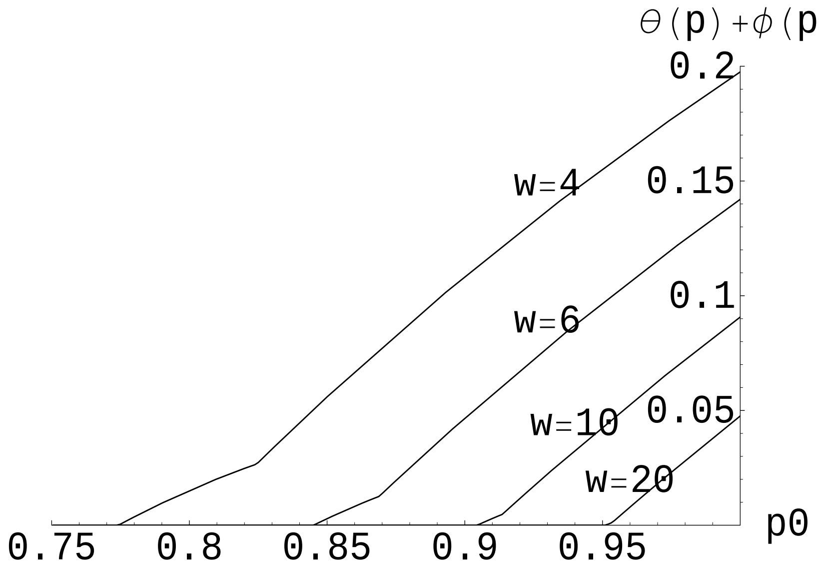

Figure 3.3: w-contours of $\theta(p_0) + \phi(p_0)$

that impacts informational trade transparency.

3.2.2 Informed Trader Profits

We now present a corollary to Proposition 1 that quantifies the expected profits of an informed trader with a high signal of the risky asset's value. Expected profits conditional on a low signal are symmetric.

Corollary 1 *The informed trader's expected trading profits for the 3-period game are a decreasing, piecewise continuous, and linear function in price. Below are the expected profits for an insider receiving the high signal ($s = h$) prior to the first*

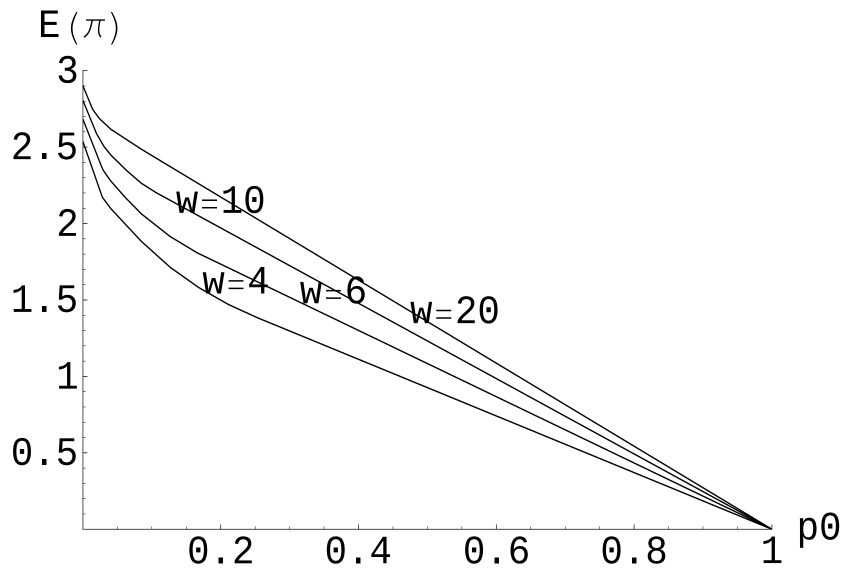

Figure 3.4: w-contours of $E(\pi(p_0))$

period's trading activity.

$$E(\pi|p_0) = \begin{cases} \pi_{base} = \frac{(1-p_0)(2w-1)(1+12w^2)}{(1+2w)^3}, & \textit{if } 1 \geq p_0 \geq 1 - p_0^{C4} \\ \pi_a = \pi_{base} + \frac{(1+12w^2)(8w^2-p_0(-1+2w)(1+2w)^2)}{16w^2(1+2w)^3}, & \textit{if } 1 - p_0^{C4} \geq p_0 \geq 1 - p_0^{C3} \\ \pi_b = \pi_a + \frac{(1+12w^2)(8w^2-p_0(1+2w)^3)}{16w^2(1+2w)^3}, & \textit{if } 1 - p_0^{C3} \geq p_0 \geq \frac{1}{1+2w} \\ \pi_c = \pi_b + \frac{4w(-1+2w)(1-p_0-2p_0w)}{(1+2w)^3}, & \textit{if } \frac{1}{1+2w} \geq p_0 \geq 1 - p_0^{C2} \\ \pi_d = \pi_c + \frac{(1+12w^2)(4w(-1-4w+4w^2)-p_0(1+2w)^2(1+12w^2))}{4w(1+2w)^3(-1-4w+12w^2)}, & \textit{if } 1 - p_0^{C2} \geq p_0 \geq 1 - p_0^{C1} \\ \pi_e = \pi_d + \frac{(1+12w^2)(8w^2(-1-8w+4w^2)-p_0(1+2w)^3(1+12w^2))}{(1+2w)^3(1+12w+16w^2-112w^3+48w^4)}, & \textit{if } 1 - p_0^{C1} \geq p_0 \geq 0. \end{cases}$$

The expressions for the price region boundaries p_0^{C1}, p_0^{C2}, p_0^{C3}, *and* p_0^{C4} *are given in the appendix.*

Figure 3.4 plots the expected 3-period profits of the informed trader as a function of pre-trade price, p_0, for various values of w. Larger values of w correspond to a market that is more liquid with a lower degree of informational trade transparency. Because liquidity increases with w, profits also increase with w. More interesting is the shape of the expected profit curves for each w. The curves are drawn for an informed trader with a high signal. Expected profits decrease in p_0 as expected: informed trader profits are lower on average when she has a smaller informational advantage. What is striking is the region in which expected profits are elevated (relative to a non-manipulation benchmark). Recall that an informed trader with a high signal may manipulate when price is close to fundamental value, but does not manipulate when price is far from fundamental value. In contrast, Figure 4 shows that the informed trader earns excess profits when price is far from fundamental value, and not when price is close to fundamental value. That is, in price regions where the informed trader engages in trade-based manipulation, her expected profits simply match those she would earn from not manipulating and always trading with her information. While in price regions where the informed trader exclusively trades *with* her information, she earns excess expected profits. This means that the high-type informed trader earns excess profits in the price region where manipulation would occur if a low-type informed trader were in the market and the low-type informed trader earns excess profits in the price region where manipulation would occur if a high-type trader were in the market.

Consider the case when price is close to zero. A price close to zero indicates that the market maker believes there is a relatively high probability that a low-type informed trader is in the market. The market maker also recognizes that when prices are close to zero, a low-type informed trader may trade against her information and submit a buy order. Therefore, if the market maker infers that an informed trader submitted a buy order, the market maker updates his beliefs based on the relative likelihood that the order came from a low-type informed trader trading against her information versus from a high-type informed trader trading with her information. Because the market maker has a high prior that the informed trader has a low signal, the market maker is reluctant to raise price too much even when he is certain that the informed trader submitted a buy order. This is an ideal situation for a high-type informed trader. Like a card player who has bluffed in the past when her cards were poor but now has a good hand, she can trade with her information and not cause the price to move too far toward fundamental value even when the market maker perfectly infers the informed trader order flow. Therefore, the expected profits for a high-type informed trader are elevated due to the likelihood that a low-type informed trader may be manipulating the market.

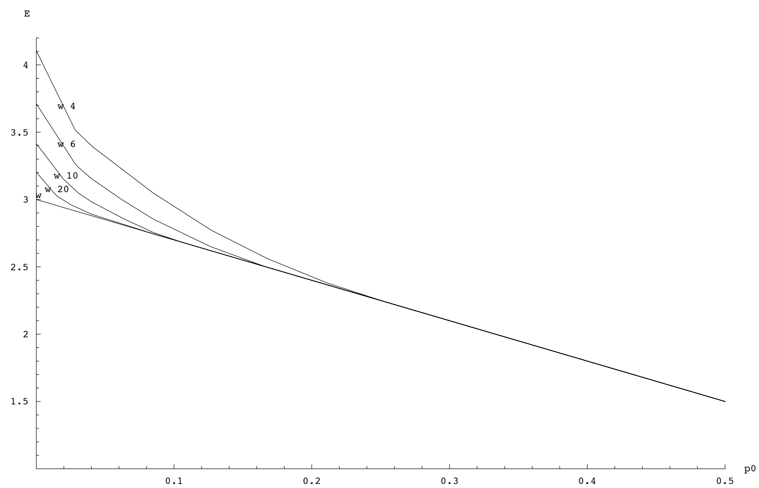

Figure 3.5: Liquidity-adjusted w-contours of $E(\pi(p_0))$

This also highlights the role of informational trade transparency. Figure 3.5 shows expected profits of the informed trader on a liquidity-adjusted basis for different values of w. The liquidity adjustment removes the non-manipulation related effects of changes in w on liquidity, so that changing w only changes the informational trade transparency of the market. Specifically, larger w's correspond with a market in which it is more difficult (i.e., less likely) for the market maker to infer the direction of informed order flow. The informed trader manipulates less, and profits less, when informational trade transparency decreases. The informed trader benefits when the informational trade transparency is high because this increases the odds that manipulative behavior will be successful in pushing price away from fundamental value. This, in turn, increases the incentive to manipulate, which expands the price region within which the market maker is ambivalent about how to react to informed trade and lowers the price responsiveness to order flow, which ultimately benefits the informed trader.

To summarize: (i) the direct effect of manipulation on informed trader profits is simply to break even, (ii) the benefits of manipulative trade accrue to informed traders who don't manipulate, and (iii) the effects of manipulation are most pronounced in markets with a high degree of informational trade transparency. Thus the benefits to informed traders from manipulation are indirect. The potential of manipulative trade changes the market dynamics to the favor of the informed trader. Specifically, the possibility of manipulation increases market liquidity by making prices more sticky and less responsive to order flow. An informed trader creates (but doesn't profit from) the price stickiness by manipulating when she has a small informational advantage. An informed trader earns excess profits from the increased liquidity by trading with her information when her informational advantage is large. This lends support to Allen and Gale's (1992) claim that trade-based manipulation is difficult to detect and eradicate. Our model suggests that, in general, an informed trader will not earn excess profits and engage in manipulation concurrently. Trade reversals occur when an informed trader has a small informational advantage and could credibly claim to have 'changed their mind' about the asset value. Excess profits occur when an informed trader trades consistently in one direction. If both trade reversals and excess profits are needed to prove manipulation, proof will be difficult.[14]

All else equal, informed traders would like to trade in a market with a high degree of informational trade transparency. This is especially so when an informed trader is expected to have a small informational advantage, but in fact has a large informational advantage. Of course, to some extent one expects informational trade transparency and market liquidity to be inversely related as they are through the joint effect of our w parameter: orders are easier to disaggregate and likely to be less anonymous in markets with low liquidity. Even in such a case the profit curves in Figure 3.4 indicate that when an informed trader has a large informational advantage she may be willing to sacrifice market depth to gain higher informational trade transparency so long as the market maker believes that the likelihood that an informed trader *might* manipulate is sufficiently high.[15] This is seen, for example, by noticing that the manipulation based profit curve for $w = 4$ would exceed a non-manipulation based (i.e., linear) profit curve for $w = 6$ for prices near 0. In any case, our model suggests that there are circumstances in which an informed trader would wish to make her actions more transparent by "leaking" her trading activity,

[14]Note, our focus is on understanding the feasibility, dynamics, and profitability of trade-based manipulation. While our work may be relevant to legal and policy discussions regarding trade-based manipulation, we explicitly are not making any arguments or claims about whether trade-based manipulation is or should be legal or illegal.

[15]Of course the market maker's beliefs can be rational if the informed trader is not expected to have so large an information advantage as she actually does.

not breaking up a large order into multiple smaller orders, and the like.

3.2.3 Market Liquidity and Price Efficiency

Figure 3.6 shows the pre-trade expectation of the post-trade residual variance of the asset's liquidation value (i.e., after the final round of trading but before the liquidation value of the asset is announced). The figure is drawn conditional on the informed trader having received a high signal, which creates an asymmetric residual variance profile.[16] Absent manipulation the informed trader trades in the direction of her information each period and the residual variance plots would be parabolas. In our setting there is a constant probability, $2/(2w+1)$, in each round that the informed trader's information will be revealed, independent of initial price. The parabolic profiles therefore simply represent a constant scaling of the initial price variance, which is parabolic owing to the binomial distribution of the informed signal. With a binomial signal uncertainty is a maximum at $p = 1/2$. For very large w it is unlikely that the market maker will perfectly infer the informed trader's information prior to the final trade date and the post-trade residual variance is very close to the ex-ante uncertainty. As w decreases there is an increasing probability that the informed trader's information will be revealed and residual uncertainty profiles are scaled appropriately.

The presence of manipulation changes the residual variance profile in a very significant way. For prices near zero the residual variance plots are not parabolic and, in fact, it is expected that the uncertainty regarding the liquidation value will *increase* over the three rounds of trade. Figure 3.7 shows a close-up of this price region. This region reflects the change in market dynamics attributable to the manipulative trading strategy. Specifically, an informed trader with a high signal can expect, when price is far from fundamental value, to trade in a more liquid market owing to the effect of manipulation. The price is less responsive to order flow because the market maker is uncertain whether to attribute an informed buy order to manipulation by a low-type informed trader or to profitable trade by a high-type informed trader. In this situation, when price is close to 0, a buy order is very rare: a low-type informed trader is likely to exist, but she only trades against her information with low probability. A high-type informed trader always trades

[16]Unconditionally, the figure would be symmetric around $p = 0.5$.

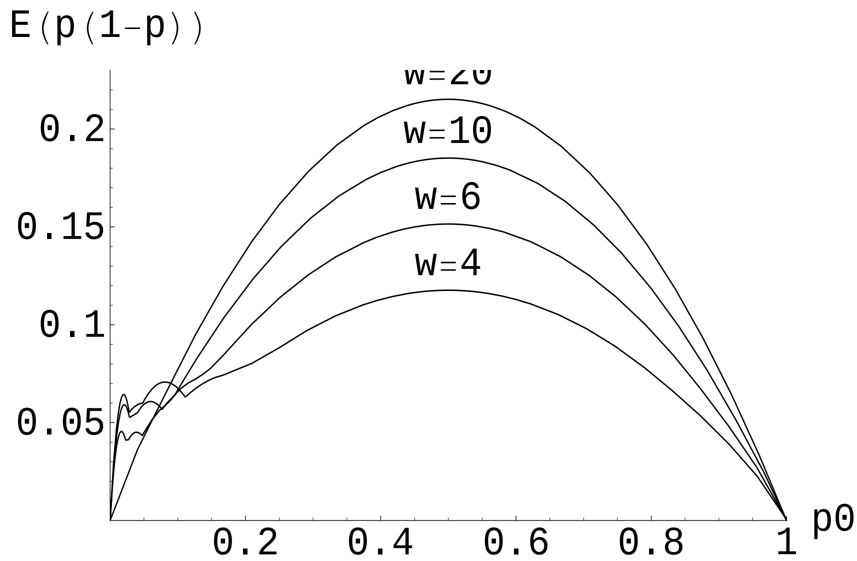

Figure 3.6: w-contours of $E_0[p_3(1 - p_3)]$

with her information, but her very existence is rare when price is close to zero. Absent manipulation, price responsiveness could be quite extreme. In particular, an inferred buy order from the informed trader would move price all the way to 1, no matter how close to zero the previous price had been. With manipulation this doesn't happen.

Also note that the expected increase in residual uncertainty over the trading horizon is most pronounced for low values of w. So much so that the effects of manipulation outweigh the effects of increasing liquidity in w. Thus there are significant price regions for which markets with higher levels of noise trade (bigger w) are expected to be more informationally efficient. We provide a new rationale for this result. Naively, one might expect that increasing levels of noise trade would make prices less efficient. Grossman and Stiglitz (1980) argued, on the contrary, that if information production is costly, then prices can become more efficient when noise trade increases because it allows more profitable trading opportunities for informed traders and thereby stimulates information production. Kyle (1985) showed that even absent costly information production, increasing levels of noise trade needn't impact price efficiency because the intensity of informed trade may increase pro-

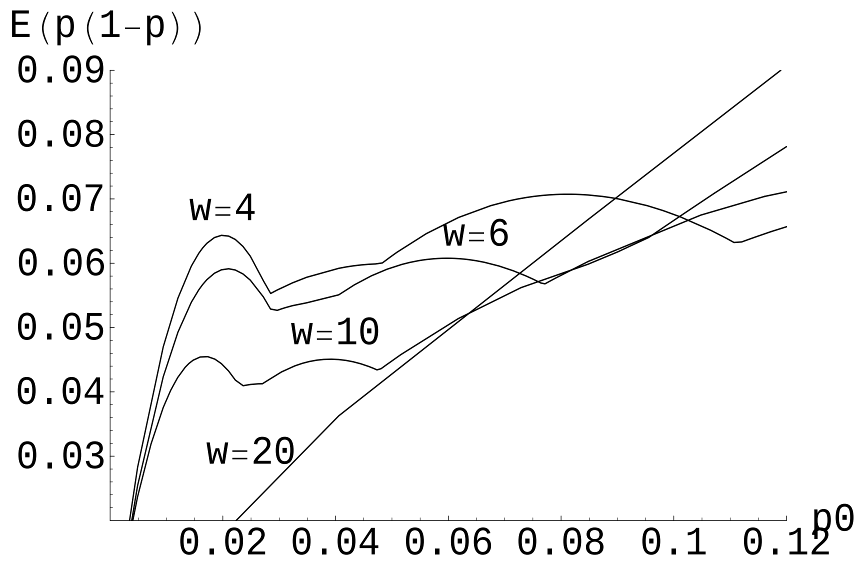

Figure 3.7: w-contours of $E_0[p_3(1 - p_3)]$

portionally. We show that even in the absence of costly information production, increasing noise trade may *increase* price efficiency by diminishing the incentives for manipulative trade. This, again, is why an informed trader may actually prefer to trade in a less liquid market versus a more liquid market, provided concerns about bluffing are larger in the less liquid market.

Lastly, we comment on the scalloping of the residual variance plots. The scalloped shape of the price efficiency curves arises from the discrete changes in market maker beliefs represented by the different price regions in Proposition 1. Within each region there is uncertainty about whether a price change will occur by exiting the region to the right and raising the price, or existing the region to the left and lowering the price. The uncertainty about the direction of the next price update is greatest in the middle of each region, which produces the scalloping.

3.2.4 Additional Considerations

Information Production

The informed trader in our model is endowed with her information. Here we discuss the interplay between manipulation, price efficiency, and costly information production. Grossman and Stiglitz (1980) showed that if information production is costly, markets must be sufficiently 'noisy' for traders who invest in information to profitably trade on their information. If the market is not 'noisy,' price is a sufficient statistic for private information and uninformed free-riding undermines the incentive to collect costly private information. Market noise is often assumed to come from liquidity-based demand or other supply shocks. Our paper shows that an informed trader can also generate market noise endogenously via trade-based manipulation. All else equal, manipulation increases the expected profit from informed trade and should lead to more information production. Additional information production will offset the negative price efficiency effects of manipulative trade. Therefore, in a setting with costly information production it is not clear whether the net effect of manipulation on expected price efficiency will be positive or negative.

Also recall that the excess profits due to manipulation are convex in the magnitude of the informed trader's informational advantage, as shown in Figure 4. This has several potentially interesting implications. First, this may create increasing returns to scale for information production. Second, if different methods of producing information have different risks with respect to the amount of information produced, the convexity of the expected profits creates a bias toward risk-taking in information production. Last, because there is a higher marginal benefit to generating a lot versus a little information, but because manipulation occurs when an informed trader has a little versus a lot of information, it is possible that a model with endogenous information production may have multiple equilibria or no equilibrium. For example, excess expected profits accruing from a market with manipulation may dictate that an informed trader should collect a lot of information. But if the informed trader does collect a lot of information then her presumption of excess profits is unjustified because no manipulation will occur in equilibrium. However, if the informed trader collects only a little information owing to the lack of excess expected profits, then in equilibrium the informed trader will manipulate and will have been better off having collected more information.

Endogenous Liquidity Trade

The amount of liquidity trade in our model is exogenously specified via w. The effect of endogenizing the liquidity trade is uncertain. On the one hand, endogenous noise trade may have a reinforcing effect on manipulative trade. All else equal, the potential for manipulative trade leads to higher expected informed trader profits. Informed trader profits are paid for with liquidity trader losses. Therefore, if liquidity traders are given some degree of control over when or where they trade, they will choose to avoid times or markets when the potential for manipulative trade are high. As shown above, manipulative trading strategies are more likely to be adopted in illiquid markets because illiquid markets are expected to have a higher degree of informational trade transparency. Therefore, it might be the case that low liquidity and manipulative trading strategies are mutually reinforcing.

On the other hand, manipulative trading strategies are more likely when the expected informational advantage of informed traders is small. All else equal, liquidity traders prefer to trade in a market where the degree of information asymmetry is small. Therefore, if we take the ex ante degree of information asymmetry between informed traders and liquidity traders as exogenous, it may be the case that high liquidity trade and manipulation will be coincident in markets with low information asymmetry while low liquidity and no manipulation will be coincident in markets with high information asymmetry.[17]

Multiple Informed Traders

In our model there is a single informed trader. The existence of multiple informed traders would effect the model significantly. Multiple informed traders would mitigate, if not eliminate, manipulative trade due to free-riding issues. Trading against one's information creates a public good (for the other informed traders), but a personal bad. Informed traders may collectively be better off if they could commit to a trading strategy including manipulative trade, but absent a commitment mechanism, each individual trader may find it in her best interest *not* to engage in manipulation.

It's likely that the correlation among the information of different informed traders may play a significant role. If multiple informed traders have heterogenous

[17] See Dow (2004) for a market model with endogenous liquidity trade and multiple equilibria.

information, then it is possible that the informed traders will compete away the common component of their information and then adopt a manipulative trading strategy with respect to the unique component of their information. This intuition is based on the results of Foster and Viswanathan (1996). A more formal treatment of the impact of multiple informed traders is beyond the scope of the current paper and left for future research.

3.3 Conclusion

This paper derives an equilibrium in which an informed trader engages in trade-based manipulation. We show that a manipulative trade strategy can be profitable even in the absence of mandatory disclosure rules or uncertainty about the presence of an informed trader. We show that manipulative profits are indirect. An informed trader who engages in manipulative trade is likely to be no better off than she would be had she traded strictly in the direction of her information. In contrast, an informed trader who does trade strictly in the direction of her information may earn significant excess profits owing to the presence of the manipulative trading strategy.

In and of itself, manipulative trade undermines price efficiency. However, if the excess profits attributable to adoption of a manipulative trading strategy encourage additional information production, the net effect on market efficiency is unclear. In general, actions and policies that make information-based trades more visible and easier to infer encourage the adoption of manipulative trading strategies. The indirect nature of the profits to manipulative trading strategies make manipulation difficult to detect and eradicate. However, the indirect nature of the profits also makes manipulative trading strategies susceptible to free-rider problems in settings with multiple informed traders. As such, concerns about manipulative trade and it's perceived harms may be more relevant to smaller, less liquid markets with fewer sophisticated participants.

3.4 Appendix

3.4.1 Detailed Strategies and Pricing Rules in Proposition 1 and Corollary 1

In the first round of trade, the informed trader's trading strategy is the following mixed strategy:

$$X_1(h;p_0) = \begin{cases} -1 & \text{w.p.} \quad \phi_1^h(p_0) \\ 0 & \text{w.p.} \quad \theta_1^h(p_0) \\ +1 & \text{w.p.} \quad 1-\phi_1^h(p_0)-\theta_1^h(p_0) \end{cases}$$

where

$$\phi_1^h(p_0) = \begin{cases} 0 \text{ for } 0 \le p_0 \le p_0^{C3}, \\ -\left(\frac{1+8\,w+32\,w^2+32\,w^3+48\,w^4+(p_0+2\,p_0\,w)^2\left(1+12\,w^2\right)-2\,p_0\left(1+6\,w+24\,w^2+40\,w^3+48\,w^4\right)}{p_0\left(1+4\,w+16\,w^2+80\,w^3+48\,w^4-p_0\,(1+2\,w)^2\,(1+12\,w^2)\right)}\right) \\ \text{for } p_0^{C3} \le p_0 \le p_0^{C4}, \\ 1-\frac{48w^4+32w^3+48w^2+8w+1}{(12w^2+1)(2w+1)^2}\cdot\frac{1}{p_0}, \text{ else.} \end{cases}$$

$$\theta_1^h(p_0) = \begin{cases} 0 & \text{for} \quad 0 \le p_0 \le p_0^{C1} \\ \frac{8\,w^2-8\,p_0\,w^2-(-1+p_0)^2\,(-1+2\,w)\,(1+2\,w)^2}{8\,p_0\,w^2-(-1+p_0)\,p_0\,(-1+2\,w)\,(1+2\,w)^2} & \text{for} \quad p_0^{C1} \le p_0 \le p_0^{C2} \\ 1-\frac{4w^2+1}{(2w+1)^2}\cdot\frac{1}{p_0} & \text{for} \quad p_0^{C2} \le p_0 \le p_0^{C3} \\ \frac{-8\,w\left(-1-6\,w-12\,w^2-24\,w^3+p_0\,(1+2\,w)^3\right)}{p_0\,(1+2\,w)^2\left(1+4\,w+16\,w^2+80\,w^3+48\,w^4-p_0\,(1+2\,w)^2\,(1+12\,w^2)\right)} & \text{for} \quad p_0^{C3} \le p_0 \le p_0^{C4} \\ \frac{8w}{12w^2+1}\cdot\frac{1}{p_0} & \text{else} \end{cases}$$

and

$$p_0^{C1} = \frac{-1-2\,w-4\,w^2+8\,w^3}{(-1+2\,w)\,(1+2\,w)^2}$$

$$p_0^{C2} = \frac{1+6\,w+4\,w^2+8\,w^3}{(1+2\,w)^3}$$

$$p_0^{C3} = \frac{1 + 8\,w + 32\,w^2 + 32\,w^3 + 48\,w^4}{(1 + 2\,w)^2\ (1 + 12\,w^2)}$$

$$p_0^{C4} = \frac{1 + 6\,w + 32\,w^2 + 144\,w^3 + 112\,w^4 + 96\,w^5}{(1 + 2\,w)^3\ (1 + 12\,w^2)}$$

$X_1(l; p_0)$ is symmetric. The market maker's pricing rule is:

$$P_1(z_1; p_0) = \begin{cases} \frac{\phi_1^h(p_0)\cdot p_0}{\phi_1^h(p_0)\cdot p_0 + [1-\theta_1^h(p_0)-\phi_1^h(p_0)](1-p_0)} & \text{for} \quad z_1 = -w-1 \\ \frac{[\theta_1^h(p_0)+\phi_1^h(p_0)]p_0}{[\theta_1^h(p_0)+\phi_1^h(p_0)]p_0 + [1-\phi_1^h(1-p_0)](1-p_0)} & \text{for} \quad z_1 = -w \\ p_0 & \text{for} \quad -w+1 \leq z_1 \leq w-1 \\ \frac{[1-\phi_1^h(p_0)]p_0}{[1-\phi_1^h(p_0)]p_0 + [\theta_1^h(1-p_0)+\phi_1^h(1-p_0)](1-p_0)} & \text{for} \quad z_1 = w \\ \frac{[1-\theta_1^h(p_0)-\phi_1^h(p_0)]p_0}{[1-\theta_1^h(p_0)-\phi_1^h(p_0)]p_0 + \phi_1^h(1-p_0)\cdot(1-p_0)} & \text{else} \end{cases}$$

In the second round of trade, the informed trader's trading strategy is the following mixed strategy:

$$X_2(h; p_1) = \begin{cases} 0 & \text{w.p.} \quad \theta_2^h(p_1) \\ +1 & \text{w.p.} \quad 1 - \theta_2^h(p_1) \end{cases}$$

where

$$\theta_2^h(p_1) = \begin{cases} 0 & \text{for} \quad 0 \leq p_1 \leq \frac{2w}{2w+1} \\ 1 - \frac{2w}{2w+1} \cdot \frac{1}{p_1} & \text{else} \end{cases}$$

$X_2(l; p_1)$ is symmetric. The market maker's pricing rule is:

$$P_2(z_2; p_1) = \begin{cases} 0 & \text{for} \quad z_2 = -w-1 \\ \frac{\theta_2^h(p_1)\cdot p_1}{(1-p_1)+\theta_2^h(p_1)\cdot p_1} & \text{for} \quad z_2 = -w \\ p_1 & \text{for} \quad -w+1 \leq z_2 \leq w-1 \\ \frac{p_1}{\theta_2^h(1-p_1)\cdot(1-p_1)+p_1} & \text{for} \quad z_2 = w \\ 1 & \text{else} \end{cases}$$

In the third and final round of trade, the informed trader's trading strategy is the following pure strategy:

$$\begin{aligned} X_3(h; p_2) &= 1 \\ X_3(l; p_2) &= -1 \end{aligned}$$

and the market maker's pricing rule is:

$$P_3(z_3; p_2) = \begin{cases} 0 & \text{for} \quad z_3 \leq -w \\ p_2 & \text{for} \quad -w+1 \leq z_3 \leq w-1 \\ 1 & \text{for} \quad z_3 \geq w \end{cases}$$

3.4.2 Proof of Proposition 1

The model is solved by backward induction. The equilibrium is presented and discussed from the perspective of an informed trader with a high signal, $s = h$, without loss of generality. We adopt the following notation. The price in trade round n is p_n. The informed trader's order flow in round n is x_n. The noise trader order flow in round n is u_n. The aggregate order flow is $z_n = x_n + u_n$. The informed trader trade strategy in round n, is:

$$X_n(h; p_{n-1}) = \begin{cases} -1 & \text{w.p.} \quad \phi_n^h(p_{n-1}) \\ 0 & \text{w.p.} \quad \theta_n^h(p_{n-1}) \\ +1 & \text{w.p.} \quad 1 - \phi_n^h(p_{n-1}) - \theta_1^h(p_{n-1}) \end{cases}$$

Period Three

In the last round of trade before the liquidation value of the risky asset is announced, the informed trader submits his order $x_3 \in \{-1, 0, +1\}$. There are no successive period profits to be considered so the informed trader maximizes expected profit in the current trading round. He is free to choose a mixed strategy over the feasible orders, but trading with his information ($x_3 = +1$) is a (weakly) dominant strategy. The terminal period payoffs $\pi|(p_2, p_1, p_0, s)$ for each pure strategy $x_3 \in \{-1, 0, +1\}$ are given by $p_2 - 1$, 0, and $1 - p_2$ respectively. Since $0 \leq p_2 \leq 1$, it is trivial to see that $x_3 = +1$ weakly dominates all other strategies. The final round expected profits equal $\frac{2w-1}{2w+1}(1-p_2)$; there are two possible order flows (out of the 2w+1 order flows possible when $x_3 = 1$) in which the insider's signal is revealed, $z_3 = +w$ amd $z_3 = +w + 1$. In these states, $p_3 = 1$ and the informed trader earns zero profit.

Period Two

Prices

During the second period, the market maker sets prices equal to the expected value of the risky asset, taking as given the strategy of the informed trader. Suppose that observed aggregate order flow were $z_2 = -w - 1$. Since the minimum value of the pure noise component is $-w$, the market maker knows that $x_2 = -1$ has been submitted. Only the underlying signal $s \in \{l, h\}$ of the insider is uncertain. Either an insider with $s = h$ (probability $= p_1$) submitted $x_2 = -1$ which occurs with conditional probability $\phi_2(p_1)$, or an insider with $s = l$ (probability $= 1 - p_1$) submitted $x_2 = -1$ which occurs with conditional probability $1 - \phi_2(1 - p_1) - \theta_2(1 - p_1)$. Applying Bayes Rule, the expected value of the asset given $z_2 = -w - 1$ is given by:

$$p_2^{++} = p_2|\{z_2 = -w - 1\} = \frac{p_1\phi_2(p_1)}{p_1\phi_2(p_1) + (1 - p_1)[1 - \theta_2(1 - p_1) - \phi_2(1 - p_1)]}$$

All other prices are identically formed, and may be interpreted as the probability that $s = h$ given z_2. The remainder of the prices are given below:

$$\begin{aligned}
p_2^{+} &= p_2|\{z_2 = -w\} = \frac{p_1[\theta_2(p_1) + \phi_2(p_1)]}{p_1[\theta_2(p_1) + \phi_2(p_1)] + (1 - p_1)[1 - \phi_2(1 - p_1)]} \\
p_2^{0} &= p_2|\{-w + 1 \leq z_2 \leq +w - 1\} = p_1 \\
p_2^{-} &= p_2|\{z_2 = +w\} = \frac{p_1[1 - \phi_2(p_1)]}{p_1[1 - \phi_2(p_1)] + (1 - p_1)[\theta_2(1 - p_1) + \phi_2(1 - p_1)]} \\
p_2^{--} &= p_2|\{z_2 = +w + 1\} = \frac{p_1[1 - \phi_2(p_1) - \theta_2(p_1)]}{p_1[1 - \phi_2(p_1) - \theta_2(p_1)] + (1 - p_1)\phi_2(1 - p_1)}
\end{aligned}$$

Expected Profits

The insider's expected profits include those from the second and third rounds of trade. Consider each the strategies $x_2 \in \{+1, 0, -1\}$ in turn. The expected profits from submitting $x_2 = +1$ allow for $-w + 1 \leq z_2 \leq +w + 1$, which eliminate two of the five possible prices. If $u_2 \leq +w-2$ (which occurs with probability $\frac{2w-1}{2w+1}$), then $p_2^0 = p_1$ as indicated above. Likewise, if $u_2 = +w-1$ (which occurs with probability $\frac{1}{2w+1}$), $p_2^+ = p_2$. Finally, p_2^{++} is possible if $u_2 = +w$. Period two expected profits, conditional on $x_2 = +1$, written as a function of possible second period prices p_2^0, p_2^+, and p_2^{++} are:

$$\mathrm{E}[\Pi_2|x_2 = +1] = \tfrac{2w-1}{2w+1}\left[(1-p_2^0) + \tfrac{2w-1}{2w+1}(1-p_2^0)\right] + \\ \cdots \tfrac{1}{2w+1}\left[(1-p_2^+) + \tfrac{2w-1}{2w+1}(1-p_2^+)\right] + \tfrac{1}{2w+1}\left[(1-p_2^{++}) + \tfrac{2w-1}{2w+1}(1-p_2^{++})\right].$$

A similar expression results for $x_2 = 0$. In this case, the most extreme prices (p_2^{++} and p_2^{--}) are precluded:

$$\mathrm{E}[\Pi_2|x_2 = 0] = \\ \tfrac{2w-1}{2w+1}\left[0 + \tfrac{2w-1}{2w+1}(1-p_2^0)\right] + \cdots \tfrac{1}{2w+1}\left[0 + \tfrac{2w-1}{2w+1}(1-p_2^+)\right] + \tfrac{1}{2w+1}\left[0 + \tfrac{2w-1}{2w+1}(1-p_2^-)\right].$$

Finally, expected profits given $x_2 = -1$ are provided for an insider with signal $s = h$. Now the two highest price regions are impossible, resulting in the following:

$$\mathrm{E}[\Pi_2|x_2 = -1] = \tfrac{2w-1}{2w+1}\left[(p_2^0 - 1) + \tfrac{2w-1}{2w+1}(1-p_2^0)\right] + \\ \cdots \tfrac{1}{2w+1}\left[(p_2^- - 1) + \tfrac{2w-1}{2w+1}(1-p_2^-)\right] + \tfrac{1}{2w+1}\left[(p_2^{--} - 1) + \tfrac{2w-1}{2w+1}(1-p_2^{--})\right]$$

Characterization of Optimal Trading Strategy for Two-Period Trading Game

We conjecture the two-period equilibrium strategy given in Proposition 1, and verify that no profitable deviations exist. For the entire price region, $x_2 = +1$ is submitted with positive probability; the profits from this strategy, therefore, represent the relevant comparison for any potentially profitable deviation. We begin by demonstrating that $x_2 = -1$ is strictly dominated over the possible price range, and can be eliminated from consideration.

Under the conjectured equilibrium, insiders never trade against their information. That is $\phi_2(p_1) = 0$ and $\phi_2(1-p_1) = 0$. There are still five possible prices, but they are greatly simplified. In particular, both price extremes are now fully revealing, i.e. $p_2^{++} = 1$ and $p_2^{--} = 0$. Under the market maker's belief that insiders never trade against their information in the second period, the following condition necessarily holds:

$$\frac{2w-1}{2w+1}\left[(1-p_1)+\frac{2w-1}{2w-1}(1-p_1)\right]+\frac{1}{2w+1}\left[\frac{(1-p_1)\theta(1-p_1)}{(1-p_1)\theta(1-p_1)+p_1}+\frac{2w-1}{2w+1}\frac{(1-p_1)\theta(1-p_1)}{(1-p_1)\theta(1-p_1)+p_1}\right]\geq$$
$$\frac{2w-1}{2w+1}\left[(p_1-1)+\frac{2w-1}{2w+1}(1-p_1)\right]+\frac{1}{2w+1}\left[\left(\frac{p_1-1}{(1-p_1)+p_1\theta(p_1)}\right)+\frac{2w-1}{2w+1}\left(\frac{1-p_1}{(1-p_1)+p_1\theta(p_1)}\right)\right]+$$
$$\frac{1}{2w+1}\left[(0-1)+\frac{2w-1}{2w+1}(1-0)\right]$$

The left-hand side, representing the insider's expected two-period profits from trading with his information, is weakly positive for the entire set of possible prices $p \in [0,1]$. The expected profits from trading against one's information are always weakly less than zero for the two-period model, which can never exceed the profits from trading with one's information. The right hand side simplifies to the following, whose value is bounded from above at zero:

$$\frac{2w-1}{2w+1}\left[\frac{-2}{2w+1}(1-p_1)\right]+\frac{1}{2w+1}\left[\frac{-2}{2w+1}\left(\frac{1-p_1}{(1-p_1)+p_1\theta(p_1)}\right)\right]+\frac{1}{2w+1}\left[\frac{-2}{2w+1}\right]$$

By iterated deletion of weakly dominated strategies, we eliminate $x_2 = -1$ from further consideration, and restrict our attention to the mixed strategy space spanned by $x_2 \in \{0, +1\}$.

To show that $x_2 = +1$ is strictly dominant for $p_1 \leq \frac{2w}{2w+1}$, we set the expected profits from submitting $x_2 = 0$ and $x_2 = +1$ respectively, simplify, and equate.

$$\frac{(2w-1)(1-p_1)}{(2w+1)^2}\left[\frac{1}{(1-p-1)+p_1\theta(p_1)}+(2w-1)+\frac{\theta(1-p_1)}{(1-p_1)\theta(1-p_1)+p_1}\right]=$$
$$\frac{4w(1-p_1)}{(2w+1)^2}\left[2w-1+\frac{\theta(1-p_1)}{(1-p_1)\theta(1-p_1)+p_1}\right]$$

Taking advantage of the symmetric structure of $\theta(p)$, we note that $p_1 \leq \frac{2w}{2w+1} \Rightarrow \theta(p_1) = 0$ necessarily implies that $p_1 \leq \frac{1}{2w+1} \Rightarrow \theta(1-p_1) = 0$. Making this substitution and solving for $\theta(p_1)$ easily results in the expected profits for the two-period game:

$$\mathrm{E}[\Pi_2] = \begin{cases} \frac{4w(2w-1)}{(2w+1)^2}(1-p_1), & \text{if } p_1 \geq \frac{1}{2w+1} \\ \frac{8w^2}{(2w+1)^2}(1-2p_1), & \text{if } p_1 < \frac{1}{2w+1} \end{cases}$$

Thus, in the penultimate round of trade, the informed trader may, depending on the price, choose to not trade rather than trade with his information, but he will never trade against his information.

Period One

We show that the informed insider's strategy is optimal given the market maker's pricing rule and that the pricing rule sets price equal to the expected value of the asset conditional on the aggregate order flow and trade strategy of the informed trader.

Prices

The expressions for prices are identical to those presented in the last section. We present only p_3^{++}, noting that only the time subscripts have been advanced by one position:

$$p_1^{++} = p_1|\{z_1 = -w-1\} = \frac{p_0\phi_1(p_0)}{p_0\phi_1(p_0) + (1-p_0)[1-\theta_1(1-p_0) - \phi_1(1-p_0)]}$$

All other prices are formed identically.

Trading Strategy and Expected Profits

Period one and period two prices are functions of the probability of manipulation (or sitting out), and expected profits, of course, depend on these prices. The functional form of the informed trader mixing probabilities change over the price region $p \in [0,1]$. Consequently, when evaluating the expected payoffs to each strategy, we must consider each region independently. We begin by describing the expected profits conditional on each pure strategy, $\mathrm{E}[\Pi_1|x_1 = +1]$, $\mathrm{E}[\Pi_1|x_1 = 0]$, and $\mathrm{E}[\Pi_1|x_1 = -1]$, and apply these payoffs to each region. The price regions correspond to different mixing probabilities, although informed traders with different signals manipulate at opposite ends of the price spectrum.

$$\mathrm{E}[\Pi_1|x_1 = +1] =$$
$$\tfrac{2w-1}{2w+1}\left[(1-p_0) + \Pi_2(p_0)\right] + \tfrac{1}{2w+1}\left[(1-p_1^+) + \Pi_2(p_1^+)\right] + \tfrac{1}{2w+1}\left[(1-p_1^{++}) + \Pi_2(p_1^{++})\right],$$

$$\mathrm{E}[\Pi_1|x_1 = 0] = \tfrac{2w-1}{2w+1}\left[(0) + \Pi_2(p_0)\right] + \tfrac{1}{2w+1}\left[(0) + \Pi_2(p_1^+)\right] + \tfrac{1}{2w+1}\left[(0) + \Pi_2(p_1^-)\right],$$

$$\mathrm{E}[\Pi_1|x_1 = -1] =$$
$$\tfrac{2w-1}{2w+1}\left[(p_0 - 1) + \Pi_2(p_0)\right] + \tfrac{1}{2w+1}\left[(p_1^- - 1) + \Pi_2(p_1^-)\right] + \tfrac{1}{2w+1}\left[(p_1^{--} - 1) + \Pi_1(p_0^{--})\right].$$

Region 1: $\frac{1+8\,w+32\,w^2+32\,w^3+48\,w^4}{(1+2\,w)^2\,(1+12\,w^2)} \le p_0 \le 1$

Given the proposed manipulation strategies in Proposition 1, and the pricing schedule above, the expected profits to each pure strategy are given, after substitution and simplification, as:

$$\mathrm{E}[\Pi_1|x_1=+1]=\mathrm{E}[\Pi_1|x_1=0]=\mathrm{E}[\Pi_1|x_1=-1]=\frac{(1-p_0)\,(-1+2\,w)\left(1+12\,w^2\right)}{(1+2\,w)^3}$$

Facing the same pricing rule, any mixed strategy $\Lambda\in\mathbb{R}_3^+\equiv\{\gamma_1,\rho_1,1-\gamma_1-\rho_1;0\le\gamma_1=Pr(x_1=1)\le 1$ and $0\le\rho_1=Pr(x_1=0)\le 1\}$ over the pure strategy space will also yield the identical payoff given above. Since the informed insider's manipulation schedule $\{\phi_1(p_0),\theta_1(p_0),1-\phi_1(p_0)-\theta_1(p_0)\}\in\Lambda$, then a rational expectations equilibrium exists at the proposed equilibrium strategy. Thus, the insider will manipulate with the schedule given by Proposition 1, and the market maker will set a price that the insider anticipates. Note that this pricing region encompasses *two* regions where all three pure strategies are utilized with positive probability.

Region 2: $\frac{1+6\,w+4\,w^2+8\,w^3}{(1+2\,w)^3}\le p_0\le\frac{1+8\,w+32\,w^2+32\,w^3+48\,w^4}{(1+2\,w)^2\,(1+12\,w^2)}$

Given the proposed manipulation strategies in Proposition 1, and the pricing schedule above, the expected profits to each pure strategy are given, after substitution and simplification, as:

$$\mathrm{E}[\Pi_1|x_1=+1]=\mathrm{E}[\Pi_1|x_1=0]=\frac{(1-p_0)\,(-1+2\,w)\left(1+12\,w^2\right)}{(1+2\,w)^3}$$

$$\mathrm{E}[\Pi_1|x_1=-1]=\frac{-1+p_0+4\,(-3+2\,p_0)\,w+8\,(-3+p_0)\,w^2+16\,(-5+6\,p_0)\,w^3-48\,(-1+p_0)\,w^4}{4\,w\,(1+2\,w)^3}$$

After some algebra, one can show that for

$$p_0<\frac{(1-p_0)\,(-1+2\,w)\left(1+12\,w^2\right)}{(1+2\,w)^3}$$

it is the case that:

$$\mathrm{E}[\Pi_1|x_1=+1]=\mathrm{E}[\Pi_1|x_1=0]<\mathrm{E}[\Pi_1|x_1=-1].$$

Since the region of interest excludes this range of prices, $x_1=-1$ is strictly dominated in this region, and cannot be part of any equilibrium strategy.

For the two remaining undominated pure strategies, their identical payoffs allow us to argue with the same reasoning applied to region 1. Since the market maker anticipates both $x_1=+1$ and $x_1=0$ to be played with positive probability in region 2, the proposed equilibrium strategy represents a rational expectations equilibrium in region 2.

Region 3: $\frac{-1-2w-4w^2+8w^3}{(-1+2w)(1+2w)^2} \leq p_0 \leq \frac{1+6w+4w^2+8w^3}{(1+2w)^3}$
In this region:

$$\mathrm{E}[\Pi_1|x_1=+1] = \mathrm{E}[\Pi_1|x_1=0] = \frac{(1-p_0)(-1+2w)\left(1+12w^2\right)}{(1+2w)^3}$$

$$\mathrm{E}[\Pi_1|x_1=-1] =$$

$$-\frac{-1-6w+16w^2+48w^3+272w^4-224w^5+p_0\left(1+6w+8w^2+48w^3-304w^4+224w^5\right)}{16w^2(1+2w)^3}$$

For $p_0 > \frac{-1-6w+80w^3+80w^4+160w^5}{(1+2w)^2(-1-2w-12w^2+40w^3)}$ one can show that $\mathrm{E}[\Pi_1|x_1=-1] > \mathrm{E}[\Pi_1|x_1=+1]$. However, for $w>0|w\in\mathbb{R}$:

$$\frac{-1-6w+80w^3+80w^4+160w^5}{(1+2w)^2(-1-2w-12w^2+40w^3)} > \frac{1+6w+4w^2+8w^3}{(1+2w)^3},$$

which is strictly outside region 3. Therefore, for the prices within region 3, $\mathrm{E}[\Pi_1|x=-1]$ is strictly dominated, and cannot be part of any equilibrium strategy. For the two remaining undominated pure strategies, their identical payoffs allow us to argue with the same reasoning applied to region 1 and 2. Since the market maker anticipates both $x_1=+1$ $x_1=0$ with positive probability in region 3, the proposed equilibrium strategy represents a rational expectations equilibrium in region 3.

Region 4: $\frac{8w^2}{(-1+2w)(1+2w)^2} \leq p_0 \leq \frac{-1-2w-4w^2+8w^3}{(-1+2w)(1+2w)^2}$
For this and all remaining regions, the claim is that both manipulation ($x_1=-1$) and sitting out ($x_1=0$) are strictly dominated for an insider facing prices governed by the proposed equilibrium strategies in Proposition 1. In region 4:

$$\mathrm{E}[\Pi_1|x_1=+1] = -\frac{(-1+p_0)(-1+2w)\left(1+12w^2\right)}{(1+2w)^3}$$

$$\mathrm{E}[\Pi_1|x_1=0] = \frac{-4w\left(-1+p_0(1-2w)^2+2w-4w^2\right)}{(1+2w)^3}$$

$$\mathrm{E}[\Pi_1|x_1=-1] = -\frac{1+2w+12w^2-8w^3+p_0\left(1+6w-20w^2+8w^3\right)}{(1+2w)^3}$$

It follows that:

$$\mathrm{E}[\Pi_1|x=-1] > E[\Pi_1|x=+1] \Longleftrightarrow p_0 > \frac{2\left(w+4w^3\right)}{(-1+2w)(1+2w)^2},$$

which for any $w\in\mathbb{R}$ is impossible within region 4. Therefore, $x_1=-1$ is strictly dominated by $x_1=+1$ in this region. Also

$$\mathrm{E}[\Pi_1|x=0] > \mathrm{E}[\Pi_1|x=+1] \Longleftrightarrow p_0 > \frac{-1-2w-4w^2+8w^3}{(-1+2w)(1+2w)^2},$$

which by inspection is revealed as the upper border on region 4. Therefore, $x_1 = 0$ is strictly dominated by $x_1 = +1$. Only $x_1 = +1$ survives iterated deletion of strictly dominated strategies.

Region 5: $\frac{8\,w^2}{(1+2\,w)^3} \le p_0 \le \frac{8\,w^2}{(-1+2\,w)\,(1+2\,w)^2}$

In this region:

$$\mathrm{E}[\Pi_1|x_1 = +1] = -\frac{\left(1+12\,w^2\right)\left[8\,(1-4\,w)\,w^2+p_0\left(-1-2\,w-12\,w^2+40\,w^3\right)\right]}{16\,w^2\,(1+2\,w)^3}$$
$$\mathrm{E}[\Pi_1|x_1 = 0] = -\frac{8\,w^2\left(3+8\,w+20\,w^2-32\,w^3\right)+p_0\left(1+10\,w+8\,w^2+16\,w^3-304\,w^4+288\,w^5\right)}{16\,w^2\,(1+2\,w)^3}$$
$$\mathrm{E}[\Pi_1|x_1 = -1] = -\frac{1+2\,w+12\,w^2-8\,w^3+p_0\left(1+6\,w-20\,w^2+8\,w^3\right)}{(1+2\,w)^3}$$

It follows that $\mathrm{E}[\Pi_1|x_1 = 0] > \mathrm{E}[\Pi_1|x_1 = +1] \iff p_0 > \frac{8\,w^2\left(1+6\,w+4\,w^2+8\,w^3\right)}{-1-6\,w-16\,w^2+80\,w^4+96\,w^5}$. However, for $w > 1$, $\frac{8\,w^2\left(1+6\,w+4\,w^2+8\,w^3\right)}{-1-6\,w-16\,w^2+80\,w^4+96\,w^5} > \frac{8\,w^2}{(-1+2\,w)\,(1+2\,w)^2}$, which is the upper bound on region 5. Thus for $p_0 \le \frac{8\,w^2}{(-1+2\,w)\,(1+2\,w)^2}$, $x_1 = 0$ is strictly dominated by $x_1 = +1$.

Similarly, $\mathrm{E}[\Pi_1|x_1 = -1] > \mathrm{E}[\Pi_1|x_1 = +1] \iff p_0 > \frac{4\,w\left(1+2\,w+8\,w^2\right)}{1-6\,w+12\,w^2+56\,w^3}$, which for all $w > 2$, is strictly greater than the upper bound of region 5.

Region 6: $\frac{1}{1+2\,w} \le p_0 \le \frac{8\,w^2}{(1+2\,w)^3}$

In this region:

$$\mathrm{E}[\Pi_1|x_1 = +1] = -\frac{\left(1+12\,w^2\right)\left(p_0-8\,w^2+12\,p_0\,w^2\right)}{4\,w\,(1+2\,w)^3}$$
$$\mathrm{E}[\Pi_1|x_1 = 0] = \frac{8\,w\left(-1-4\,w-4\,w^2+8\,w^3\right)+p_0\left(1+12\,w+16\,w^2+80\,w^3-80\,w^4\right)}{4\,w\,(1+2\,w)^3}$$
$$\mathrm{E}[\Pi_1|x_1 = -1] = -\frac{1+2\,w+12\,w^2-8\,w^3+p_0\left(1+6\,w-20\,w^2+8\,w^3\right)}{(1+2\,w)^3}$$

$\mathrm{E}[\Pi_1|x_1 = 0] > \mathrm{E}[\Pi_1|x_1 = +1] \iff p_0 > \frac{4\,w\left(1+5\,w+4\,w^2+4\,w^3\right)}{(1+2\,w)^2\,(1+2\,w+8\,w^2)}$. However, for $w > 2$, $\frac{4\,w\left(1+5\,w+4\,w^2+4\,w^3\right)}{(1+2\,w)^2\,(1+2\,w+8\,w^2)}$ is strictly greater than the upper bound for region 6, $p_0 = \frac{8\,w^2}{(1+2\,w)^3}$. Therefore, $x_1 = 0$ is strictly dominated in this region, and cannot be part of any equilibrium strategy.

$\mathrm{E}[\Pi_1|x_1 = -1] > \mathrm{E}[\Pi_1|x_1 = +1] \iff p_0 > \frac{4\,w\left(1+2\,w+8\,w^2\right)}{1-6\,w+12\,w^2+56\,w^3}$. However, for $w > 0$, $\frac{4\,w\left(1+2\,w+8\,w^2\right)}{1-6\,w+12\,w^2+56\,w^3}$ is strictly greater than the upper bound for region 6. Therefore, $x_1 = -1$ is strictly dominated in this region, and cannot be part of any equilibrium strategy.

Region 7: $\frac{4\,w\left(-1-4\,w+4\,w^2\right)}{(1+2\,w)^2\,(1+12\,w^2)} \le p_0 \le \frac{1}{1+2\,w}$

In this region:

$$E[\Pi_1|x_1=+1] = -\frac{p_0+8\,(1+p)\,w^2-32\,w^3+16\,(-6+13\,p)\,w^4}{4\,w\,(1+2\,w)^3}$$
$$E[\Pi_1|x_1=0] = \frac{8\,w\left(-1-6\,w+8\,w^3\right)+p_0\left(1+12\,w+32\,w^2+80\,w^3-144\,w^4\right)}{4\,w\,(1+2\,w)^3}$$
$$E[\Pi_1|x_1=-1] = -\frac{1+6\,w+4\,w^2-8\,w^3+p_0\,(1-2\,w)^2\,(1+6\,w)}{(1+2\,w)^3}$$

$E[\Pi_1|x_1=0] > E[\Pi_1|x_1=+1] \iff p_0 > \frac{4\,w\left(1+5\,w+4\,w^2+4\,w^3\right)}{(1+2\,w)^2\,(1+2\,w+8\,w^2)}$. However, for $w>0$, $\frac{4\,w\left(1+5\,w+4\,w^2+4\,w^3\right)}{(1+2\,w)^2\,(1+2\,w+8\,w^2)} > \frac{1}{1+2\,w}$, indicating that $x_1=0$ is strictly dominated by $x_1=+1$ in region 7.
$E[\Pi_1|x_1=-1] > E[\Pi_1|x_1=+1] \iff p_0 > \frac{4\,w\left(1+2\,w+8\,w^2\right)}{1-6\,w+12\,w^2+56\,w^3}$. However, for $w>0$, $\frac{4\,w\left(1+2\,w+8\,w^2\right)}{1-6\,w+12\,w^2+56\,w^3} > \frac{1}{1+2\,w}$, indicating that $x_1=-1$ is strictly dominated by $x_1=+1$ in region 7.
Region 8: $\frac{8\,w^2\left(-1-8\,w+4\,w^2\right)}{(1+2\,w)^3\,(1+12\,w^2)} \le p_0 \frac{4\,w\left(-1-4\,w+4\,w^2\right)}{(1+2\,w)^2\,(1+12\,w^2)}$
In this region:

$$E[\Pi_1|x_1=+1] = -\frac{1+2\,w\left(1+4\,w+4\left(p_0+2\,p\,w+4\,(4+p)\,w^2-2\,(3+4\,p)\,w^3+12\,(-3+8\,p_0)\,w^4\right)\right)}{(-1+2\,w)\,(1+2\,w)^3\,(1+6\,w)}$$
$$E[\Pi_1|x_1=0] = \frac{8\,w\left(-1-6\,w+8\,w^3\right)+p_0\left(1+12\,w+32\,w^2+80\,w^3-144\,w^4\right)}{4\,w\,(1+2\,w)^3}$$
$$E[\Pi_1|x_1=-1] = -\frac{1+6\,w+4\,w^2-8\,w^3+p_0\,(1-2\,w)^2\,(1+6\,w)}{(1+2\,w)^3}$$

$E[\Pi_1|x_1=0] > E[\Pi_1|x_1=+1] \iff p_0 > \frac{4\,w\left(-3-16\,w+32\,w^3+48\,w^4\right)}{-1-14\,w-8\,w^2+16\,w^3+304\,w^4+672\,w^5}$. However, for $w>1$, $\frac{4\,w\left(-3-16\,w+32\,w^3+48\,w^4\right)}{-1-14\,w-8\,w^2+16\,w^3+304\,w^4+672\,w^5}$ is strictly greater than the upper bound for region 8. Therefore, $x_1=0$ is strictly dominated in this region.
$E[\Pi_1|x_1=-1] > E[\Pi_1|x_1=+1] \iff p_0 > \frac{2\left(-1-6\,w-12\,w^2-32\,w^3+64\,w^4+96\,w^5\right)}{(1+2\,w)^2\,(1+10\,w-52\,w^2+120\,w^3)}$.
However, for $w>1$, $\frac{2\left(-1-6\,w-12\,w^2-32\,w^3+64\,w^4+96\,w^5\right)}{(1+2\,w)^2\,(1+10\,w-52\,w^2+120\,w^3)}$ is strictly greater than the upper bound for region 8. Therefore, $x_1=-1$ is strictly dominated by $x_1=+1$ in this region.
Region 9: $0 \le p_0 \le \frac{8\,w^2\left(-1-8\,w+4\,w^2\right)}{(1+2\,w)^3\,(1+12\,w^2)}$
In this region:

$$E[\Pi_1|x_1=+1] = -\frac{1+6\,w+192\,w^3+112\,w^4-96\,w^5+p_0\,(1-2\,w)^2\left(-1+2\,w+20\,w^2+88\,w^3\right)}{(1+2\,w)^3\,(-1-8\,w+4\,w^2)}$$
$$E[\Pi_1|x_1=0] = \frac{8\,w\left(-1-6\,w+8\,w^3\right)+p_0\left(1+12\,w+32\,w^2+80\,w^3-144\,w^4\right)}{4\,w\,(1+2\,w)^3}$$
$$E[\Pi_1|x_1=-1] = -\frac{1+6\,w+4\,w^2-8\,w^3+p_0\,(1-2\,w)^2\,(1+6\,w)}{(1+2\,w)^3}$$

$\mathrm{E}[\Pi_1|x_1 = 0] > \mathrm{E}[\Pi_1|x_1 = +1] \iff p_0 > \frac{4\,w\left(-3-34\,w-88\,w^2-128\,w^3+16\,w^4+32\,w^5\right)}{(1+2\,w)^2\left(-1-20\,w-16\,w^2-112\,w^3+208\,w^4\right)}$.
However, for $w > 3$, this condition cannot be satisfied within the bounds of the region. Therefore, $x_1 = -1$ is strictly dominated by $x_1 = +1$ for region 9.
$\mathrm{E}[\Pi_1|x_1 = -1] > \mathrm{E}[\Pi_1|x_1 = +1] \iff p_0 > \frac{-\left(1+10\,w+24\,w^2+96\,w^3+16\,w^4-32\,w^5\right)}{8\,w\left(1-4\,w^2\right)^2}$.
However, for $w > 2$, this condition cannot be satisfied within the bounds of the region. Therefore, $x_1 = -1$ is strictly dominated by $x_1 = +1$ for region 9.

Q.E.D.

This completes the proof of the equilibrium strategies proposed in Proposition 1.

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