Do Overconfident Insiders Always Overreact?

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Abstract

Regulation requires corporate insiders to disclose their trades after the trading is completed. We study the impact of trade disclosure rule on the dynamic trading behavior of overconfident corporate insiders. We show that overconfident insiders underreact to their private information in trading prior to the disclosure: the higher the degree of insider overconfidence, the lower the insider's trading volume. When disclosure requirement is ineffective in the final round of trading, insiders overreact only if their overconfidence degree exceeds a threshold value. The finding is in sharp contrast to the conventional wisdom that overconfidence always breeds overreaction.

Keywords: Overconfidence, Insider Trading, Trade Disclosure, Dissimulation Strategy

JEL classification: D03, G12, G14, G18

1 Introduction

Investors and managers are prone to be overconfident. They tend to overestimate the precision of their private information or underestimate the risk of assets, as a result, they overreact to their private information. In the realm of portfolio choice and asset pricing, economists have proposed theories based on this observation that help to explain the excessive trading and price volatility, return momentum and reversal, and asset bubbles in security markets. In particular, a quite consistent finding is that more overconfident investors trade more aggressively. In the arena of corporate finance, companies with overconfident executives have been shown to overreact in investments and mergers and acquisitions.[1] More significantly, overconfidence and overreaction are typically accompanied by undesirable inferior performance.[2]

Do overconfident investors and managers always overreact to their own private information in the form of aggressive trading?[3] Usually a negative answer is expected for such a strong question, yet to the best of our knowledge, the existing literature seems to deem overconfidence and overreaction as two sides of one coin. Another quite natural suspicion is that the constructed counterexample might be too trivial to deserve serious attention. In this paper we show that a particular group of investors, namely, corporate insiders, who are subject to the public disclosure requirements after the trade is completed, tend to underreact to their private information in trading prior to the mandatory disclosure. Given the paramount role of public disclosure requirements in the regulation of insider trading, the circumstance is sufficiently substantial to warrant a formal investigation.

Corporate insiders generally know more about the prospects of their companies than other market participants. The profitability of insider trading has been vastly documented since Jaffe (1974). It is widely believed that the most potent weapon against abuse of insider information is full and prompt publicity. Conventional wisdom suggests truthful trade disclosure can help reduce information asymmetry between insiders and average investors, provide a more level playing field among market participants, and ultimately increase market liquidity and efficiency, which lends support to the enactment

[1]Overconfidence has also been offered as a potential explanation for wars, strikes, litigations, entrepreneurial failures, etc.

[2]The literature shows that overconfidence has positive value along some dimensions such as counteracting risk aversion, inducing entrepreneurship, allowing firms to make credible threats or commitments, and attracting similarly-minded employees.

[3]The literature finds that people tend to underestimate the precision of public information and the knowledge and ability of others. Therefore people may underreact to public information or advice from others.

of mandatory trade disclosure rule in many countries. In the pre-Sarbanes-Oxley era of the United States, Section 16(a), called the trade disclosure rule, of the Securities and Exchange Act of 1934 requires the insiders of a firm to report any equity transactions they conduct to the SEC within 10 days after the end of the month in which the transactions occurred. The Sarbanes Oxley Act establishes more stringent rule by requiring insiders to report their trades not later than two business days following the transaction. Despite the positive role of the regulation, economists debate on the effectiveness of the trade disclosure rule. Fishman and Hagerty (1995) and John and Narayanan (1997) analyze an insider's manipulation strategy so that the trade disclosure may lead to mispricing from which the insider can increase trading profits. In contrast, Huddart, Hughes, and Levine (2001) study an insider's strategic use of information by adding a random noise in trading in order to prevent the disclosure from fully revealing her private information. Importantly, they show such a dissimulation strategy does not improve the insider's profits, therefore the regulation is beneficial to the disadvantaged investors.

The ideas that corporate executives are largely overconfident and overconfidence breeds overreaction date back to the hubris and optimism hypotheses of Roll (1986) and Heaton (2002) respectively. Malmendier and Tate (2005, 2008) creatively construct indirect proxies of managerial optimism from CEOs' trading behavior of stock options and their coverage in business media. They present strong evidence that companies with overconfident CEOs overinvest and engage in more mergers and acquisitions, especially when they have plenty of internal funds. Ben-David, Graham and Harvey (2007, 2010) collect direct measure of managerial overconfidence by asking CFOs to forecast the short- and long-term distributions of stock market returns. They find that CFOs are miscalibrated and their companies are positively correlated with overinvestment.

The literature is yet to address how overconfident corporate insiders use private information to trade their own company stocks when the public disclosure requirement is in place. We follow the modeling of overconfidence in Wang (1998) and provide an answer in light of Huddart, Hughes, and Levine (2001). Similar to the existing work, we consider a two-period stock trading model in which an overconfident insider has to disclose her trade to market makers after the first period. After the trading in the second period the insider liquidate stock holdings. As a result, in order to maintain information superiority and diminish market makers' ability to draw inference from disclosure, the insider's order flow in the first period consists of an information-based component for making profit and a random component for hiding information. In the second period, insiders do not have to worry about the effect of trade disclosure on future expected profits, thus the dissimulation motive disappears and the insider trades on information only. We show that overconfident insiders underreact to their private information in trading prior to the disclosure: the higher the degree of insider overconfidence, the lower the insider's trading volume; when disclosure requirement is ineffective in the final round of trading, insiders overreact only if their overconfidence degree exceeds a threshold value.

To see the economics intuition, note that the overconfident insiders face a dilemma in trade choice. If they trade more aggressively in the early round, the market makers will adjust the price more intensely so that the insiders face a worse condition of trade in the second period. In order to receive the liquidation value of the stock, they have to pay a higher price in the second period. Therefore the first period high profits is partially offset by the second period low profits. On the other hand, if they do the opposite, the second period high profits may more than compensate for the first period low profits. To strike a balance, the insiders realize that the optimal choice is to equalize the profits across periods. Consequently, the overconfident insiders choose to underreact to their information in the first period. The same argument applies to the underconfident insiders; They trade more aggressively in the first period so that the accumulated stock holding will be more valuable in the second period.

The rest of the paper is structured as follows. Section 2 provides brief review on the effect of overconfidence in financial markets and the impact of trade disclosure requirement on trading and asset pricing. Section 3 develops two-period trading models with and without the public disclosure rule and analyzes whether overconfidence leads one insider to trade more or less in exploiting her private information. Section 4 studies several extensions of the benchmark model to see if the main results are robust or to what extent they will be modified. Section 5 concludes with future research plans. All the proofs are presented in the Appendix.

2 Literature Review

Inspired by the experimental findings from cognitive psychology research,[4] an extensive finance literature on the theme of overconfidence has been built in the past two decades. Benos (1998), Wang (1998), Odean (1998), Gervais and Odean (2001), among others, show that investors' overconfidence in private information contributes to aggressive trading, enormous price volatility and market liquidity, and sub-par performance. They also find that overconfident insiders improve price quality and market efficiency but overconfident

[4] Odean (1998), Moore and Healy (2008), Glaser and Weber (2010) provide excellent surveys.

price takers worsen them. More recently, Cao and Ou-Yang (2009) show that high trading volume and price volatility can result from investors' differences of opinion, generated from optimism and overconfidence, of public information. Scheinkman and Xiong (2003) demonstrate that investor overconfidence in conjunction with short-sale constraints can generate speculative bubbles which are accompanied by large trading volume and high price volatility. Odean (1999) find discount brokerage investors trade too much and on average their returns are reduced through trading. Using indirect measures of overconfidence such as gender and past success, Barber and Odean (2001, 2002) report empirical evidence that more overconfident investors trade more intensely but suffer more in return performance. Grinblatt and Keloharju (2009) employ mandatory psychological profiles of all Finnish males to construct direct measure of overconfidence, and document that overconfident investors trade more frequently.

The excessive trading resulted from overconfidence in turn leads to return autocorrelation. De Bondt and Thaler (1985) argue that return reversal might be attributed to investor overconfidence and overreaction. The idea is further extended by Daniel, Hirshleifer, and Subrahmanyam (1998) who show investor's overconfidence and biased self-attribution, namely, overreaction to private information and underreaction to public information, together account for the return momentum and reversal at different time horizons. In addition, momentum and reversal are positively associated with trading volume and volatility. Cui, Titman, and Wei (2010) rely on the individualism index developed by social pyschologist to proxy overconfidence, and find that individualism is positively correlated with trading volume and volatility, as well as to the magnitude of momentum and reversal profits across non-Asian countries. Statman, Thorley, and Vorkink (2006) report evidence that confirms the implications of overconfidence and self-attribution bias on trading volume and return autocorrelation.

In particular, these studies have a unanimous finding: the higher the degree of investor overconfidence, the higher the investor's trading volume. Odean (1998, p.1888) calls it "the most robust effect of overconfidence." De Bondt and Thaler (1995, pp.392-393) remark that the high trading volume observed in financial markets "is perhaps the single most embarrassing fact to the standard finance paradigm" and that "the key behavioral fact needed to understand the trading puzzle is overconfidence."

The popularity of overconfidence literature has attracted followers as well as critics. For instance, García, Sangiorgi and Urošević (2007) show that when rational and overconfident agents coexist and private information acquisition is endogenized, overconfidence does not affect price volatility, information efficiency, and rational agents' welfare. Intuitively, the rational agents respond to the presence of overconfident agents by reducing their information acquisition activities since the aggressive trading of the latter reveals more of their information through prices. Ko and Huang (2007) find that overconfident price takers can increase price quality through greater information acquisition when rational traders are absent. Kyle and Wang (1997), Wang (2001), and Hirshleifer and Luo (2001) show overconfident investors can have higher expected profits or utility either by using overconfidence as a commitment device to aggressive trading or by taking more risk, accumulating more wealth thus surviving in the long run. It is noteworthy that in these papers "the most robust effect" remains intact as overconfidence is still positively correlated with higher trading volume. In contrast, our paper establishes that the effect does not hold when corporate insiders have to disclose their trades after the fact. Overconfident insiders choose to underreact to their private information and trade less prior to the disclosure. This finding is new to the literature.

Next, we turn to review the effect of public disclosure requirement on corporate insider's trading behavior. Earlier studies explore insider's market manipulation based on voluntary but fraudulent information or trade disclosure.[5] Benabou and Laroque (1992) argue that mandatory and truthful trade disclosure requirement has advantage in preventing price manipulation because actions speak louder than words. Nonetheless, Fishman and Hagerty (1995) first point out the perverse effect of insider's truthful disclosure of actual trade. The insight stems from the possibility that even the insider may possess no private information on asset value and the market cannot fully separate her from the informed one. Even though an informed insider is always worse off with disclosure, an uninformed benefits from a round-trip transaction as she can take advantage of the adverse price movement after the disclosure. As a result, when the likelihood of an insider being informed is low, her ex ante expected trading profit could be higher in comparison to the case when the disclosure rule is absent. John and Narayanan (1997) further show that even an informed insider can gain from the truthful disclosure if she sometimes trade in the direction against her information. The contrarian trading makes it is harder for the market to disentangle information content and allows the insider to keep information advantage over the market for a longer period of time. The insider reaps large profits in later periods by trading in the right direction which can more than compensate for the losses suffered by earlier trading in the wrong direction. Both papers demonstrate the main re-

[5] Allen and Gale (1992) distinguish between action-based, information-based, and trade based stock market manipulations. Trade-based manipulation occurs when informed traders undertake unprofitable trades early on in order to undertake profitable future trades at more favorable prices. Manipulation often involves round-trip transactions but does not necessarily rely on direct disclosure of information.

sults in two-period trading models, and insider is restricted to trade a fixed number of shares in each period.[6]

Huddart, Hughes, and Levine (2001) study the impact of trade disclosure on insider's dynamic trading in the framework of Kyle (1985) from a distinct perspective. They are concerned with an insider's strategic use of private information over time without the intention to manipulate the market.[7] In equilibrium, the insider employs dissimulation which involves playing a mixed trading strategy except the final round of trading. Huddart, Hughes, and Levine (2001) further show that the disclosure rule impairs insider's profits but makes market more efficient and liquid irrespective of trading rounds. In other words, public disclosure should be encouraged as it accelerates the price discovery, lowers trading costs and reduces uninformed traders' loss. Consistent with the mixed strategy, some empirical studies on legal insider trading show that insiders place both informed and uninformed trades (Lakonishok and Lee, 2001; Fidrmuc, Goergen, and Renneboog, 2006).

Zhang (2004) and Buffa (2010) derive the dissimulation strategy for a single risk averse insider and show that transparency brought by disclosure may have adverse consequences when trading frequency becomes large. To understand the results we only need to see what would happen in absence of trade disclosure. Holden and Subrahmanyam (1994) show that a risk averse insider trades more aggressively than her risk neutral counterpart in the early rounds because she wants to protect herself against future price risk imposed by noise traders. Such motive becomes stronger when the insider faces more frequent trading, which in turn enhances market efficiency and liquidity at the cost of insider's profits. On the contrary, the dissimulation strategy induces the insider to trade less intensely, and the added noises impede the dissemination of private information. Cao and Ma (2000) generalize the dissimulation strategy by analyzing imperfect competition among multiple risk neutral insiders whose collective signals fully reveal the asset value. Therefore, not only can market makers partially infer the asset value from trade disclosure, but also insiders update their posteriors through learning from each other's

[6]In fact, John and Narayanan (1997) show that allowing multiple trade sizes would reduce insider's incentive to manipulate because the multiple trade sizes endogenously increase the threat of early revelation of the insider's information due to the absence of pooling. Hence, overconfidence does not change insider's quantity demanded in this type of model.

[7]Kyle (1985, p.1323) makes a clear note that "the second order condition (3.20) rules out a situation in which the insider can make unbounded profits by first destablizing prices with unprofitable trades made at the nth auction, then recouping the losses and much more with profitable trades at future auctions." However, Chakraborty and Yılmaz (2004) show that insider's manipulation is possible in Kyle (1985) when market makers face uncertainty about insider's presence and the number of trading rounds are sufficiently large.

actual trade. Consequently, the results in Huddart, Hughes, and Levine (2001) are largely reestablished and often strengthened since insiders trade against each other more competitively and reveal private information more quickly.

3 The Model

We consider a two-period trading model à la Kyle (1985) and conform to the notation of Huddart, Hughes, and Levine (2001). There are one risk-free asset and one risky asset in our economy. The risk-free rate is taken to be zero. The risky asset is traded in two sequential auctions in periods $n \in \{1, 2\}$ with liquidation value v at the end of period 2, which is normally distributed with prior mean p_0 and prior variance Σ_0. A risk neutral insider receives a long-lived signal s prior to the first period and submits market order to buy or sell x_n shares of the risky asset at the beginning of period n. The insider's initial wealth is normalized to be zero. Noise traders, whose trading is driven by exogenous motives, submit an exogenous aggregate order u_n at the beginning of period n which are normally distributed with mean 0 and variance σ_u^2. All random variables are mutually independent. Trading takes place through uninformed risk neutral competitive market makers who only observe the total order flow $y_n = x_n + u_n$ and set the prices, p_n, equal to the posterior expectation of v at the n^{th} auction.

We depart from Kyle (1985) and Huddart, Hughes, and Levine (2001) by assuming that the signal s is a scalar multiple of the liquidation value v. Following Wang (1998), we allow that the insider and the market makers agree to disagree in the sense that the former thinks $s = v/k$ while the latter think $s = v$ where k is a positive constant. Therefore, traders' heterogeneous prior beliefs are completely captured by the belief parameter k. Without loss of generality, we interpret the market makers' beliefs (i.e. $k = 1$) as the benchmark "rational"case, then the insider is "overconfident" if her probability distribution of the signal s is too tight (i.e., $k > 1$) and "underconfident" if it is too loose (i.e., $0 < k < 1$). k is also called the confidence degree.

3.1 No Public Disclosure Requirement

Insider's trading strategy and market makers' pricing strategy are denoted by sets of real-valued functions $X = \{X_1, X_2\}$ and $P = \{P_1, P_2\}$ such that, given an initial price p_0, $x_n = X_n(s, p_{n-1})$, $p_1 = P_1(y_1)$, and $p_2 = P_2(y_1, y_2)$ when the insider is not required to disclose her trade after the fact. Let π_n be the portion of the insider's total profits directly attributable to her period n trade, $\pi(x_n, p_n) = x_n(v - p_n)$, $n \in \{1, 2\}$. Denote $E_k[\cdot]$ and $Var_k[\cdot]$ to be the expectation and variance operators under the belief parameter k respectively.

Throughout the paper we represent the economy as an extensive form game with imperfect information, and employ the notion of perfect Bayesian equilibrium. This equilibrium notion is studied because it captures the fact that informed traders are rational and forward-looking. That is, each informed trader takes into account that her demand will be used by others to update their beliefs concerning the fundamental value of the stock.

When public disclosure is not required, a perfect Bayesian equilibrium is defined by trading strategy X and pricing strategy P such that, first, given P the insider maximizes profits under her belief parameter $k \neq 1$,

$$E_k\left[\sum_{t=n}^{2} \pi_t(x_t, p_t) \,|s, p_{t-1}\right] \geq E_k\left[\sum_{t=n}^{2} \pi_t(\hat{x}_t, p_t) \,|s, p_{t-1}\right] \text{ for } n \in \{1, 2\}$$

for any strategy $\{\hat{X}_1, \hat{X}_2\}$; and second, given X the market makers set prices to achieve semi-strong market efficiency,

$$p_1 = E_1[v|y_1],$$
$$p_2 = E_1[v|y_1, y_2].$$

This equilibrium concept is based on dynamic programming argument. The strategy of trader 1 in period 2 is required to be optimal, not only when trader 1 plays her optimal strategy in period 1, but also when she plays any arbitrary strategy in period 1. However, there is no off-equilibrium observation of order flows by other market participants in the model (even when trader 1 deviates from her optimal strategy) as liquidity trades make every order flow possible. Consequently, we do not have to concern ourselves with the issue of how to assign off-equilibrium beliefs.

Note that the amount of asymmetric information after n^{th} round of trading, denoted by Σ_n, is

$$\Sigma_n = E_1[(v - p_n)^2] = Var_1[v|y_1, \cdots, y_n].$$

As in Kyle (1985), this measure is called the error variance of price at the end of period n. The zero-profit condition also implies that the price volatility, denoted by $Var_1(p_n - p_{n-1}) = \Sigma_n - \Sigma_{n-1}$ for $n \in \{1, 2\}$.

Theorem 1 *In the two-period single insider trading model with no public disclosure requirement, for $k \in (0, 2)$, a linear perfect Bayesian equilibrium for trading and pricing strategies exists in* *which*

$$x_n = \beta_n (s - p_{n-1}) + \theta_n s \tag{3.1}$$

$$p_n = (1 + \gamma_n) p_{n-1} + \lambda_n y_n \tag{3.2}$$

where the trading intensity parameters β_n, θ_n, pricing adjustment parameters γ_n, and liquidity parameters λ_n for $n \in \{1, 2\}$ satisfy:

$$\beta_1 = \frac{2L - (2-k)^2}{4L - (2-k)^2} \frac{1+\gamma_1}{\lambda_1}, \qquad \beta_2 = \frac{1+\gamma_2}{2\lambda_2}, \tag{3.3}$$

$$\theta_1 = -\frac{\gamma_1}{\lambda_1}, \qquad \theta_2 = -\frac{\gamma_2}{\lambda_2}, \tag{3.4}$$

$$\gamma_1 = \frac{1}{L} (1-k) (L - 2 + k), \qquad \gamma_2 = 1 - k, \tag{3.5}$$

$$\lambda_1 = \frac{\sqrt{2k (2-k) (L - 1 + k) (2L - 2 + k) \Sigma_0}}{\sigma_u [4L - (2-k)^2]}, \tag{3.6}$$

$$\lambda_2 = \frac{2-k}{\sigma_u} \sqrt{\frac{k (L - 1 + k) \Sigma_0}{2[4L - (2-k)^2]}}, \tag{3.7}$$

$$\Sigma_1 = \frac{2 (2-k) (L - 1 + k)}{4L - (2-k)^2} \Sigma_0, \qquad \Sigma_2 = \frac{(2-k)^2 (L - 1 + k)}{4L - (2-k)^2} \Sigma_0. \tag{3.8}$$

where $L = \lambda_2 / \lambda_1 > 1 - k/2$ is the unique solution to

$$8L^3 - 4 (2-k) L^2 - 4 (2-k) L + (2-k)^3 = 0.$$

Furthermore, the insider has unconditional expected profits in period $n \in \{1, 2\}$,

$$E_1 [\pi_n] = \lambda_n \sigma_u^2.$$

Proof. All proofs are provided in the Appendix. ■

As explained by Wang (1998), the inequality condition for the belief parameter $k \in (0, 2)$ results from the fact that the error variance of price is positive and strictly decreasing over time, i.e., $0 < \Sigma_n < \Sigma_{n-1}$ for any n. In our two-period model, it is simply the outcome of second-order condition of maximization problem being positive. Intuitively, it means that if a rational trader thinks a risky asset is worth \$100, then an irrational insider's subjective value cannot be less than \$0 or more than \$200 for equilibrium to exist. When the insider is extremely overconfident so that her confidence degree $k \to 2$, calculation shows that both market liquidity and insider's trade explode in the last period. On the contrary, the extremely underconfident insider's trades approach zero for all periods because insider's ex post expected value of the risky asset given her signal is always identical to the asset's ex ante common expected value. In this case market makers are willing to provide infinite liquidity.

We write insider's trading strategy (3.1) in two terms. The first term represents the trading on information, and the second term represents the trading on heterogeneous prior beliefs. Therefore, parameters β_n and θ_n measure the intensity of insider trading due to asymmetric information and heterogeneous prior beliefs, respectively. The market makers' pricing rule (3.2) is a linear combination of the current order flow y_n and the updated price of previous period. The order flow help the market makers to forecast the unobservable insider trading under common prior beliefs. The liquidity parameter λ_n is an inverse measure of market depth. The update of the pervious price, represented by the term $\gamma_n p_{n-1}$, is needed because part of the current order flow is induced by heterogeneous prior beliefs rather than information.

We are particularly interested in understanding whether overconfident insiders overreact in form of aggressive trading. The total trading volume at the n^{th} auction, denoted Vol_n, is defined by

$$Vol_n = \frac{1}{2}\left(|x_n| + |u_n| + |y_n|\right)$$

Because x_n, u_n and y_n are normally distributed with zero mean, applying the standard statistical formula we derive the expected trading volume

$$E_1\left[Vol_n\right] = \frac{1}{\sqrt{2\pi}}\left(\sqrt{Var_1\left(x_n\right)} + \sqrt{Var_1\left(u_n\right)} + \sqrt{Var_1\left(x_n\right) + Var_1\left(u_n\right)}\right)$$

Since our purpose is to study the strategic utilization of private information of the insider over time, we assume the trading volume generated by the noise traders in both periods are constant. It is clearly that we can restrict our attention to the component generated by the insider in order to fully capture the patterns of total trading volume. Let $V_n^I = \sqrt{Var_1\left(x_n\right)/2\pi}$ be the insider's scaled expected trading volume in period n. Simple calculation yields

$$V_1^i = \left(\beta_1 + \theta_1\right)\sqrt{\Sigma_0} = \sigma_u\sqrt{\frac{k\left(2L - 2 + k\right)}{2\left(2 - k\right)\left(L - 1 + k\right)}} \tag{3.9}$$

$$V_2^i = \sqrt{\left(\beta_2 + \theta_2\right)^2\Sigma_1 + \theta_2^2\left(\Sigma_0 - \Sigma_1\right)} = \sigma_u\sqrt{\frac{k}{2 - k} + \frac{2\left(1 - k\right)^2\left(2L - 2 + k\right)}{\left(2 - k\right)^2\left(L - 1 + k\right)}} \tag{3.10}$$

Even though we can express insider's expected trading volume in closed-form, the dependence of trading volume on the confidence degree k is quite involved due to the non-monotonicity relationship between L and k. Nonetheless, the numerical analysis shows that in general, both trading volumes V_n^i are increasing in k. Therefore, Overconfident insiders overreact in the form of aggressive trading. This positive relationship between trading volume and confidence degree is consistent with the existing models. It is straightforward to show that the excessive trading behavior generate tremendous price volatility, higher market efficiency (measured by the inverse of price error Σ_n) and lower expected profits. The numerical analysis also show a clear time-varying pattern of trading volume, price volatility, market efficiency and expected profits.

Next, we turn to the main finding of this paper. When insiders are required to disclose their trading after the fact. We show that overconfident insiders underreact to their private information whereas underconfident insider overreact.

3.2 Public Disclosure Requirement

Assume the insider's trade in period one is publicly disclosed after trading in period 1 and before trading in period 2, therefore the market makers can ex post distinguish between the order flow of informed traders and noise traders. It is easy to see such a regulation requirement negates the equilibrium trading and pricing strategies described above. Suppose the market makers conjecture that the overconfident insider employs the first period strategy $x_1 = \beta_1 (s - p_0) + \theta_1 s$, then the disclosure of x_1 enables the market makers to infer

$$s = \frac{x_1 + \beta_1 p_0}{\beta_1 + \theta_1}.$$

Accordingly they would set $p_2 = s$ and $\lambda_2 = 0$. The insider foresees it and would have incentive to defect by choosing $\hat{x}_1 \neq x_1$. The deviation induces mispricing in the second period as the market depth is infinite as a consequence of $\lambda_2 = 0$. The insider's second period profits are unbounded.

We follow the idea of Huddart, Hughes and Levine (2001) and show an equilibrium exists in which the insider's first-period trade consists of an information based linear component, and a noise component, z_1 so that

$$x_1 = X_1 (s, z_1, p_0),$$

where z_1 is normally distributed with mean 0 and variance $\sigma_{z_1}^2$ and is mutually independent from all other random variables. We call such a trading strategy "dissimulation".

Public disclosure of x_1 allows the maker makers to update their expectation of liquidation value v from

$$p_1 = P_1 (y_1) = E_1 [v|y_1]$$

to

$$p_1^* = P_1^* (x_1) = E_1 [v|x_1] = E_1 [v|x_1, y_1, p_1]$$

since x_1 is a sufficient statistic for $\{x_1, y_1, p_1\}$ with respect to v. In period 2, it is unnecessary for the insider to employ the dissimulation strategy as the asset value will be realized at the end of period 2. Consequently,

$$x_2 = X_2 (s, p_1^*) .$$

The market makers set price according to

$$p_2 = P_2 (y_2, p_1^*) = E_1 [v|y_2, p_1^*] .$$

We can define the perfect Bayesian equilibrium for this economy as above similarly so that both profits maximization and semi-strong efficiency conditions are met. The equilibrium is characterized below.

Theorem 2 *In the two-period single insider trading model with public disclosure requirement, for $k \in (0, 2)$, a linear subgame perfect equilibrium for trading and pricing strategies exists in which*

$$x_1 = \beta_1 (s - p_0) + \theta_1 s + z_1, \quad x_2 = \beta_2 (s - p_1^*) + \theta_2 s, \tag{3.11}$$

$$p_1 = (1 + \gamma_1) p_0 + \lambda_1 y_1, \quad p_2 = (1 + \gamma_2) p_1^* + \lambda_2 y_2, \tag{3.12}$$

$$p_1^* = (1 + \gamma_1^*) p_0 + \lambda_1^* x_1, \tag{3.13}$$

where the trading intensity parameters β_n, θ_n, pricing adjustment parameters γ_n, γ_1^*, λ_1^*, and *liquidity parameters λ_n for $n \in \{1,2\}$ satisfy:*

$$\beta_1 = \frac{3k-2}{4\lambda_1}, \quad \beta_2 = \frac{2-k}{2\lambda_2}, \tag{3.14}$$

$$\theta_1 = \frac{1-k}{\lambda_1}, \quad \theta_2 = \frac{k-1}{\lambda_2}, \tag{3.15}$$

$$\gamma_1 = k-1, \quad \gamma_2 = 1-k, \quad \gamma_1^* = \frac{2(k-1)}{2-k}, \tag{3.16}$$

$$\lambda_1 = \lambda_2 = \frac{\sqrt{k(2-k)\Sigma_0}}{2\sqrt{2}\sigma_u}, \quad \lambda_1^* = \frac{2\lambda_1}{2-k}, \tag{3.17}$$

$$\sigma_{z_1}^2 = \frac{2-k}{2k}\sigma_u^2, \quad \Sigma_1 = \frac{\Sigma_0}{2}. \tag{3.18}$$

Furthermore, the insider has unconditional expected profits in period $n \in \{1,2\}$,

$$E_1[\pi_n] = \lambda_n \sigma_u^2.$$

As the prior analysis, the existence of equilibrium requires that the confidence degree $k \in (0,2)$. We separate the effect of asymmetric information and heterogeneous prior beliefs, the trading intensity of them are measured by the parameters β_n and θ_n respectively.

The pricing update effects are captured by γ_n, γ_1^*, λ_1^*. It is interesting to observe that, contrary to the prior analysis, the liquidity parameters λ_n are identical in the presence of disclosure requirement. Intuitively, marginal trading costs must be the same across the two periods for the insider to achieve the indifference in the first period demands necessary to sustain a mixed strategy. Any disparity in such costs would create an incentive to deviate from a mixed strategy in order to exploit the lower cost.

Proposition 1 *When the public disclosure is required. The insider's scaled expected trading volumes V_n^I in period $n \in \{1,2\}$ are*

$$V_1^i = \sigma_u \sqrt{\frac{2-k}{k}}, \tag{3.19}$$

$$V_2^i = \sigma_u \sqrt{\frac{5k^2-8k+4}{k(2-k)}}. \tag{3.20}$$

In particular, the overconfident insider always underreacts in the first period, and she overreacts in the second period only if her confidence degree exceeds a threshold value.

To understand the seemingly puzzling trading behavior of the insider, we note the following: First, insider's total trading intensity on information $\beta_1 + \theta_1$ is decreasing in k, so is the variance of the random component z_1. Second, the price adjustment parameters γ_1^* and λ_1^* are increasing in k. Naturally, market makers positively respond to the quantity of disclosed trade. Therefore the overconfident insider face a trade-off; she can choose to trade a large amount in the first period, but then she is facing higher marginal trading cost in the second period since the market makers adjust the price more aggressively to a large trade. As a result, higher profits generated in the first period is partially offset in the second period trading. On the other hand, the overconfident insider can choose to trade a small amount in the first period so that she will face a more favorable condition of trade in the second period, but doing so implies that higher profits in the second period is counterbalanced by the small profits in the first period. In the equilibrium, the overconfident insider optimally trade less aggressively in the first period as the "information hiding effect" dominates the "share accumulation effect". It is interesting to note that such a consideration does not necessarily imply the overconfident insider would trade less than a rational insider in the first period. However, because the market maker responds to the order submitted by overconfident insider so intensely, the higher the overconfidence, the smaller the order prior to the disclosure. Another interesting fact is that the overconfident insider choose to trade in a way such that her expected profits in each period is equalized. This can be seen from the result that

$$E_1 [\pi_1] = E_2 [\pi_2]$$

Note that these expected profits are unconditional and they are the true profits that the insider would earn on average, but these are different from what the insider believes they would earn as their beliefs regarding the stock payoff is biased.

The same argument applies to the underconfident insider who choose to trade aggressively in the first period in order to boost up the price so that her stock holding accumulated in the first period is more valuable in the second period.

4 Extensions

In this section, we extend our analysis in two directions. In the first model we consider multiple insiders who are equally informed and equally over- or underconfident. In the second model we allow two insiders to differ in the confidence degree. The goal is to see if the main results of last section are robust or to what extent they will be modified.

4.1 Imperfect Competition with Common Confidence Degree

Introducing imperfect competition among multiple insiders has a great impact on the insider's trading behavior and the resulting asset pricing implications. Holden and Subrahmanyam (1992) show that in this situation the insiders compete against each other very aggressively and cause most of their common private information to be revealed very rapidly. In sharp contrast, the monopolistic insider of Kyle (1985) moderates her trade and causes her information to be incorporated into prices only gradually. We examine if the competition effect will drive away our main result that overconfident insiders underreact to their information with trade disclosure requirement. The answer is a clear-cut "no".

Since we have seen that the asset's prior mean p_0 does not affect the trading and asset pricing implications. We assume without loss of generality that $p_0 = 0$ in the following analysis. Doing so implies that insiders' trading intensity encompasses the effect of asymmetric information and heterogeneous prior beliefs. In addition, we follow Holden and Subrahmanyam (1992) to assume that m insiders employ symmetric equilibrium so that they choose the same trading intensity and make the same trade in each period.[8]

Theorem 3 *In the two-period m-insider trading model with public disclosure requirement, for* $i \in \{1, \cdots, m\}$*,* $k \in \left(0, \frac{m+1}{m}\right)$*, a linear subgame perfect equilibrium for trading and pricing strategies exists in which*

$$x_{i1} = \beta_{i1} s + z_1, \qquad x_{i2} = \beta_{i2} s - \delta_{i2} p_1^*, \tag{4.1}$$

$$p_1 = \lambda_1 y_1, \qquad p_2 = (1 + \gamma_2)\, p_1^* + \lambda_2 y_2, \tag{4.2}$$

$$p_1^* = \lambda_1^* \left(\sum_{i=1}^{n} x_{i1} \right), \tag{4.3}$$

where the trading intensity parameters β_n*, pricing adjustment parameters* γ_2*,* λ_1^**, and liquidity*

[8] This assumption implies that the added noise component in the first period trading is identical across insiders. For our purpose of equilibrium analysis, we argue that this assumption is more reasonable than the alternative assumption that insiders add noises that are independently and identically distributed. The problem of the latter assumption lies in the equilibrium selection of different insiders cannot be settled down. It is hard to specify why commonly informed insiders make different trades. Another technical trouble is allowing i.i.d noise generates multiple equilibria.

parameters λ_n for $n \in \{1,2\}$ satisfy:

$$\beta_{i1} = \frac{m^2 (m+1-mk) \left[m+k+m^2(1-k)\right]}{\left[4+m^2(m+1)^2\right] \lambda_1}, \qquad \beta_{i2} = \frac{k}{(m+1)\lambda_2}, \tag{4.4}$$

$$\delta_{i2} = \frac{1+m(1-k)}{(m+1)\lambda_2}, \qquad \gamma_2 = m(1-k), \qquad \lambda_1^* = \frac{(m+1)^2 \lambda_2}{2\left[1+m(1-k)\right]}, \tag{4.5}$$

$$\lambda_1 = \frac{m(m+1)\lambda_2}{2}, \qquad \lambda_2 = \frac{2}{(m+1)\sigma_u} \sqrt{\frac{mk(m+1-mk)\Sigma_0}{4+m^2(m+1)^2}}, \tag{4.6}$$

$$\sigma_{z_1}^2 = \frac{\left[1+m(1-k)\right] \left[4+m^2\left[(m+1)^2 - \left(m+k+m^2(1-k)\right)^2\right]\right] \sigma_u^2}{mk\left[4+m^2(m+1)^2\right]}, \tag{4.7}$$

$$\Sigma_1 = \frac{4\Sigma_0}{4+m^2(m+1)^2}. \tag{4.8}$$

Furthermore, each insider i has unconditional expected profits in period $n \in \{1,2\}$

$$E_1\left[\pi_{in}\right] = \frac{\lambda_n \sigma_u^2}{m}.$$

Two major changes in the equilibrium conditions deserve special attention. First, when m insiders engage in the imperfect competition, the upper bound of confidence degree k is restricted to be $(m+1)/m$ while the lower bound remains the same as 0. The reason is that when the overconfident insiders are not concerned about the trade disclosure in period 2, their trade explode if their confidence degree exceeds the upper bound. The lower bound is uncorrelated with the numbers of insiders because the market does not break down when extremely underconfident insiders choose not to trade. Second, the marginal trading costs do not have to be the same across the two periods in the presence of multiple insiders. The mixed trading strategy is sustained and the insiders have no incentive to deviate from it.

Proposition 2 *When the public disclosure is required in the m-insider trading model. Insider i's scaled expected trading volumes V_{in}^I in period $n \in \{1,2\}$ are*

$$V_{i1}^I = \sigma_u \sqrt{\frac{m+1-mk}{mk}}, \tag{4.9}$$

$$V_{i2}^I = \frac{\sigma_u}{2} \sqrt{\frac{4k^2 + m^2(m+1)^4(1-k)^2}{mk(m+1-mk)}}. \tag{4.10}$$

The overconfident insiders always underreact in the first period and they overreact in the second period only if their confidence degree exceeds a threshold value.

We have already understood the incentive of underreaction of the overconfident insider prior to the disclosure so we ask if the insights of Holden and Subrahmanyam (1992) still holds. Put it another way, if the overconfident insiders always trade less in the first period, how can we tell they trade more aggresively compared to the one-insider case? The anwer relies in the liquidity paramter λ_1 set by the market maker. When there is only one insider, we see from Theorem 2 that $\lambda_1 = \lambda_2$, but with multiple insiders, Theorem 3 tells us that $\lambda_1 > \lambda_2$. In order words, when the insiders trade more aggressively the adverse selection becomes more severe and the market maker chooses a higher marginal cost to protect herself. The insiders compete more intensely as soon as possible because this is the only way they can exploit their information against each other. Even so, because the price adjustment after the public disclosure is so heavy that insiders also chooses to trade more intensely in the second period.

Again, we can analyze the resulting asset pricing implications such as market liquidity, price volatility and informativeness.

4.2 Duopoly Competition with Heterogeneous Confidence Degrees

To simplify the analysis we still assume $p_0 = 0$ and set $m = 2$, but we allow the insiders to have different confidence degree. The information structure is presented in the following table.

Private Signals	s_1	s_2
Insider 1's distributions	$\frac{v}{k_1}$	$\frac{v}{k_2}$
Insider 2's distributions	$\frac{v}{k_1}$	$\frac{v}{k_2}$
Market makers' distributions	v	v

Table 1: Information structure in the duopoly competition

Note that in this case each insiders can learn from other's trade and update their posteriors after the disclosure.

$$v_1^* = E_k\left[v|s_1, x_{21}\right] = E_k\left[v|s_1, \beta_{21}s_2 + z_2\right] = k_1 s_1$$

Similarly,

$$v_2^* = k_2 s_2$$

Because the posteriors are simple transformation of each insider's private signal. We do not have to introduce the v_n^* in the equilibrium analysis. Instead, each insider's trade in the second period depends on her private signal and the adjusted price set by the market makers.

Remark 1 ***The equilibrium characterization has not been fully completed yet. We will finish the analysis soon.***

5 Conclusion

The existing studies has established the strong positive relationship between overconfidence and overreaction in the form of aggressive trading. We reexamine the relationship when corporate insiders are required to truthfully disclose their trade after the fact in two-period models and find that prior to the disclosure, the higher the degree of insider overconfidence, the lower the insider's trading volume. When disclosure requirement is no longer a concern in the second period, insiders overreact only if their overconfidence degree exceeds a threshold value. This new finding is in sharp contrast to the widely held belief that overconfidence always breeds overreaction.

Provided the tremendous significance of the insider trading regulation, our findings deserve further exploration. In particular, we are keen to confront the theoretical predictions with a thorough analysis of field data. Existing studies on insider trading using various datasets have been vastly developed. Direct and indirect measures of overconfidence have been creatively constructed. We hope to carry out the empirical and experimental investigation and shed new lights on this important issue soon.[9]

From a broader perspective, our work is constructive in deepening our understanding of the theoretical foundations of under- and overreaction in financial markets. Many asset pricing anomalies have been attributed to investors' under- or overreaction to information. Behavioral theories of under- and overreaction have been built as potential alternatives to the market efficiency hypothesis even though the underlying mechanisms can be multifarious (Barberis, Shleifer, and Vishny, 1998; Daniel, Hirshleifer and Subrahmanyam, 1998; Hong and Stein, 1999), among which overconfidence, overreaction to private information, and underreaction to public information, have been regarded as synonymous or interchangeable. After presenting an excellent review of the empirical

[9] Deaves, Lüders, and Luo (2009) provide one illustrative example of asset market experiment in which they find that pre-identified overconfident individuals, who are then induced to believe that their signals are more informative, engender more trades.

findings of asset prices over- and underreaction, Fama (1998) concludes that "apparent overreaction to information is about as common as underreaction, and post-even continuation of pre-event abnormal returns is about as frequent as post-event reversal." Rather than engaging in the debate, the goal we wish to achieve is to seek more endeavors to scrutinize the role of overconfidence in the behavioral theories.

Furthermore, even though finance literature has paid remarkable individual attention to the impact of behavioral biases or regulatory constraints on trading behavior and asset pricing, it seems that the their joint effect has not been adequately examined. We provide another concrete example: To reduce the incidence of stock market manipulation, both Fishman and Hagerty (1995) and John and Narayanan (1997) advocate the short-swing profit rule, mandated in the Section 16(b) of the Securities and Exchange Act of 1934, which requires insiders to return to the firm any profits made from a round-trip transaction in the firm's stock within a 6-month period. Nonetheless, legal scholars Black (1990) and Roe (1991) argue that this rule has adverse effects on deterring shareholder activism because the liability for short-swing profits reduces the liquidity of activists' investments. How will overconfident activists respond to this rule? At first blush, the shareholder activism will be curbed if overconfident activists mistakenly believe they are able to exit successful investment less than 6 months. But if they overestimate the returns from the governance control but correctly predict that well-executed activism takes more than 6 months, then the short-swing rule is no longer binding and we should observe more shareholder activism. We attempt to address this topic both theoretically and empirically in the future research.

A Appendix

Proof of Theorem 1. Consider the two-period version of Wang (1998) and rewrite the conditions given in his Theorem 1 so that the parameters of our Theorem 1 satisfy:

$$\beta_1 = \frac{(1+\gamma_1)(1-2\alpha_1\lambda_1)}{2\lambda_1(1-\alpha_1\lambda_1)}, \qquad \beta_2 = \frac{1+\gamma_2}{2\lambda_2}, \tag{A.1}$$

$$\theta_1 = -\frac{\gamma_1}{\lambda_1}, \qquad \theta_2 = -\frac{\gamma_2}{\lambda_2}, \tag{A.2}$$

$$\gamma_1 = 1-k-\omega_1\lambda_1, \qquad \gamma_2 = 1-k, \tag{A.3}$$

$$\lambda_1 = \frac{(\beta_1+\theta_1)\Sigma_1}{\sigma_u^2}, \qquad \lambda_2 = \frac{(\beta_2+\theta_2)\Sigma_2}{\sigma_u^2}, \tag{A.4}$$

$$\Sigma_1 = (1+\gamma_1)\left(1-\frac{\lambda_1\beta_1}{1+\gamma_1}\right)\Sigma_0, \quad \Sigma_2 = (1+\gamma_2)\left(1-\frac{\lambda_2\beta_2}{1+\gamma_2}\right)\Sigma_1, \tag{A.5}$$

$$\alpha_1 = \frac{(1+\gamma_2)^2}{4\lambda_2}, \qquad \omega_1 = \frac{(2-k)\gamma_2}{\lambda_2}. \tag{A.6}$$

Substituting expressions for β_2, θ_2, γ_2 into λ_2, and using the Second Order Condition (SOC) $\lambda_2 > 0$ yields

$$\lambda_2 = \frac{1}{\sigma_u}\sqrt{\frac{k\Sigma_2}{2}}, \tag{A.7}$$

where, from (A.5)

$$\Sigma_2 = \frac{2-k}{2}\Sigma_1. \tag{A.8}$$

Let $L = \lambda_2/\lambda_1$, substituting expressions for β_1, θ_1, γ_1, α_1, ω_1 into λ_1 yields

$$\lambda_1^2 = \frac{k(2L-2+k)\Sigma_1}{[4L-(2-k)^2]\sigma_u^2} = \frac{2k(2-k)(L-1+k)(2L-2+k)}{\left[4L-(2-k)^2\right]^2\sigma_u^2}\Sigma_0, \tag{A.9}$$

where, from (A.1), (A.3) and (A.5)

$$\Sigma_1 = \frac{2(2-k)(L-1+k)}{4L-(2-k)^2}\Sigma_0. \tag{A.10}$$

The SOC $\lambda_1(1-\alpha_1\lambda_1) > 0$ implies $\lambda_1 > 0$ which requires

$$k(2-k)(L-1+k)(2L-2+k) > 0$$

so we must have

$$0 < k < 2, \; L > 1 - \frac{k}{2}$$

Therefore, under these conditions, (A.9) yields

$$\lambda_1 = \frac{\sqrt{2k(2-k)(L-1+k)(2L-2+k)\Sigma_0}}{\sigma_u[4L-(2-k)^2]}. \tag{A.11}$$

Substituting (A.7), (A.8), (A.10) and (A.11) into $L = \lambda_2/\lambda_1$ we obtain

$$8L^3 - 4(2-k)L^2 - 4(2-k)L + (2-k)^3 = 0 \tag{A.12}$$

and we next show (A.12) has a unique solution $\bar{L} > (2-k)/2$. Denote $f(L) = 8L^3 - 4\ell L^2 - 4\ell L + \ell^3$ where $\ell = 2-k$. The existence of solution to $f(L) = 0$ is guaranteed by the Intermediate Value Theorem since

$$f\left(\frac{\ell}{2}\right) = -k\ell^2 < 0 \text{ and } \lim_{\ell\to\infty} f(\ell) > 0. \tag{A.13}$$

Note that $\partial f(L)/\partial L = 4\left(6L^2 - 2\ell L - \ell\right) = 0$ has a positive root $\bar{L}$ satisfying

$$\bar{L} = \frac{\ell + \sqrt{\ell^2 + 6\ell}}{6} > \frac{\ell}{2} \text{ for } 0 < \ell < 2,$$

therefore we have, because of (A.13),

$$\frac{\partial f(L)}{\partial L} < 0 \text{ for } \frac{\ell}{2} < L < \bar{L},$$
$$\frac{\partial f(L)}{\partial L} > 0 \text{ for } L > \bar{L}.$$

Taking the analysis together the root $\bar{L} > (2-k)/2$ must be unique.

Given λ_1 and λ_2, all parameters in Theorem 1 can be readily derived from (A.1)-(A.6).

Finally, we calculate the insider's unconditional expected profits in both periods. Her conditional expected profit in period 1 under the correct belief is

$$\begin{aligned}
E_1[\pi_1|s] &= E_1[x_1(v-p_1)|s] \\
&= x_1[s-(1+\gamma_1)p_0 - \lambda_1 x_1] \\
&= [\beta_1(s-p_0)+\theta_1 s][s-(1+\gamma_1)p_0 - \lambda_1\beta_1(s-p_0) - \lambda_1\theta_1 s] \\
&= [(\beta_1+\theta_1)(s-p_0)+\theta_1 p_0][(1-\lambda_1\beta_1-\lambda_1\theta_1)(s-p_0) - (\gamma_1+\lambda_1\theta_1)p_0]
\end{aligned}$$

Taking expectation on both sides and substituting the values of parameters given in Theorem 1 yields the insider's unconditional expected profit in period 1

$$\begin{aligned}
E_1[\pi_1] &= (\beta_1+\theta_1)(1-\lambda_1\beta_1-\lambda_1\theta_1)\Sigma_0 - \theta_1(\gamma_1+\lambda_1\theta_1)p_0^2 \\
&= \frac{\sigma_u\sqrt{2k(2-k)(L-1+k)(2L-2+k)\Sigma_0}}{4L-(2-k)^2}
\end{aligned}$$

Similarly, the insider's unconditional expected profit in period 2 is

$$
\begin{aligned}
E_1[\pi_2] &= E_1[E_1[x_2(v-p_2)|s]] \\
&= E_1[x_2(s-(1+\gamma_2)p_1-\lambda_2 x_2)] \\
&= E_1[[\beta_2(s-p_1)+\theta_2 s][s-(1+\gamma_2)p_1-\lambda_2\beta_2(s-p_1)-\lambda_2\theta_2 s]] \\
&= E_1[[(\beta_2+\theta_2)(s-p_1)+\theta_2 p_1][(1-\lambda_2\beta_2-\lambda_2\theta_2)(s-p_1)-(\gamma_2+\lambda_2\theta_2)p_1]] \\
&= (\beta_2+\theta_2)(1-\lambda_2\beta_2-\lambda_2\theta_2)\Sigma_1 \\
&= \sigma_u(2-k)\sqrt{\frac{k(L-1+k)\Sigma_0}{2[4L-(2-k)^2]}}
\end{aligned}
$$

It is clear that the expressions can be simplified as $E_1[\pi_n] = \lambda_n \sigma_u^2$ for period $n \in \{1,2\}$. ■

Proof of Theorem 2. We use backward induction to solve the equilibrium conditions. Given the linear pricing rule of the market makers, the biased insider maximizes her expected utility by choosing x_2

$$\pi_2 = \max_{x_2} E_k[x_2(v-p_2)|s,p_1^*] = \max_{x_2} x_2[ks-(1+\gamma_2)p_1^*-\lambda_2 x_2].$$

The First Order Condition (FOC) delivers

$$x_2 = \beta_2(s-p_1^*)+\theta_2 s, \tag{A.14}$$

where

$$\beta_2 = \frac{1+\gamma_2}{2\lambda_2}, \tag{A.15}$$

$$\theta_2 = \frac{k-1-\gamma_2}{2\lambda_2}, \tag{A.16}$$

and the SOC is $\lambda_2 > 0$. Furthermore,

$$\pi_2(s,p_1^*) = \lambda_2 x_2^2 = \frac{1}{4\lambda_2}[ks-(1+\gamma_2)p_1^*]^2.$$

Stepping back to period 1, the biased insider solves

$$
\begin{aligned}
&\max_{x_1} E_k\left[x_1(v-p_1)+\frac{1}{4\lambda_2}[ks-(1+\gamma_2)p_1^*]^2 \middle| s\right] \\
&= \max_{x_1} x_1[ks-(1+\gamma_1)p_0-\lambda_1 x_1]+\frac{1}{4\lambda_2}[ks-(1+\gamma_2)[(1+\gamma_1^*)p_0+\lambda_1^* x_1]]^2.
\end{aligned}
$$

The FOC delivers

$$\left[1-\frac{\lambda_1^*(1+\gamma_2)}{2\lambda_2}\right]ks-\left[1+\gamma_1-\frac{\lambda_1^*(1+\gamma_1^*)(1+\gamma_2)^2}{2\lambda_2}\right]p_0+\left[\frac{[\lambda_1^*(1+\gamma_2)]^2}{2\lambda_2}-2\lambda_1\right]x_1 = 0.$$

The insider must be indifferent across all values of x_1 for the mixed trading strategy to hold in equilibrium, therefore it requires that

$$1 - \frac{\lambda_1^* (1+\gamma_2)}{2\lambda_2} = 0,$$
$$1 + \gamma_1 - \frac{\lambda_1^* (1+\gamma_1^*) (1+\gamma_2)^2}{2\lambda_2} = 0,$$
$$\frac{[\lambda_1^* (1+\gamma_2)]^2}{2\lambda_2} - 2\lambda_1 = 0.$$

Rearrangement yields

$$\lambda_1 = \lambda_2 = \frac{\lambda_1^* (1+\gamma_2)}{2}, \tag{A.17}$$
$$1 + \gamma_1 = (1+\gamma_1^*) (1+\gamma_2). \tag{A.18}$$

Next, we turn to market makers' optimal pricing strategy in period 1 and we have

$$p_1 - p_0 = E_1 [v - p_0 | y_1] = E_1 [v - p_0 | \beta_1 (s - p_0) + \theta_1 s + z_1 + u_1] = \gamma_1 p_0 + \lambda_1 y_1,$$

where

$$\gamma_1 = -\theta_1 \lambda_1, \tag{A.19}$$
$$\lambda_1 = \frac{(\beta_1 + \theta_1) \Sigma_0}{(\beta_1 + \theta_1)^2 \Sigma_0 + \sigma_{z_1}^2 + \sigma_u^2}, \tag{A.20}$$

by applying the projection theorem for normally distributed random variables. Similarly,

$$p_1^* - p_0 = E_1 [v - p_0 | x_1] = E_1 [v - p_0 | \beta_1 (s - p_0) + \theta_1 s + z_1] = \gamma_1^* p_0 + \lambda_1^* x_1,$$

where

$$\gamma_1^* = -\theta_1 \lambda_1^*, \tag{A.21}$$
$$\lambda_1^* = \frac{(\beta_1 + \theta_1) \Sigma_0}{(\beta_1 + \theta_1)^2 \Sigma_0 + \sigma_{z_1}^2}. \tag{A.22}$$

In period 2, we can first determine γ_2 by using the martingale property of prices $E_1 [p_2 - p_1^* | x_1] = 0$. It follows from $E_1 [\gamma_2 p_1^* + \lambda_2 (x_2 + u_2) | x_1] = 0$ and (A.14) that $\gamma_2 + \lambda_2 \theta_2 = 0$ and

$$\gamma_2 = 1 - k. \tag{A.23}$$

Moreover, we have

$$p_2 - p_1^* = \gamma_2 p_1^* + \lambda_2 y_2, \tag{A.24}$$

and

$$\begin{aligned}p_2 - p_1^* &= E_1\left[v - p_1^* | p_1^*, y_2\right] \\ &= E_1\left[v - p_1^* \middle| \frac{\gamma_2}{\lambda_2} p_1^* + x_2 + u_2\right] \\ &= E_1\left[v - p_1^* \middle| \frac{1-\gamma_2}{2\lambda_2}\left(s - p_1^*\right) + u_2\right]. \end{aligned} \tag{A.25}$$

The second equality comes from the fact that $p_2 - p_1^*$ is the projection of $v - p_1^*$ onto the 2-dimension space spanned by $\left(p_1^*, x_2 + u_2\right)$ so that λ_2 is the coefficient of the second orthogonal basis $\frac{\gamma_2}{\lambda_2} p_1^* + x_2 + u_2$, implied by (A.24). The third equality comes from substituting the trading strategy x_2 given in (A.14), (A.15), (A.16) and using (A.23). Applying the projection theorem to (A.25) and comparing the result to (A.24), we obtain

$$\lambda_2 = \frac{2\lambda_2\left(1-\gamma_2\right)\Sigma_1}{\left(1-\gamma_2\right)^2\Sigma_1 + 4\lambda_2^2\sigma_u^2},$$

which, together with the SOC of $\lambda_2 > 0$, (A.17) and (A.23), yields

$$\lambda_1 = \lambda_2 = \frac{\sqrt{k\left(2-k\right)\Sigma_1}}{2\sigma_u}. \tag{A.26}$$

Substituting (A.19) and (A.21) into (A.18),

$$1 - \theta_1\lambda_1 = \left(1 - \theta_1\lambda_1^*\right)\left(1 + \gamma_2\right),$$

which yields, because of (A.17) and (A.23),

$$\theta_1 = \frac{1-k}{\lambda_1}. \tag{A.27}$$

Substituting (A.20), (A.22) and (A.23) into (A.17),

$$\frac{\left(\beta_1+\theta_1\right)\Sigma_0}{\left(\beta_1+\theta_1\right)^2\Sigma_0 + \sigma_{z_1}^2 + \sigma_u^2} = \frac{2-k}{2}\frac{\left(\beta_1+\theta_1\right)\Sigma_0}{\left(\beta_1+\theta_1\right)^2\Sigma_0 + \sigma_{z_1}^2},$$

which yields

$$\left(\beta_1+\theta_1\right)^2\Sigma_0 + \sigma_{z_1}^2 = \frac{\left(2-k\right)\sigma_u^2}{k}. \tag{A.28}$$

Note that

$$\begin{aligned}\Sigma_1 = Var_1\left[v|p_1^*\right] &= Var_1\left[v|x_1\right]\\ &= \Sigma_0 - \frac{\left(\beta_1+\theta_1\right)^2\Sigma_0^2}{\left(\beta_1+\theta_1\right)^2\Sigma_0+\sigma_{z_1}^2}\\ &= \Sigma_0 - \lambda_1^{*2}\left[\left(\beta_1+\theta_1\right)^2\Sigma_0+\sigma_{z_1}^2\right]\\ &= \Sigma_0 - \left(\frac{2\lambda_2}{2-k}\right)^2\frac{\left(2-k\right)\sigma_u^2}{k}\\ &= \Sigma_0 - \Sigma_1,\end{aligned}$$

because of (A.22), (A.17), (A.28) and (A.26) respectively. We obtain

$$\Sigma_1 = \frac{\Sigma_0}{2}. \tag{A.29}$$

Substituting (A.27) and (A.28) into (A.20) yields

$$\lambda_1 = \left[\beta_1 + \frac{1-k}{\lambda_1}\right]\frac{k\Sigma_0}{2\sigma_u^2},$$

therefore,

$$\beta_1 = \frac{2\sigma_u^2\lambda_1}{k\Sigma_0} - \frac{1-k}{\lambda_1} = \frac{3k-2}{4\lambda_1}, \tag{A.30}$$

where the last equality comes from (A.26) and (A.29). In addition, substituting (A.27) and (A.30) into (A.28), we obtain

$$\sigma_{z_1}^2 = \frac{2-k}{2k}\sigma_u^2.$$

Hence all parameters given in Theorem 2 are readily derived. Note that the existence of equilibrium requires $k \in (0,2)$.

Finally, we calculate the insider's unconditional expected profits in both periods. We obtain

$$\begin{aligned}E_1\left[\pi_1\right] &= E_1\left[E_1\left[x_1\left(v-p_1\right)|s\right]\right]\\ &= E_1\left[\left[\beta_1\left(s-p_0\right)+\theta_1 s+z_1\right]\left[s-\left(1+\gamma_1\right)p_0-\lambda_1\beta_1\left(s-p_0\right)-\lambda_1\theta_1 s-\lambda_1 z_1\right]\right]\\ &= E_1\left[\left[\left(\beta_1+\theta_1\right)\left(s-p_0\right)+\theta_1 p_0+z_1\right]\left[\left(1-\lambda_1\beta_1-\lambda_1\theta_1\right)\left(s-p_0\right)-\left(\gamma_1+\lambda_1\theta_1\right)p_0-\lambda_1 z_1\right]\right]\\ &= \left(\beta_1+\theta_1\right)\left(1-\lambda_1\beta_1-\lambda_1\theta_1\right)\Sigma_0-\lambda_1\sigma_{z_1}^2\\ &= \frac{\sigma_u}{2}\sqrt{\frac{k\left(2-k\right)\Sigma_0}{2}},\end{aligned}$$

and

$$\begin{aligned}
E_1[\pi_2] &= E_1\left[E_1\left[x_2(v-p_2)\,|s,p_1^*\right]\right] \\
&= E_1\left[\left[\beta_2\left(s-p_1^*\right)+\theta_2 s\right]\left[s-(1+\gamma_2)\,p_1^*-\lambda_2\beta_2\left(s-p_1^*\right)-\lambda_2\theta_2 s\right]\right] \\
&= E_1\left[\left[(\beta_2+\theta_2)\left(s-p_1^*\right)+\theta_2 p_1^*\right]\left[(1-\lambda_2\beta_2-\lambda_2\theta_2)\left(s-p_1^*\right)-(\gamma_2+\lambda_2\theta_2)\,p_1^*\right]\right] \\
&= (\beta_2+\theta_2)(1-\lambda_2\beta_2-\lambda_2\theta_2)\,\Sigma_1 \\
&= \frac{\sigma_u}{2}\sqrt{\frac{k(2-k)\,\Sigma_0}{2}}.
\end{aligned}$$

Again, we can write $E_1[\pi_n] = \lambda_n\sigma_u^2$ for period $n \in \{1,2\}$. ■

Proof of Proposition 1. The trading volume is defined

$$E_1[Vol_n] = \frac{1}{\sqrt{2\pi}}\left(\sqrt{Var_1[x_n]}+\sqrt{Var_1[u_n]}+\sqrt{Var_1[x_n+u_n]}\right)$$

where

$$\begin{aligned}
Var_1[x_1] &= Var_1\left[(\beta_1+\theta_1)(s-p_0)+\theta_1 p_0+z_1\right] = (\beta_1+\theta_1)^2\,\Sigma_0+\sigma_{z_1}^2 = \frac{(2-k)\,\sigma_u^2}{k} \\
Var_1[x_2] &= Var_1\left[(\beta_2+\theta_2)\left(s-p_1^*\right)+\theta_2 p_1^*\right] = (\beta_2+\theta_2)^2\,\Sigma_1+\theta_2^2\,(\Sigma_0-\Sigma_1) = \frac{\left(5k^2-8k+4\right)\sigma_u^2}{k(2-k)}
\end{aligned}$$

Therefore

$$\begin{aligned}
E_1[Vol_1] &= \frac{\sigma_u}{\sqrt{2\pi}}\left[\sqrt{\frac{2-k}{k}}+\sqrt{\frac{2}{k}}+1\right] \\
E_1[Vol_2] &= \frac{\sigma_u}{\sqrt{2\pi}}\left[\sqrt{\frac{5k^2-8k+4}{k(2-k)}}+\sqrt{\frac{4k^2-6k+4}{k(2-k)}}+1\right]
\end{aligned}$$

Clearly, the expected trading volume contributed by the insider in period 1 is strictly decreasing in $k \in (0,2)$. It is easy to show the monotonicity of insider's expected trading volume in period 2 depends on the sign of k^2+4k-4, so it's strictly decreasing in $k \in \left(0, 2\left(\sqrt{2}-1\right)\right)$ and strictly increasing in $k \in \left(2\left(\sqrt{2}-1\right), 2\right)$. Therefore in period 2, for insider with confidence degree $k \in \left(4\sqrt{2}-5, 1\right)$, her expected trading volume is always smaller than any overconfident insider's. But there exists underconfident insider with confidence degree $k \in \left(0, 4\sqrt{2}-5\right)$ whose expected trading volume is higher than some overconfident insider's. In particular, for underconfident insider with confidence degree $k^{'} \in (0,\bar{k})$ where $\bar{k} \leq 4\sqrt{2}-5$, her expected trading volume in period 2 is higher than that of overconfident insider with confidence degree $k^{''} \in \left(1, 4\left(\sqrt{2}-1\right)-\bar{k}\right)$. ■

Proof of Theorem 3. The proof of m-insider trading and pricing equilibrium is similar to the proof of Theorem 2. For the sake of space, we only provide the main results from intermediate steps and the full proof is available from author upon request.

We focus on the symmetric equilibrium. In period 2, each insider's profit maximization problem yields

$$\beta_{i2} = \frac{k}{(m+1)\,\lambda_2}, \tag{A.31}$$

$$\delta_{i2} = \frac{1+\gamma_2}{(m+1)\,\lambda_2}. \tag{A.32}$$

In period 1, insider's dissimulation implies

$$\lambda_1 = \frac{(1+\gamma_2)\,m\lambda_1^*}{m+1}, \tag{A.33}$$

$$\lambda_2 = \frac{2\,(1+\gamma_2)\,\lambda_1^*}{(m+1)^2}. \tag{A.34}$$

which yields

$$\lambda_1 = \frac{m\,(m+1)\,\lambda_2}{2}. \tag{A.35}$$

The market makers set semi-strong efficient prices in period 1 so that

$$\lambda_1 = \frac{m\beta_{i1}\Sigma_0}{m^2\beta_{i1}^2\Sigma_0 + m^2\sigma_{z_1}^2 + \sigma_u^2}. \tag{A.36}$$

The price adjustment after insiders disclose their trades yields

$$\lambda_1^* = \frac{m\beta_{i1}\Sigma_0}{m^2\beta_{i1}^2\Sigma_0 + m^2\sigma_{z_1}^2}. \tag{A.37}$$

The martingale property of prices implies

$$\gamma_2 = m\,(1-k)\,. \tag{A.38}$$

The market makers set prices in period 2 so that

$$\lambda_2 = \frac{\sqrt{mk\,(m+1-mk)\,\Sigma_1}}{(m+1)\,\sigma_u}, \tag{A.39}$$

where the requirement of $mk\,(m+1-mk) > 0$ implies

$$0 < k < \frac{m+1}{m}.$$

We also obtain

$$\Sigma_1 = \Sigma_0 - \frac{m^2\beta_{i1}^2\Sigma_0^2}{m^2\beta_{i1}^2\Sigma_0 + m^2\sigma_{z_1}^2}. \tag{A.40}$$

Substituting (A.36) and (A.37) into (A.33) yields

$$\beta_{i1}^2\Sigma_0+\sigma_{z_1}^2=\frac{[1+m(1-k)]\,\sigma_u^2}{mk}, \tag{A.41}$$

which leads to rewrite of (A.36)

$$\lambda_1=\frac{mk\beta_{i1}\Sigma_0}{[m+k+m^2(1-k)]\,\sigma_u^2}, \tag{A.42}$$

Note that

$$\begin{aligned}\Sigma_1&=\Sigma_0-(\lambda_1^*)^2\left(m^2\beta_{i1}^2\Sigma_0+m^2\sigma_{z_1}^2\right)\\&=\Sigma_0-\frac{(m+1)^4\lambda_2^2}{4[1+m(1-k)]}\frac{m\sigma_u^2}{k},\end{aligned} \tag{A.43}$$

where the second equality comes from (A.34), (A.38) and (A.41). We thus obtain

$$\Sigma_1=\frac{4\Sigma_0}{4+m^2(m+1)^2}$$

by rearrangement of (A.39) and (A.43).

Given Σ_1, we get λ_2 and λ_1 from (A.39) and (A.35) respectively, β_{i1}, β_{i2}, δ_{i2}, γ_2 and λ_1^* and γ_2 are derived from (A.42), (A.31), (A.32), (A.34) and (A.38) respectively. Finally, we obtain $\sigma_{z_1}^2$ from (A.41).

Insider i's unconditional expected profits in two periods are

$$\begin{aligned}E_1[\pi_1]&=E_1[E_1[x_{i1}(v-p_1)\,|s_i]]\\&=E_1[[(\beta_{i1}s_i+z_1)(s-\lambda_1(m\beta_{i1}s+mz_1))]]\\&=\beta_{i1}(1-\lambda_1m\beta_{i1})\Sigma_0-\lambda_1m\sigma_{z_1}^2\\&=\sigma_u\sqrt{\frac{mk(m+1-mk)\Sigma_0}{4+m^2(m+1)^2}}\end{aligned}$$

and

$$\begin{aligned}E_1[\pi_2]&=E_1[E_1[x_{i2}(v-p_2)\,|s_i,p_1^*]]\\&=E_1[[\beta_{i2}(s-p_1^*)+(\beta_{i2}-\delta_{i2})p_1^*][(1-\lambda_2m\beta_{i2})(s-p_1^*)-(\lambda_2m(\beta_{i2}-\delta_{i2})+\gamma_2)p_1^*]]\\&=\beta_{i2}(1-\lambda_2m\beta_{i2})\Sigma_1\\&=\frac{2\sigma_u}{m+1}\sqrt{\frac{k(m+1-mk)\Sigma_0}{m\left[4+m^2(m+1)^2\right]}}\end{aligned}$$

respectively, both of which can be written as $E_1[\pi_{in}]=\lambda_n\sigma_u^2/m$ for $n\in\{1,2\}$. ■

Proof of Proposition 2. We have

$$\begin{aligned} Var_1[x_{i1}] &= Var_1[\beta_{i1}s_i + z_1] \\ &= \beta_{i1}^2\Sigma_0 + \sigma_{z_1}^2 \\ &= \sigma_u\sqrt{\frac{m+1-mk}{mk}}, \end{aligned}$$

and

$$\begin{aligned} Var_1[x_{i2}] &= Var_1[\beta_{i2}s_i - \delta_{i2}p_1^*] \\ &= \beta_{i2}^2\Sigma_1 + (\beta_{i2}-\delta_{i2})^2(\Sigma_0 - \Sigma_1) \\ &= \frac{\sigma_u}{2}\sqrt{\frac{4k^2 + m^2(m+1)^4(1-k)^2}{mk(m+1-mk)}}. \end{aligned}$$

Apparently, overconfident insiders always underreact in period 1. They underreact in period 2 when the following condition is satisfied.

$$\left[8k - 2m^2(m+1)^4(1-k)\right][mk(m+1-mk)] < \left[4k^2 + m^2(m+1)^4(1-k)^2\right]\left[m(m+1) - 2m^2k\right].$$

■

Proof of Theorem 4. In period 2, insider 1 chooses x_{12} to solve

$$\begin{aligned} \pi_{12} &= \max_{x_{12}} E_k[x_{12}(v-p_2)|s_1, x_{21}, p_1^*] \\ &= \max_{x_{12}} E_k[x_{12}[v - (1+\gamma_2)p_1^* - \lambda_2(x_{12} + \beta_{22}s_2 - \delta_2 p_1^* + u_2)]|s_1, x_{21}, p_1^*] \\ &= \max_{x_{12}} x_{12}[k_1 s_1 - (1+\gamma_2)p_1^* - \lambda_2(x_{12} + \beta_{22}s_1 - \delta_2 p_1^*)]. \end{aligned}$$

The FOC delivers

$$x_{12} = \beta_{12}s_1 - \delta_1 p_1^*, \tag{A.44}$$

where

$$\begin{aligned} \beta_{12} &= \frac{k_1 - \lambda_2\beta_{22}}{2\lambda_2}, \\ \delta_1 &= \frac{1+\gamma_2 - \lambda_2\delta_2}{2\lambda_2}, \end{aligned}$$

and the SOC is $\lambda_2 > 0$. Similarly, insider 2 chooses

$$x_{22} = \beta_{22}s_2 - \delta_2 p_1^* \tag{A.45}$$

where

$$\beta_{22} = \frac{k_2 - \lambda_2\beta_{12}}{2\lambda_2},$$
$$\delta_2 = \frac{1+\gamma_2 - \lambda_2\delta_1}{2\lambda_2}.$$

Rearrangement yields

$$\beta_{12} = \frac{2k_1 - k_2}{3\lambda_2}, \tag{A.46}$$
$$\beta_{22} = \frac{2k_2 - k_1}{3\lambda_2}, \tag{A.47}$$
$$\delta_1 = \delta_2 = \frac{1+\gamma_2}{3\lambda_2}. \tag{A.48}$$

In addition, given s_1 and p_1^*, insider 1's profit in period 2 is

$$\pi_{12}(s_1, p_1^*) = \lambda_2 x_{12}^2 = \frac{1}{9\lambda_2}\left[(2k_1 - k_2)s_1 - (1+\gamma_2)p_1^*\right]^2.$$

In period 1, insider 1 chooses x_{11} to solve

$$\begin{aligned}
&\max_{x_{11}} E_k\left[x_{11}(v - p_1) + \pi_{12}(s_1, p_1^*) \middle| s_1\right] \\
=&\max_{x_{11}} E_k\left[x_{11}\left[v - \lambda_1(x_{11} + \beta_{21}s_2 + z_2 + u_1)\right] + \frac{1}{9\lambda_2}\left[(2k_1 - k_2)s_1 - (1+\gamma_2)\left(\lambda_1^* x_{11} + \lambda_2^*(\beta_{21}s_2 + z_2)\right)\right]^2 \middle| s_1\right] \\
=&\max_{x_{11}} x_{11}\left[k_1 s_1 - \lambda_1(x_{11} + \beta_{21}s_1)\right] + \frac{1}{9\lambda_2}\left[(2k_1 - k_2)s_1 - (1+\gamma_2)\left(\lambda_1^* x_{11} + \lambda_2^*\beta_{21}s_1\right)\right]^2 + \frac{\left[\lambda_2^*(1+\gamma_2)\right]^2\sigma_{z_2}^2}{9\lambda_2},
\end{aligned}$$

The FOC delivers

$$\left[k_1 - \lambda_1\beta_{21} - \frac{2\lambda_1^*(1+\gamma_2)(2k_1 - k_2)}{9\lambda_2} + \frac{2\lambda_1^*\lambda_2^*\beta_{21}(1+\gamma_2)^2}{9\lambda_2}\right]s_1 + 2\left[\frac{\left[\lambda_1^*(1+\gamma_2)\right]^2}{9\lambda_2} - \lambda_1\right]x_{11} = 0$$

Insider 1 must be indifferent across all values of x_{11} for the mixed trading strategy to hold in equilibrium, therefore it requires that

$$k_1 - \lambda_1\beta_{21} - \frac{2\lambda_1^*(1+\gamma_2)(2k_1 - k_2)}{9\lambda_2} + \frac{2\lambda_1^*\lambda_2^*\beta_{21}(1+\gamma_2)^2}{9\lambda_2} = 0,$$
$$\frac{\left[\lambda_1^*(1+\gamma_2)\right]^2}{9\lambda_2} - \lambda_1 = 0.$$

Similarly, insider 2 must be indifferent across all values of x_{21} for the mixed trading strategy to hold in equilibrium,

$$k_2 - \lambda_1 \beta_{11} - \frac{2\lambda_2^* (1+\gamma_2)(2k_2 - k_1)}{9\lambda_2} + \frac{2\lambda_1^* \lambda_2^* \beta_{11} (1+\gamma_2)^2}{9\lambda_2} = 0,$$

$$\frac{[\lambda_2^* (1+\gamma_2)]^2}{9\lambda_2} - \lambda_1 = 0.$$

Rearrangement yields

$$\beta_{11} = \frac{2(2k_1 - k_2)}{3\sqrt{\lambda_1 \lambda_2}} - \frac{k_1}{\lambda_1} \tag{A.49}$$

$$\beta_{21} = \frac{2(2k_2 - k_1)}{3\sqrt{\lambda_1 \lambda_2}} - \frac{k_2}{\lambda_1} \tag{A.50}$$

$$\lambda_1^* = \lambda_2^* = \frac{3\sqrt{\lambda_1 \lambda_2}}{1+\gamma_2} \tag{A.51}$$

Next, we turn to market makers' optimal pricing strategy in period 1 and we have

$$p_1 = E_1[v|y_1] = E_1[v|\beta_{11}s_1 + z_1 + \beta_{21}s_2 + z_2 + u_1] = \lambda_1 y_1,$$

where

$$\lambda_1 = \frac{(\beta_{11} + \beta_{21})\Sigma_0}{(\beta_{11} + \beta_{21})^2 \Sigma_0 + \sigma_{z_1}^2 + \sigma_{z_2}^2 + \sigma_u^2}, \tag{A.52}$$

Similarly,

$$p_1^* = E_1[v|x_{11}, x_{21}] = E_1[v|\beta_{11}s_1 + z_1, \beta_{21}s_2 + z_2] = \lambda_1^* x_{11} + \lambda_2^* x_{21},$$

where

$$\lambda_1^* = \frac{\beta_{11}\sigma_{z_2}^2 \Sigma_0}{(\beta_{11}^2 \sigma_{z_2}^2 + \beta_{21}^2 \sigma_{z_1}^2)\Sigma_0 + \sigma_{z_1}^2 \sigma_{z_2}^2},$$

$$\lambda_2^* = \frac{\beta_{21}\sigma_{z_1}^2 \Sigma_0}{(\beta_{11}^2 \sigma_{z_2}^2 + \beta_{21}^2 \sigma_{z_1}^2)\Sigma_0 + \sigma_{z_1}^2 \sigma_{z_2}^2}.$$

Because of (A.51), we obtain

$$\beta_{11}\sigma_{z_2}^2 = \beta_{21}\sigma_{z_1}^2, \tag{A.53}$$

and thus

$$\lambda_1^* = \frac{\beta_{11}\Sigma_0}{\beta_{11}(\beta_{11} + \beta_{21})\Sigma_0 + \sigma_{z_1}^2} = \frac{\beta_{21}\Sigma_0}{\beta_{21}(\beta_{11} + \beta_{21})\Sigma_0 + \sigma_{z_2}^2} = \lambda_2^* \tag{A.54}$$

In period 2, we can first determine γ_2 by using the martingale property of prices $E_1[p_2 - p_1^*|x_{11}, x_{21}] = 0$. It follows from $\gamma_2 p_1^* + \lambda_2(\beta_{12} + \beta_{22})E_1[v|x_{11}, x_{21}] - \lambda_2(\delta_1 + \delta_2)p_1^* = 0$ that

$$\gamma_2 = -\lambda_2(\beta_{12} + \beta_{22} - \delta_1 - \delta_2). \tag{A.55}$$

Substituting (A.46)-(A.48) into (A.55) yields

$$\gamma_2 = 2 - k_1 - k_2. \tag{A.56}$$

Market makers set price in period 2 according to

$$p_2 - p_1^* = \gamma_2 p_1^* + \lambda_2 y_2,$$

Moreover, we have

$$\begin{aligned} p_2 - p_1^* &= E_1 \left[v - p_1^* | p_1^*, y_2 \right] \\ &= E_1 \left[v - p_1^* \middle| \frac{\gamma_2}{\lambda_2} p_1^* + x_{12} + x_{22} + u_2 \right] \\ &= E_1 \left[v - p_1^* \middle| \left(\frac{2 - \gamma_2}{3\lambda_2} \right) (v - p_1^*) + u_2 \right] \end{aligned}$$

where the third equality comes from substituting (A.44), (A.45) and using (A.55), (A.48). Applying the projection theorem we obtain

$$\lambda_2 = \frac{3\lambda_2 \left(2 - \gamma_2\right) \Sigma_1}{\left(2 - \gamma_2\right)^2 \Sigma_1 + 9\lambda_2^2 \sigma_u^2},$$

which yields , because of (A.56),

$$\lambda_2 = \frac{\sqrt{\left(k_1 + k_2\right)\left(3 - k_1 - k_2\right)\Sigma_1}}{3\sigma_u}. \tag{A.57}$$

It is required that

$$k_1 + k_2 < 3. \tag{A.58}$$

In addition,

$$\Sigma_1 = Var_1 \left[v | p_1^* \right] = Var_1 \left[v | x_{11} + x_{21} \right] = \Sigma_0 - \frac{\left(\beta_{11} + \beta_{21}\right)^2 \Sigma_0^2}{\left(\beta_{11} + \beta_{21}\right)^2 \Sigma_0 + \sigma_{z_1}^2 + \sigma_{z_2}^2}.$$

■

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