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Abstract

We assume that the aim of informed institutions is to maximize the joint profits of multiple investing sessions. The model shows that when the aggregate informed trades are relatively large, institutions would reach agreement in private, delaying the use of the information. Such delaying action is quite different from prior studies adopting rational expectations models, which mainly infer that institutions obtain and use information immediately, and the action can explain some market anomalies.

Key words: Informed trading, institutions, multiple transactions, market anomalies

I. Introduction

The role of institutions is increasingly important in the financial market (Gompers and Metrick (2001) and Sheppard (2013)). Firstly, they hold the 60% equities of the U.S. stock market and contribute to 90% daily trading volume. Secondly, they collect the relevant information of stock value and pass it on to other investors through transactions. Thirdly, they play an important role in the corporate governance of firms (Gillan and Starks (2003) and McCahery, Sautner, and Starks (2016)). Finally, they take the arbitrage of market anomalies to get the market back to being efficient (Lewellen (2011)).

Many studies of noisy rational expectations models deeply investigate the issues related to informed trading timing of institutions. For example, Kyle (1985) discusses how an insider uses the monopolized information; Holden and Subrahmanyam (1992) analyze many institutions with homogeneous private information; Foster and Viswanathan (1994) investigate how the informed traders employ their common information and the extra heterogeneous

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information; Foster and Viswanathan (1996) examine the influence of correlations among private information on trading behavior of institutions; Wang (1998) discusses institutions' informed trading and their heterogeneous beliefs about private information. Back, Cao, and Willard (2000) analyze the imperfect competition among informed traders, such as the influence of information correlation and number of informed traders. All above-mentioned studies come to a conclusion that institutions with homogeneous private information would use the information immediately and fully.

However, these models only discuss the behavior in one investing session, which implies that the institutions in these models pursue the maximizing benefits of the current investing session. In the real financial markets, institutions are not only involved in one but often in many investing sessions. If the involved investing sessions are not completely unrelated, the rational behavior of institutions should be to maximize the aggregate benefits of the current and future sessions, rather than just maximizing the benefits of the current investing session.[1] Based on this realistic prospection, this paper re-examines how the institutions decide their informed trading strategy in any of investing sessions, whether such decisions differ from the past literature conclusions, and how this trading strategy would influence the behavior of stock prices.

Based on the noisy rational expectations model of Holden and Subrahmanyam (2002), this paper applies the single investing session as basic unit and duplicates the unit continuously to design the model with multiple investing sessions. The model structure of a basic unit is formally described as follows. In any investing session, all traders invest one stock and there are four time-points in the session: dates 0, 1, 2, and 3. Date 0 is the beginning of investing session; the stock is traded at dates 1 and 2; Date 3 is the closing of investing session and the liquidation value of the stock is disclosed. The institutions, at date 0, would choose either date 1 or date 2 to use the private information that is relevant to the liquidation value of the stock.

We find the following. If some institutions use the information at date 1 and others use the information at date 2, the former could obtain higher expected utility than the latter. The intuitive reason for this finding is easy to understand. The earlier use of information represents more informed trading opportunities and thus more benefits. As a result, the expected utility of institutions that use information at date 1 would be higher than that of institutions that use information at date 2. However, if all institutions choose the same date (date 1 or date 2) to use the information, it would be two alternative results. First, when

[1] Past literature (DeLong et al. (1990), Barberis, Shleifer and Vishny (1998), Daniel, Hirshleifer, and Subrahmanyam (1998), and Sias (2004)) mentions that investors' trading behavior in current session does affect the following behavior of themselves or other investors. It implies that the relations among investing sessions are not completely unrelated.

the private information is not precise enough and the institutions are not numerous (resulting in that the aggregate informed trades are not large), all of the institutions are inclined to choose date 1 and could obtain higher expected utility than choosing date 2. Second, when the private information is precise enough or the institutions are numerous (resulting in that the aggregate informed trades are large enough), the above-mentioned result is reversed. The second finding is caused by the price impact of aggregate informed trades. In the different market parameter, the benefits of institutions that use information early might be higher or lower than the harm caused by the impact of price shocks. For example, a large number of aggregate informed trades bring huge price impacts, and thus institutions that early use the private information contrarily bear low profit. Therefore, in the case of large aggregate trades, institutions would tend to use information later rather than earlier.

These findings suggest that there is no interior equilibrium in any investing session. The reason is any institution that chooses date 2 unavoidably wants to become one of the institutions that choose date 1. Moreover, all institutions that choose date 1 to use the information could be one equilibrium since under that situation none of the institutions wants to change its choice. In addition, if institutions could reach agreement in private, then all institutions together choosing date 2 could be the other equilibrium. Section III.C. describes a feasible design to let each institution have the ability to detect the departure of other institutions and to punish the "traitor," certainly preventing any institution from deviating from the private agreement. Therefore, there are two equilibriums of informed trading strategies in any investing session of our model. When the aggregate informed trades are not large, all institutions would together choose the early date (date 1) to use the information; when the aggregate informed trades are sufficiently large, they would together choose the late date (date 2) to use the information. It is noted that, if institutions take each investing session as independent, the private agreement among institutions is never possible. This displays the important result of this paper that all institutions could together postpone using the information that is related to the assumption that institutions pursue to maximize the aggregate benefits of the current and future sessions.

The conclusion of the model can explain the phenomena of excess volatility and price momentum when satisfying some conditions. Under the situation in which the aggregate informed trades are large, the equilibrium is all institutions choose date 2 to use the stock's private information. As a result, the transaction price at date 1 contains no fundamental information of the stock. Under such circumstances, the liquidity trades have a great influence on the date 1 price, and hence the date 1 price will be with large fluctuation. In addition, the situation of all institutions choosing date 2 also yields the following price patterns: the date 1 price includes no information; the date 2 price reveals some of the private

information of stock; and the date 3 price discloses all liquidation value of the stock. This price pattern, which gradually discloses the stock's liquidation value, will result in a monotonously decreased risk premium by the market and thus let the stock returns exhibit continuation. Hence, under the condition of sufficiently large aggregate informed trades, the model can explain the phenomena of excess volatility and price momentum.

The model proves that stocks which are small in size or receive less attention from analysts are more likely to show price momentum than those stocks which are large in size or receive more attention from analysts. This is because the informed trading proportion of small-sized stocks is on average higher than that of large-sized stocks, and the value provided by private information for those stocks attracting low levels of attention amongst analysts is more than that for those stocks receiving much attention from analysts. Both above-mentioned reasons make the aggregate informed trades large, bring the tendency of institutions to choose date 2 together using the information, and thus the stocks are likely to exhibit the price momentum.

The model can explain the "investigative herding" behavior of institutions to some extent. According to the definition of Hirshleifer, Subrahmanyam, and Titman (1994), the "investigative herding" behavior describes institutions that would together acquire the private information of the same stock. Although in our model we focus on a single stock, the corner-type equilibrium of the model (all institutions would choose either date 1 or date 2 to acquire private information of the stock) could be applied to the following stock-choice problem. When there are many stocks available for investment and these stocks are with exactly the same properties except the disclosing time of fundamental values, it is concluded that all institutions would choose the stock with close (far) disclosing time and acquire its private information under the market parameter values where the aggregate informed trades are (not) large enough. Such behavior of all institutions choosing to acquire the private information of the same stock is by analogy with investigative herding.

Finally, the conclusion of our model could more or less explain the phenomenon that active arbitrage and mispricing co-exist. Imagine that the institutions acquire the private information and thus know whether the stock price is in error and the degree of mispricing. The conclusion proves that, when the aggregate informed trades are large in the market (means active arbitrage), institutions would not immediately acquire and use the information (if so, the market anomalies will be eliminated right now), but choose to postpone acquiring and using the information for trading. As a result, the mispricing (or market anomalies) would last for a period. Therefore, this paper supports that some market anomalies may still be robust in the era of active arbitrage.

This study attempts to supplement the findings of earlier studies. Firstly, different from prior literature of rational expectations model (Kyle (1985),

Holden and Subrahmanyam (1992), Foster and Viswanathan (1994, 1996), Wang (1998), and Back, Cao, and Willard (2000)), we consider that the rational institutions should concern the aggregate benefits of the current and future sessions. And thus we obtain the conclusion that, when the aggregate informed trades are large, all institutions might form the private agreement and together postpone using the information. Undoubtedly, such argument is different from the common conclusion of past studies that institutions with homogeneous private information would use the information immediately and fully.

Next, actually some other financial models also claimed that the institutions would postpone to use the information. For example, Hirshleifer, Subrahmanyam, and Titman (1994) assume that some institutions obtain and use information earlier due to luck, and the rest of institutions would only obtain and use the information at a later time. Holden and Subrahmanyam (2002) assume the institution must wait for a period of time after putting into the resources, and thus all institutions would be late to use the information. DeLong et al. (1990) assume that there are the positive feedback traders in the market, and the institutions will wait for these traders to push the price away from the stock's true value to obtain more benefits. Compared with the above-mentioned studies, the assumption of this paper is relatively robust.

Thirdly, the mainstream of financial literature tends to set up some biased behavior of (irrational) traders to explain market anomalies. For example, the positive feedback traders in DeLong et al. (1990), overconfidence in Dumas, Kurshev, and Uppal (2009), representativeness bias in Barberis, Shleifer and Vishny (1998), and biased self-attribution in Daniel, Hirshleifer, and Subrahmanyam (1998). Jegadeesh and Titman (1993, 2001) argue that the overreaction of traders leads to the momentum effects that are significant in small firms. Hong, Lim, and Stein (2000) and Zhang (2006) also conclude that biased behavior of traders let the momentum profits higher for firms with low analyst coverage. Unlike mainstream studies, this paper does not assume any traders with behavioral error, but assumes institutions would maximize the aggregate benefits of the current and future sessions. It is proved that, under some market parameter values, institutions would together choose to late use the information, and such conclusion can explain the market anomalies to some degree. Hence, this paper can be seen providing a rational explanation to understand market anomalies, besides the argument of mainstream literature.

The remainder of this paper is organized as follows. Section II provides an introduction to the basic framework and settings, followed by analysis of the model equilibrium in Section III. Since the two corner equilibria are confirmed, the ways in which informed traders choose their informed trading timing are then determined. Market phenomena, such as the effects on price volatility and continuity, are discussed in Section IV, based upon the features of timing selection. Finally, Section V contains the conclusions and recommendations.

II. Basic Framework

Holden and Subrahmanyam (2002) provide the noisy rational expectations model in an investing session. We take it as the basic unit and duplicate it continuously to compose the noisy rational expectations model with infinite investing sessions (each basic unit corresponds to an investing session). The basic unit of our model has two differences from the model of Holden and Subrahmanyam (2002). First, there is one investing session in the Holden and Subrahmanyam (2002) model, implying the institutions would not consider the influence on the following sessions. But in our model, institutions want to maximize the aggregate benefits, so they need to consider the influence of current session's decision on the following sessions. In addition, the institutions of Holden and Subrahmanyam (2002) cannot choose the informed trading timing. Some of them are set to use the information late just due to the assumption, which assumes institutions must wait for some time to use their information after inputting resources. However, the institutions in each investing session of our model can choose to use the information at an early or late time-point.

Next section describes formally the structure of one investing session of our model. Each investing session has four dates, dates 0, 1, 2, and 3, where beginning date is date 0 and date 3 is ending date. Investors will trade on the same stock, but some of them obtain private information of the stock and the others do not. These investors interact with each other until the ending date of the session. The stock is traded at dates 1 and 2 and the liquidation value of the stock is disclosed at date 3. This liquidation value, V, is drawn from a normal distribution with mean 0 and variance 1. The transaction prices of stock at dates 1 and 2 are denoted by P_1 and P_2, respectively. The liquidity shocks of stock are random and equal to Z_1 at date 1, and Z_2 at date 2. For simplicity, these random shocks are normally distributed with mean 0 and variance σ_Z^2.

There are two types of rational expectations traders: institutions and individuals. The former can obtain the private information of stock but the latter cannot. At date 0, there are three events happening in sequence. First of all, the private information of stock, represented by $S = V + \varepsilon$, is available to the market, where ε is error term as a normally distributed random variable with mean 0 and variance σ_ε^2. Second, the institutions decide either date 1 or date 2 to use the information S. Third, after the decision, the market consists of a proportion p of institutions that choose date 1 to use S (named early-use institutions), along with the proportion $1-p$ of institutions that choose date 2 (named late-use institutions). Individuals are unable to observe S directly but they can infer some of the signals of private information from the transaction prices P_1 and P_2. Assume the number of individuals as N and the number of institutions as

M (comprised of pM early-use institutions and $(1-p)M$ late-use institutions). Since M and N can be interpreted as the proportions of each type of investors in the economy, this study normalizes $M+N=1$. Both institutions and individuals are assumed to have negative exponential utility over terminal wealth, W, with a common risk aversion coefficient, γ; that is, $U(W)=-e^{-\gamma W}$. For simplicity, our model assumes that the endowment of each investor is normalized to 0, the random variables V, ε, Z_1, and Z_2 are independent of each other, and the market settings of the model (depicted by the parameters M, σ_Z^2, σ_ε^2 and γ) are the common knowledge possessed by all institutions and individuals.

The complete equilibrium is implemented by computing the value of p and the accompanying trading equilibrium. Firstly, we describe how the market reaches the trading equilibrium with a given p-value (hereafter named accompanying trading equilibrium). When all institutions have made their timing decisions at date 0, there will have a specific value of p representing the results of their timing selections. Under this specific value of p, all institutions and individuals determine their optimal demand functions at dates 1 and 2 by the standard procedure of maximizing their expected utility. Then using the market-clearing condition obtains the equilibrium prices at dates 1 and 2. Thus, for this specific p, the accompanying trading equilibrium is achieved.

Next, we discuss the optimal time of using the information for the institutions that continue investing in the financial market, i.e., the determination of the variable p. Let $EU^E(p)$ and $EU^L(p)$ denote the expected utility of early-use and late-use institutions, respectively. For any $p^* \in (0,1)$, if the condition $EU^E(p^*)=EU^L(p^*)$ is satisfied and any institution changing its current choice would decrease its expected utility, then the p^* is an equilibrium. We refer to this as an "interior equilibrium". It is likely that the "corner equilibrium" could also exist in our model. For example, if $EU^E(1)>EU^L(1)$, all institutions using the information at date 1 will be an equilibrium.

III. Model Equilibrium

This section computes the complete equilibrium in each investing session of our model referring to the method of Holden and Subrahmanyam (2002). For every possible value of p, Section III.A. computes the accompanying trading equilibrium and Section III.B. calculates the corresponding expected utilities of institutions. Section III.C. focuses on the institutions that continue investing in the financial market and discusses how they decide their informed trading strategy (obtaining p^*). Finally, Section III.D. solves the complete equilibrium in each investing session of our model which is formed by the p^* and its accompanying trading equilibrium.

A. Accompanying Trading Equilibrium with a Given p-Value

In this section, it is assumed that the value of p is given. Under the assumption, there will be p proportion early-use institutions and $(1-p)$ proportion late-use institutions within the market.[2] For convenience of analysis, we consider the linear equilibria (analogous with the traditional dynamic rational expectations model). The procedure to derive the linear equilibria is that, first of all, we postulate that the stock prices are linear functions of private information signal and the liquidity shocks. Afterward, we compute this market equilibrium and verify that the conjecture is consistent with the market equilibrium we derive. The prices at dates 1 and 2 are hypothesized as the following:

$$P_1 = aS + bZ_1, \tag{1}$$

$$P_2 = cS + dZ_1 + eZ_2. \tag{2}$$

The price coefficients a, b, c, d, and e are denoted as follows. In the price function P_1, a represents the percentage of private information S reflected in the price P_1. The coefficient a conforms with $0 \leqq a \leqq 1$. When $a=0$, it means that P_1 cannot reflect S; conversely, when $a=1$, it means that P_1 fully reflects S. The coefficient b represents the effect of liquidity shocks Z_1 on P_1. When Z_1 is positive, the amount that must be held by the investors in the market increases and thus price must drop. This implies that b must be a negative value. Since a and b determine the response of price to information and liquidity shocks, they are sometimes referred to as response rates. In the price function P_2, c and d have similar meanings as a and b in P_1, respectively. Since there are additional liquidity shocks added in the market at date 2, in the price function P_2, e represents the response of P_2 to the Z_2.

Let x_1^E and $x_1^E + x_2^E$ denote the demand (holdings) of each early-use institution, x_1^L and $x_1^L + x_2^L$ denote the demand of each late-use institution, and x_1^U and $x_1^U + x_2^U$ denote the demand of each individual at dates 1 and 2, respectively. Also let ϕ_{i1}^E and ϕ_{i2}^E denote the information set of early-use institutions, ϕ_{i1}^L and ϕ_{i2}^L denote the information set of late-use institutions, and ϕ_{u1} and ϕ_{u2} denote the information set of individuals at dates 1 and 2, respectively. It is easily understood that $\phi_{i1}^E = \{S, P_1\}$, $\phi_{i2}^E = \{S, P_1, P_2\}$, $\phi_{i1}^L = \{P_1\}$, $\phi_{i2}^L = \{S, P_1, P_2\}$, $\phi_{u1} = \{P_1\}$, and $\phi_{u2} = \{P_1, P_2\}$.

The equilibrium concept adopted for our model is the so-called "rational expectations equilibrium" (REE); hence, the equilibrium demand of each

[2] Such an assumption is similar with Hirshleifer, Subrahmanyam, and Titman (1994), which is exogenously given a fixed proportion of institutions that acquire and use the information in the early time and the others use the information in the later time.

investor on each date is obtained by maximizing their expected utility based upon the information available at that date. This equilibrium demand is derived in the appendix, and the following proposition outlines the results.

PROPOSITION 1:

For all investors in our model, the optimal demand functions at date 1 and date 2 are given by:

$$x_1^E + x_2^E = \frac{\lambda \cdot S - P_2}{\gamma \cdot \tau_i}, \tag{3}$$

$$x_1^E = \left(\frac{\lambda}{\gamma \cdot \tau_i} + \frac{c}{\gamma \cdot e^2 \cdot \sigma_z^2}\right) \cdot S + \left(\frac{d}{\gamma \cdot e^2 \cdot \sigma_z^2}\right) \cdot Z_1 - \left(\frac{1}{\gamma \cdot \tau_i} + \frac{1}{\gamma \cdot e^2 \cdot \sigma_z^2}\right) \cdot P_1, \tag{4}$$

$$x_1^L + x_2^L = \frac{\lambda \cdot S - P_2}{\gamma \cdot \tau_i}, \tag{5}$$

$$x_1^L = \left(\frac{c^L}{\gamma \cdot G_{11}^L} + \frac{G_{11}^L - G_{12}^L}{G_{11}^L} \cdot \frac{k^L - c^L}{\gamma \cdot \tau_i}\right) \cdot S + \left(\frac{b}{a}\right) \cdot \left(\frac{c^L}{\gamma \cdot G_{11}^L} + \frac{G_{11}^L - G_{12}^L}{G_{11}^L} \cdot \frac{k^L - c^L}{\gamma \cdot \tau_i}\right) \cdot Z_1 + \left(\frac{-1}{\gamma \cdot G_{11}^L}\right) \cdot P_1, \tag{6}$$

$$x_1^U + x_2^U = \left(\frac{k_1^U + k_2^U}{\gamma \cdot \tau_u}\right) \cdot S + \cdot \left(\frac{\left(\frac{b}{a}\right) \cdot k_1^U}{\gamma \cdot \tau_u} - \frac{\sigma_\varepsilon^2 \cdot k_2^U}{M \cdot \tau_u}\right) \cdot Z_1 + \cdot \left(-\frac{\sigma_\varepsilon^2 \cdot k_2^U}{M \cdot \tau_u}\right) \cdot Z_2 + \left(\frac{-1}{\gamma \cdot \tau_u}\right) \cdot P_2, \tag{7}$$

$$x_1^U = \left(\frac{c^U}{\gamma \cdot G_{11}^U} + \frac{G_{11}^U - G_{12}^U}{G_{11}^U} \cdot \frac{k^U - c^U}{\gamma \cdot \tau_u}\right) \cdot S + \left(\frac{b}{a}\right) \cdot \left(\frac{c^U}{\gamma \cdot G_{11}^U} + \frac{G_{11}^U - G_{12}^U}{G_{11}^U} \cdot \frac{k^U - c^U}{\gamma \cdot \tau_u}\right) \cdot Z_1 + \left(\frac{-1}{\gamma \cdot G_{11}^U}\right) \cdot P_1, \tag{8}$$

where $\lambda, \tau_i, c^L, k^L, c^U, k^U, \tau_u, k_1^U, k_2^U$, G_{11}^L, G_{12}^L, G_{11}^U, and G_{12}^U are constant functions derived in the appendix.

Given that, in equilibrium, the prices on each date have to clear the market, the prices at dates 1 and 2 can be obtained by solving the market-clearing condition as follows:

Date 1: $p \cdot M \cdot x_1^E + (1-p) \cdot M \cdot x_1^L + (1-M) \cdot x_1^U = Z_1$

Date 2: $p \cdot M \cdot \left(x_1^E + x_2^E\right) + (1-p) \cdot M \cdot \left(x_1^L + x_2^L\right) + (1-M) \cdot \left(x_1^U + x_2^U\right) = Z_1 + Z_2$

Through simple substitution and arrangement, we obtain implicit expressions for the constants *a*, *b*, *c*, *d*, and *e*, which simultaneously satisfy the market-clearing condition and correspond to the optimal demand functions of all investors. The results are shown in Proposition 2, and the derivations are provided in the Appendix.

PROPOSITION 2:

In our model, the accompanying trading equilibrium is given by:

$$a=\frac{pM\left(\frac{\lambda}{\gamma\tau_i}+\frac{c}{\gamma e^2\sigma_z^2}\right)+(1-p)M\left(\frac{c^L}{\gamma G_{11}^L}+\frac{G_{11}^L-G_{12}^L}{G_{11}^L}\cdot\frac{k^L-c^L}{\gamma\tau_i}\right)+(1-M)\left(\frac{c^U}{\gamma G_{11}^U}+\frac{G_{11}^U-G_{12}^U}{G_{11}^U}\cdot\frac{k^U-c^U}{\gamma\tau_u}\right)}{pM\left(\frac{1}{\gamma\tau_i}+\frac{1}{\gamma e^2\sigma_z^2}\right)+(1-p)M\left(\frac{1}{\gamma G_{11}^L}\right)+(1-M)\left(\frac{1}{\gamma G_{11}^U}\right)},$$

$$b=\frac{pM\left(\frac{d}{\gamma e^2\sigma_z^2}\right)+(1-p)M\left(\frac{b}{a}\right)\left(\frac{c^L}{\gamma G_{11}^L}+\frac{G_{11}^L-G_{12}^L}{G_{11}^L}\cdot\frac{k^L-c^L}{\gamma\tau_i}\right)+(1-M)\left(\frac{b}{a}\right)\left(\frac{c^U}{\gamma G_{11}^U}+\frac{G_{11}^U-G_{12}^U}{G_{11}^U}\cdot\frac{k^U-c^U}{\gamma\tau_u}\right)-1}{pM\left(\frac{1}{\gamma\tau_i}+\frac{1}{\gamma e^2\sigma_z^2}\right)+(1-p)M\left(\frac{1}{\gamma G_{11}^L}\right)+(1-M)\left(\frac{1}{\gamma G_{11}^U}\right)},$$

$$c=\frac{\frac{M\lambda}{\gamma\tau_i}+\frac{1-M}{\gamma\tau_u}\left(k_1^U+k_2^U\right)}{\frac{M}{\gamma\tau_i}+\frac{1-M}{\gamma\tau_u}},$$

$$d=\frac{\frac{1-M}{\gamma\tau_u}\left(\left(\frac{b}{a}\right)k_1^U-\frac{\gamma\sigma_\varepsilon^2}{M}k_2^U\right)-1}{\frac{M}{\gamma\tau_i}+\frac{1-M}{\gamma\tau_u}},$$

$$e=\frac{\frac{1-M}{\gamma\tau_u}\left(-\frac{\gamma\sigma_\varepsilon^2}{M}k_2^U\right)-1}{\frac{M}{\gamma\tau_i}+\frac{1-M}{\gamma\tau_u}}.$$

where $\lambda, \tau_i, c^L, k^L, c^U, k^U, \tau_u, k_1^U, k_2^U$, G_{11}^L, G_{12}^L, G_{11}^U, and G_{12}^U are functions of the price coefficients *a*, *b*, *c*, *d*, and *e*.

Proposition 2 shows a system of five non-linear equations in five unknowns (*a*, *b*, *c*, *d*, and *e*). If we will obtain the exact values of the five price coefficients when we solve the non-linear system, the linear conjecture of Equations (1) and (2) is proved correct and the linear accompanying trading equilibrium is achieved.

B. Determining the Corresponding Expected Utilities of Institutions

In this section, we employ the method introduced by Hirshleifer, Subrahmanyam, and Titman (1994) to calculate the corresponding expected

utilities of institutions and discuss its implications. The wealth of each institution at date 3 is the function of p, as follows:

$$W^j(p)=\left(x_1^j(p)+x_2^j(p)\right)\cdot V-x_1^j(p)\cdot P_1-x_2^j(p)\cdot P_2,$$

where $j=E$, L respectively indicates early-use and late-use institutions. Substituting for P_1, P_2, $x_1^E+x_2^E$, and x_1^E in respective Equations (1), (2), (3), and (4) provides the terminal wealth of early-use institutions, as follows:

$$\begin{aligned}W^E(p)=&I_1(p)\cdot S^2+I_2(p)\cdot S\cdot\varepsilon+I_3(p)\cdot S\cdot Z_1+I_4(p)\cdot S\cdot Z_2+I_5(p)\cdot\varepsilon^2\\&+I_6(p)\cdot\varepsilon\cdot Z_1+I_7(p)\cdot\varepsilon\cdot Z_2+I_8(p)\cdot Z_1^2+I_9(p)\cdot Z_1\cdot Z_2+I_{10}(p)\cdot Z_2^2,\end{aligned}$$

where the $I_m(p)$, for $1\le m\le 10$, are dependent upon a, b, c, d, and e in a complicated non-linear way. Similarly, substituting for P_1, P_2, $x_1^L+x_2^L$, and x_1^L in Equations (1), (2), (5), and (6), we have the terminal wealth of each late-use institution as :

$$\begin{aligned}W^L(p)=&J_1(p)\cdot S^2+J_2(p)\cdot S\cdot\varepsilon+J_3(p)\cdot S\cdot Z_1+J_4(p)\cdot S\cdot Z_2+J_5(p)\cdot\varepsilon^2\\&+J_6(p)\cdot\varepsilon\cdot Z_1+J_7(p)\cdot\varepsilon\cdot Z_2+J_8(p)\cdot Z_1^2+J_9(p)\cdot Z_1\cdot Z_2+J_{10}(p)\cdot Z_2^2,\end{aligned}$$

where the $J_m(p)$, for $1\le m\le 10$, are once again dependent upon a, b, c, d, and e in a complicated non-linear way.[3]

The expected utility of all institutions is a function of their terminal wealth, $EU(W^j(p))=E[-\exp(-\gamma W^j(p))]$; by defining a random vector $Y\equiv[S\varepsilon Z_1 Z_2]^T$, where Y is a normal vector with zero-mean and variance-covariance matrix Σ, we can obtain a square and symmetric matrix $A^j(p)$, such that $\gamma W^j(p)=Y^T A^j(p)Y$ since the wealth levels of the early-use and late-use institutions are quadratic forms of multivariate normal random variables. The expected utility of each institution is therefore presented as:

$$EU^j(p)=E\left[-\exp\left(-Y^T A^j(p)Y\right)\right].$$

Applying Lemma A1 in the appendix, the expected utility of agent j can be solved, taking the form of:

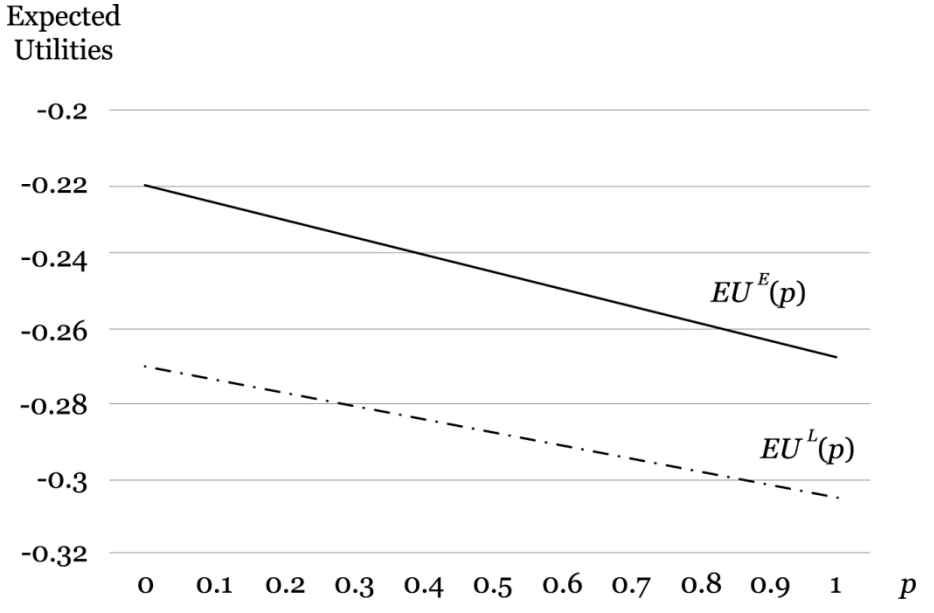
$$EU^j(p)=-\left|\Sigma-\frac{1}{2}\right|\cdot\left|2A^j(p)+\Sigma^{-1}\right|-\frac{1}{2}.$$

The expression for $EU^j(p)$ is too complex to analyze; we therefore focus on numerical simulations in the remainder of this section. The complete numerical procedure begins with the calculation of the price coefficients a, b, c, d, and e given a fixed p-value, followed by the computation of the values of

3 The expressions for $I_m(p)$ and $J_m(p)$ are provided in the appendix.

$EU^E(p)$ and $EU^L(p)$; the procedure is repeated for all possible values of p. Here the basic market parameter values used for our numerical simulations are $\gamma = 2.5, \sigma_\varepsilon^2 = 2.0, M = 0.4,$ and $\sigma_Z^2 = 0.4$.[4] Finally, we discuss the implications about market equilibrium.

Under the setting of these basic parameter values, the expected utilities for early-use and late-use institutions are as arranged in Figure 1, from which an interesting result is that for every $p \in (0,1)$, the early-use institutions can obtain a higher expected utility than the late-use institutions.



p	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
$EU^E(p)$	-0.220	-0.225	-0.230	-0.234	-0.239	-0.244	-0.249	-0.253	-0.258	-0.262	-0.267
$EU^L(p)$	-0.270	-0.274	-0.277	-0.281	-0.284	-0.288	-0.292	-0.295	-0.298	-0.302	-0.305

Figure 1. The Expected Utilities of the Early-Use and Late-Use Institutions under the Standard Parameters

This figure presents the numerical results of expected utilities of the early-use and late-use institutions under the standard parameters $\gamma = 2.5, \sigma_\varepsilon^2 = 2, M = 0.4,$ and $\sigma_Z^2 = 0.4$, where $EU^E(p)$ and $EU^L(p)$ represent the expected utilities of the early-use and late-use institutions, respectively. The parameter p represents the proportion of these institutions that will choose to acquire the information at date 1; γ represents the risk aversion coefficient; M represents the proportion of institutions; σ_ε^2 and σ_Z^2 represent the variances of signal error term and liquidity shock, respectively. There are two findings can be drawn from this table. First, there is a decline in the expected utilities for both early-use and late-use institutions with an increase in the p-values. Second, no matter what the p-value is, the early-use institutions can obtain a higher expected utility than the late-use institutions.

4 Refer to Hirshleifer, Subrahmanyam, and Titman (1994) and Holden and Subrahmanyam (1996, 2002) for details of the basic parameters values.

Intuitively, the early-use institutions obtain more chances of informed trading than the late-use institutions. Since informed trading can acquire positive benefits from the counterparty, institutions will undoubtedly prefer to use the information at date 1 rather than at date 2. The Hirshleifer, Subrahmanyam, and Titman (1994) model also yields the similar result that the early informed get higher expected utility than the later informed. This finding also brings two inferences for the equilibrium in our model. First, there is no interior equilibrium. Because in the situation of $p \in (0,1)$, any late-use institution unavoidably wants to become one of the early-use institutions. Second, all institutions choosing early to acquire the information could be one equilibrium of the model, since under such situation none of the institutions wants to change its choice (to be one of the late-use institutions whose expected utility is relatively low).

Now, we turn to examine whether the above finding will hold under the other parameter values. To perform this examination, we carry out numerical simulations where the parameter values are extended, with the values of M, γ, σ_ε^2 and σ_Z^2 being replaced referred to the basic parameter values, and the results are summarized in Tables I, II, III, and IV.[5] The results clearly show that the selection of specific parameter values is irrelevant.

Table I

The Impact of the Proportion of Institutions (M) on the Expected Utilities of the Early-Use and Late-Use Institutions

This table presents the numerical simulations of expected utilities of the early-use and late-use institutions given different proportions of institutions, where $EU^E(p)$ and $EU^L(p)$ represent the expected utilities of the early-use and late-use institutions, respectively. The standard parameters are $\gamma = 2.5, \sigma_\varepsilon^2 = 2, M = 0.4,$ and $\sigma_Z^2 = 0.4$. The parameter p represents the proportion of these institutions that will choose to acquire at date 1; γ represents the risk aversion coefficient; M represents the proportion of institutions; σ_ε^2 and σ_Z^2 represent the variances of signal error term and liquidity shock, respectively. The above-mentioned two characteristics still can be drawn from the table. First, there is a decline in the expected utilities for both early-use and late-use institutions with an increase in the p-values. Second, no matter what the p-value is, early-use institutions can expect a higher utility than late-use institutions. The results clearly show that the selection of specific parameter values for the proportion of institutions is irrelevant.

p		0	0.1	0.3	0.5	0.7	0.9	1
M=0.1	$EU^E(p)$	-0.205	-0.206	-0.208	-0.210	-0.213	-0.215	-0.216
	$EU^L(p)$	-0.242	-0.243	-0.244	-0.246	-0.248	-0.250	-0.250
M=0.3	$EU^E(p)$	-0.215	-0.218	-0.225	-0.232	-0.239	-0.246	-0.249
	$EU^L(p)$	-0.260	-0.263	-0.268	-0.274	-0.279	-0.284	-0.287
M=0.5	$EU^E(p)$	-0.225	-0.231	-0.244	-0.256	-0.268	-0.279	-0.285
	$EU^L(p)$	-0.280	-0.284	-0.294	-0.303	-0.312	-0.320	-0.324
M=0.7	$EU^E(p)$	-0.234	-0.244	-0.263	-0.281	-0.299	-0.314	-0.321
	$EU^L(p)$	-0.299	-0.307	-0.321	-0.334	-0.346	-0.356	-0.361
M=0.9	$EU^E(p)$	-0.241	-0.255	-0.283	-0.309	-0.331	-0.349	-0.357
	$EU^L(p)$	-0.318	-0.329	-0.349	-0.366	-0.380	-0.392	-0.397

5 All of the parameters are simultaneously varied in the unreported numerical results. The nature of the results remains unchanged under such a wide range of parameter values.

Table II
The Impact of the Signal Error Term's Variance (σ_ε) on the Expected Utilities of the Early-Use and Late-Use Institutions

This table presents the numerical simulations of expected utilities of the early-use and late-use institutions given different signal error term's variances, where $EU^E(p)$ and $EU^L(p)$ represent the expected utilities of the early-use and late-use institutions, respectively. The standard parameters are $\gamma = 2.5$, $\sigma_\varepsilon^2 = 2$, $M = 0.4$, and $\sigma_z^2 = 0.4$. The parameter p represents the proportion of these institutions that will choose to acquire at date 1; γ represents the risk aversion coefficient; M represents the proportion of institutions; σ_ε^2 and σ_z^2 represent the variances of signal error term and liquidity shock, respectively. The above-mentioned two characteristics still can be drawn from the table. First, there is a decline in the expected utilities for both early-use and late-use institutions with an increase in the p-values. Second, no matter what the p-value is, early-use institutions can expect a higher utility than late-use institutions. The results clearly show that the selection of specific parameter values for the signal error term's variances is irrelevant.

p		0	0.1	0.3	0.5	0.7	0.9	1
$\sigma_\varepsilon^2 = 0.1$	$EU^E(p)$	-0.084	-0.122	-0.245	-0.355	-0.449	-0.513	-0.536
	$EU^L(p)$	-0.353	-0.434	-0.502	-0.567	-0.598	-0.628	-0.640
$\sigma_\varepsilon^2 = 0.25$	$EU^E(p)$	-0.119	-0.138	-0.181	-0.227	-0.273	-0.312	-0.328
	$EU^L(p)$	-0.293	-0.322	-0.361	-0.390	-0.416	-0.435	-0.440
$\sigma_\varepsilon^2 = 1$	$EU^E(p)$	-0.186	-0.194	-0.210	-0.226	-0.243	-0.259	-0.267
	$EU^L(p)$	-0.266	-0.273	-0.286	-0.299	-0.312	-0.323	-0.328
$\sigma_\varepsilon^2 = 2$	$EU^E(p)$	-0.220	-0.225	-0.234	-0.244	-0.253	-0.262	-0.267
	$EU^L(p)$	-0.270	-0.274	-0.281	-0.288	-0.295	-0.302	-0.305
$\sigma_\varepsilon^2 = 10$	$EU^E(p)$	-0.268	-0.269	-0.272	-0.274	-0.276	-0.278	-0.279
	$EU^L(p)$	-0.281	-0.282	-0.283	-0.285	-0.286	-0.288	-0.289

Table III
The Impact of the Risk Aversion Coefficient (γ) on the Expected Utilities of the Early-Use and Late-Use Institutions

This table presents the numerical simulations of expected utilities of the early-use and late-use institutions given different risk aversion coefficients, where $EU^E(p)$ and $EU^L(p)$ represent the expected utilities of the early-use and late-use institutions, respectively. The standard parameters are $\gamma = 2.5$, $\sigma_\varepsilon^2 = 2$, $M = 0.4$, and $\sigma_z^2 = 0.4$. The parameter p represents the proportion of these institutions that will choose to acquire at date 1; γ represents the risk aversion coefficient; M represents the proportion of institutions; σ_ε^2 and σ_z^2 represent the variances of signal error term and liquidity shock, respectively. The above-mentioned two characteristics still can be drawn from the table. First, there is a decline in the expected utilities for both early-use and late-use institutions with an increase in the p-values. Second, no matter what the p-value is, early-use institutions can expect a higher utility than late-use institutions. The results clearly show that the selection of specific parameter values for the risk aversion coefficients is irrelevant.

p		0	0.1	0.3	0.5	0.7	0.9	1
$\gamma = 1$	$EU^E(p)$	-0.498	-0.521	-0.566	-0.601	-0.626	-0.644	-0.651
	$EU^L(p)$	-0.652	-0.652	-0.656	-0.664	-0.672	-0.679	-0.683
$\gamma = 2$	$EU^E(p)$	-0.292	-0.299	-0.312	-0.326	-0.338	-0.351	-0.356
	$EU^L(p)$	-0.359	-0.363	-0.371	-0.380	-0.387	-0.395	-0.398
$\gamma = 2.5$	$EU^E(p)$	-0.220	-0.225	-0.234	-0.244	-0.253	-0.262	-0.267
	$EU^L(p)$	-0.270	-0.274	-0.281	-0.288	-0.295	-0.302	-0.305
$\gamma = 3$	$EU^E(p)$	-0.169	-0.173	-0.180	-0.187	-0.194	-0.201	-0.204
	$EU^L(p)$	-0.207	-0.210	-0.216	-0.223	-0.229	-0.234	-0.237
$\gamma = 4$	$EU^E(p)$	-0.106	-0.108	-0.113	-0.117	-0.122	-0.126	-0.128
	$EU^L(p)$	-0.130	-0.132	-0.137	-0.141	-0.145	-0.150	-0.152

Table IV

The Impact of the Liquidity Shock Variance (σ_z^2) on the Expected Utilities of the Early-Use and Late-Use Institutions

This table presents the numerical simulations of expected utilities of the early-use and late-use institutions given different variances of the liquidity shock, where $EU^E(p)$ and $EU^L(p)$ represent the expected utilities of the early-use and late-use institutions, respectively. The standard parameters are $\gamma = 2.5, \sigma_\varepsilon^2 = 2, M = 0.4$, and $\sigma_z^2 = 0.4$. The parameter p represents the proportion of these institutions that will choose to acquire at date 1; γ represents the risk aversion coefficient; M represents the proportion of institutions; σ_ε^2 and σ_z^2 represent the variances of signal error term and liquidity shock, respectively. The above-mentioned two characteristics still can be drawn from the table. First, there is a decline in the expected utilities for both early-use and late-use institutions with an increase in the p-values. Second, no matter what the p-value is, early-use institutions can expect a higher utility than late-use institutions. The results clearly show that the selection of specific parameter values for the liquidity shock variance is irrelevant.

p		0	0.1	0.3	0.5	0.7	0.9	1
$\sigma_z^2 = 0.2$	$EU^E(p)$	-0.334	-0.342	-0.358	-0.375	-0.390	-0.404	-0.410
	$EU^L(p)$	-0.413	-0.417	-0.425	-0.433	-0.441	-0.449	-0.453
$\sigma_z^2 = 0.4$	$EU^E(p)$	-0.220	-0.225	-0.234	-0.244	-0.253	-0.262	-0.267
	$EU^L(p)$	-0.270	-0.274	-0.281	-0.288	-0.295	-0.302	-0.305
$\sigma_z^2 = 0.8$	$EU^E(p)$	-0.131	-0.133	-0.139	-0.144	-0.149	-0.155	-0.157
	$EU^L(p)$	-0.160	-0.162	-0.168	-0.173	-0.178	-0.183	-0.185
$\sigma_z^2 = 1$	$EU^E(p)$	-0.109	-0.111	-0.115	-0.120	-0.124	-0.128	-0.131
	$EU^L(p)$	-0.133	-0.135	-0.139	-0.144	-0.148	-0.152	-0.155
$\sigma_z^2 = 1.5$	$EU^E(p)$	-0.076	-0.078	-0.081	-0.084	-0.087	-0.090	-0.092
	$EU^L(p)$	-0.093	-0.095	-0.098	-0.102	-0.105	-0.108	-0.110

Arising from these tables, a further finding indicates under some market parameter values, all of the institutions choosing date 2 to acquire the information (p=0) may obtain higher expected utility than they would otherwise obtain in a situation where all institutions choose date 1 (p=1).[6] This finding is caused by the price impact of aggregate informed trades. For example, the large amount of aggregate informed trades brings huge price impacts, and thus early using the private information contrarily bears low profit. Therefore, in the case of large aggregate trades, institutions would tend to use information at a later rather than earlier stage.

Result 1 summarizes the above-mentioned arguments.

Result 1a: Under $p \in (0,1)$, the early-use institutions always obtain a higher expected utility than the late-use institutions, which implies that our model has no interior equilibrium.

Result 1b: All institutions choose to be the early-use institutions (p=1) must be the equilibrium in our model.

6 It should be noted that a situation in which all institutions choose to acquire the information at date 2 is not stable yet, because under the situation institutions would change their mind and choose date 1 to gain the higher expected utility level since $EU^E(p) > EU^L(p)$ with $p \in (0,1)$.

Result 1c: There exist some market parameter values within which all institutions choosing date 2 to use the stock's private information (p=0) obtain higher expected utility levels than all institutions choosing to use at date 1 (p=1).

Result 1a implies that any investing session of the model has only the corner-type equilibrium (p=0 or p=1). Result 1b presents that the p=1 is surely the equilibrium. While, it is not sure that the p=0 is also the alternative equilibrium of our model by Result 1c, unless all of the institutions can form a private agreement to choose date 2 together and no one has the incentive to deviate from the choice. It is noted that, if institutions take each investing session as independent, the private agreement among institutions is never possible. This implies the important result of this paper that all institutions could together postpone using the information that is related to the assumption that institutions pursue to maximize the aggregate benefits of the current and future sessions. Below, we discuss this agreement that can be available in equilibrium.

C. Alternative Equilibrium of Informed Trading Strategy

It has been proven that, under some market parameter values, all institutions choosing date 2 to use the information could obtain higher expected utility levels than all institutions choosing to use at date 1. But it is not yet guaranteed that the institutions using information at date 2 would not change their decision to use information at date 1, since the early-use institutions might obtain a higher expected utility than the late-use institutions. Only when each institution have the ability to detect the departure of other institutions and to punish the "traitor" (make the departure unprofitable), it is an alternative equilibrium that all institutions form and maintain a private agreement to jointly choose date 2.

Before describing the feasible design, we first assume that all of the investing sessions maintain stable state during the period of our consideration, that is, each investing session is with homogeneous market parameter values (i.e., the same values of M, σ_z^2, and σ_ε^2). In addition, under such market parameter values, all institutions choosing date 2 to use the information are assumed to obtain higher expected utility levels than choosing to use at date 1.

Next, we introduce a mechanism to detect whether the other institutions follow the rules of private agreement. In our model, if all institutions comply with the private agreement, the price at date 1 would only have a random term, representing $P_1 = b' \times Z_1$, where $Z_1 \sim N(0, \sigma_z^2)$ and b' is constant. Conversely, if any institution deviates from the private agreement, the price at date 1 would have a certain term and a random term, representing $P_1 = a \times S + b \times Z_1$, where $Z_1 \sim N(0, \sigma_z^2)$, S is known, and both a and b are constant. Hence, observing the signal of price at date 1 would be the detective mechanism of recognizing whether all institutions obey the private agreement or someone has departed.

That is, the price at date 1 is within the range of $[\underline{P_1}\overline{P_1}]$ where $\underline{P_1} < 0$ and $\overline{P_1} > 0$, the investing session would be judged as in the private agreement, and vice versa.

It may be inferred that such detective mechanism only can describe the session state as in a value of probability. In other words, the fact in the private agreement might be misidentification that someone has departed, and the fact of departing might also be wrongly regarded as all institutions following the rules of private agreement. Above-mentioned situations can be simply described by conditional probability. Given all institutions actually follow the rules of private agreement, we define the probability of judging none of institutions departing from the agreement as m_1, and thus, Prob (judging someone departing from the agreement | all institutions follow the rules) $= 1 - m_1$. Given the fact that someone has departed, the probability of judging none departed, as shown in Figure 2, is m_2, where

$$m_2 = \int_{\underline{P_1}}^{\overline{P_1}} f(a \times S + b \times Z_1) d(a \times S + b \times Z_1).$$

The latter is more harmful to the private agreement. If the value of m_2 is high, the probability of recognizing the departing behavior is diminished, and thus the institutions would have the incentive to early use the information. It is easy to decrease the value of m_2 by setting a smaller range of $[\underline{P_1}\overline{P_1}]$, but such setting also decreases the value of m_1. As a result, institutions would be punished more easily, but it would not directly hurt the ultimate purpose of avoiding someone departure.

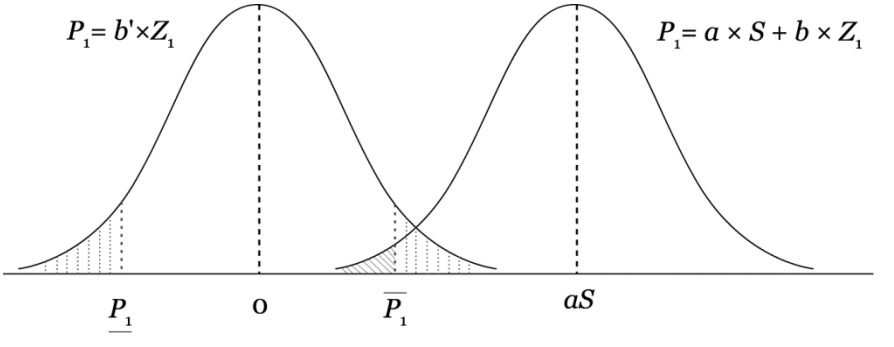


Figure 2. Illustration of Detective Mechanism

Next, we describe the design of punishment mechanism by referring to the work of Green and Porter (1984). In the investing session of k+1, the informed trading strategy of institutions is to choose date 1 or date 2 to use the information. The choice depends on the detective result of previous investing session (i.e., the investing session of k). If the institution believes that all of them follow the rules of private agreement in the investing session of k, it will continue to comply with the agreement at session of k+1. Conversely, if the

institution judge that someone has departed from the agreement, it will not obey the private agreement at session of k+1 as well as the following investing sessions. The institution would not return to obey the private agreement until investing session of k+T. Immediately punishing $T-1$ investing sessions after detecting the departure will significantly decrease the aggregate profits of all institutions. For the departing "traitor," the departure behavior can bring marginal profit in that investing session, but also increase the probability of detecting, which makes the marginal loss in the following $T-1$ investing sessions. As long as the value of T is large enough to let the marginal profit smaller than marginal loss, and thus make the departing "traitor" unprofitable. This punishment mechanism will certainly prevent any institution from deviating from the private agreement.

According to the practice of Green and Porter (1984), to find the optimal combination of price range ($[P_1\overline{P_1}]$) and punishing number of investing sessions ($T-1$) is feasible but complex and difficult. Derivations of the optimal detecting and punishing mechanism exceed the range of this paper and remain for future research. To sum up, based on the above-mentioned mechanism of detection and punishment to prevent departure of the agreement, the model has two alternative equilibria in any investing session. When the aggregate informed trades are not large, all institutions choose date 1 to use the information, and thus p=1 is the equilibrium of the current session. Conversely, when the aggregate informed trades are large enough, all institutions would choose date 2 to use the information, and thus p=0 is the equilibrium.

D. The Complete Equilibrium of Our Model

This section provides the closed-form solutions of these two corner equilibria. We first compute the accompanying trading equilibrium for p=1 and p=0, respectively. When all institutions choose to acquire the information at date 1, the stock prices at dates 1 and 2 are represented by:

$$P_1 = a_1 S + b_1 Z_1, \qquad P_2 = c_1 S + d_1 Z_1 + e_1 Z_2.$$

The accompanying trading equilibrium is described in Proposition 3.

PROPOSITION 3:

When all institutions choose to use the private information of stock at date 1, the closed-form solution for the accompanying trading equilibrium is given by:

$$a_1 = \frac{M(M+\gamma^2\sigma_Z^2\sigma_\varepsilon^2)}{M^2 + M(M+\gamma^2\sigma_Z^2)\sigma_\varepsilon^2 + \gamma^2\sigma_Z^2\sigma_\varepsilon^4},$$

$$b_1 = \frac{-\gamma\sigma_\varepsilon^2(M+\gamma^2\sigma_Z^2\sigma_\varepsilon^2)}{M^2 + M(M+\gamma^2\sigma_Z^2)\sigma_\varepsilon^2 + \gamma^2\sigma_Z^2\sigma_\varepsilon^4},$$

$$c_1 = \frac{M(M+\gamma^2\sigma_Z^2\sigma_\varepsilon^2)}{M^2+M(M+\gamma^2\sigma_Z^2)\sigma_\varepsilon^2+\gamma^2\sigma_Z^2\sigma_\varepsilon^4},$$

$$d_1 = \frac{-\gamma\sigma_\varepsilon^2(M+\gamma^2\sigma_Z^2\sigma_\varepsilon^2)}{M^2+M(M+\gamma^2\sigma_Z^2)\sigma_\varepsilon^2+\gamma^2\sigma_Z^2\sigma_\varepsilon^4},$$

$$e_1 = \frac{-\gamma\sigma_\varepsilon^2(M^2+\gamma^2\sigma_Z^2\sigma_\varepsilon^2)}{M^2+M(M+\gamma^2\sigma_Z^2)\sigma_\varepsilon^2+\gamma^2\sigma_Z^2\sigma_\varepsilon^4}.$$

Proof: Shown in the appendix.

In the alternative situation, where all institutions choose to acquire the information at date 2, the prices of the stock at dates 1 and 2 are represented by:

$$P_1 = b_2 Z_1, \qquad P_2 = c_2 S + d_2 Z_1 + e_2 Z_2.$$

The accompanying trading equilibrium is described in Proposition 4, the solution of which is also closed-form.

PROPOSITION 4:

When all institutions choose to use the information at date 2, the closed-form solution for the accompanying trading equilibrium is given by:

$$b_2 = -\gamma,$$

$$c_2 = \frac{M(M+\gamma^2\sigma_Z^2\sigma_\varepsilon^2)}{M^2+M(M+\gamma^2\sigma_Z^2)\,\sigma_\varepsilon^2+\gamma^2\sigma_Z^2\sigma_\varepsilon^4},$$

$$d_2 = \frac{-\gamma\sigma_\varepsilon^2(M^2+\gamma^2\sigma_Z^2\sigma_\varepsilon^2)}{M^2+M(M+\gamma^2\sigma_Z^2)\,\sigma_\varepsilon^2+\gamma^2\sigma_Z^2\sigma_\varepsilon^4},$$

$$e_2 = \frac{-\gamma\sigma_\varepsilon^2(M+\gamma^2\sigma_Z^2\sigma_\varepsilon^2)}{M^2+M(M+\gamma^2\sigma_Z^2)\,\sigma_\varepsilon^2+\gamma^2\sigma_Z^2\sigma_\varepsilon^4}.$$

Proof: Shown in the appendix.

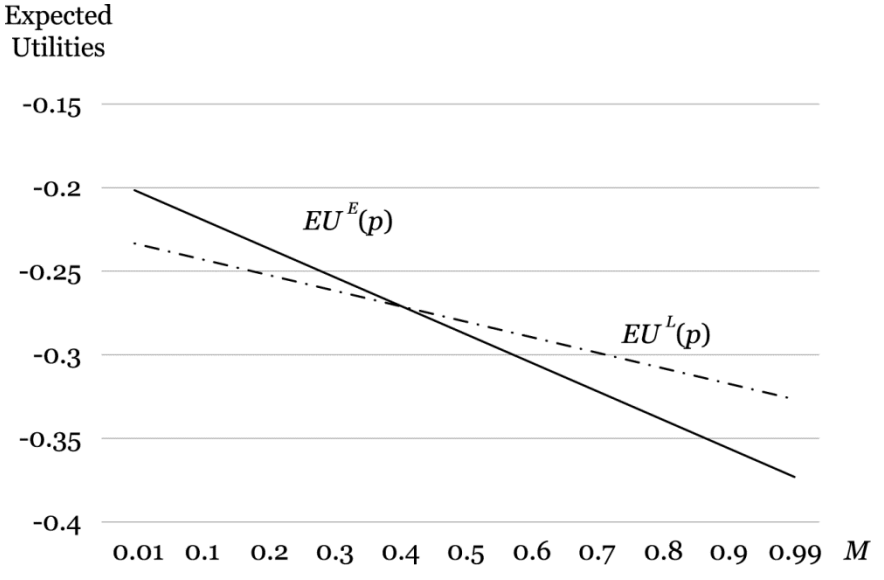
Next, we compute the expected utility of institutions under the equilibrium of p=1 and p=0, respectively. Since our model has alternative corner-type equilibrium, we select the higher expected utility and let the corresponding p-value be the equilibrium. Here we continue to use the basic market parameter values adopted in Section III.B. as the basis of our numerical analysis, and the numerical results are presented in Result 2.

Result 2a: When the proportion of institutions (M) is large enough, all institutions will tend to choose date 2, whereas, when the proportion is not large, all institutions will tend to choose date 1.

Result 2b: When the precision of the private information $(1/\sigma_{\varepsilon}^{2})$ is sufficiently high, all institutions will tend to choose date 2, whereas, when the precision of the private information is not sufficiently high, all institutions will tend to choose date 1.

Result 2c: Movements in the risk-aversion coefficient (γ) and the variance in liquidity shocks (σ_{Z}^{2}) are not determinants of the timing selection.

The first two conclusions in Result 2 (2a and 2b) can be drawn from the results of Figures 3 and 4, in which the intuitive argument is as follows. When the proportion of institutions is large enough or when the precision of private information is sufficiently high, the aggregate informed trades of all institutions would be large, and thus their impact on the market price would also be strong. Under this condition, if all institutions choose date 1 to acquire the information

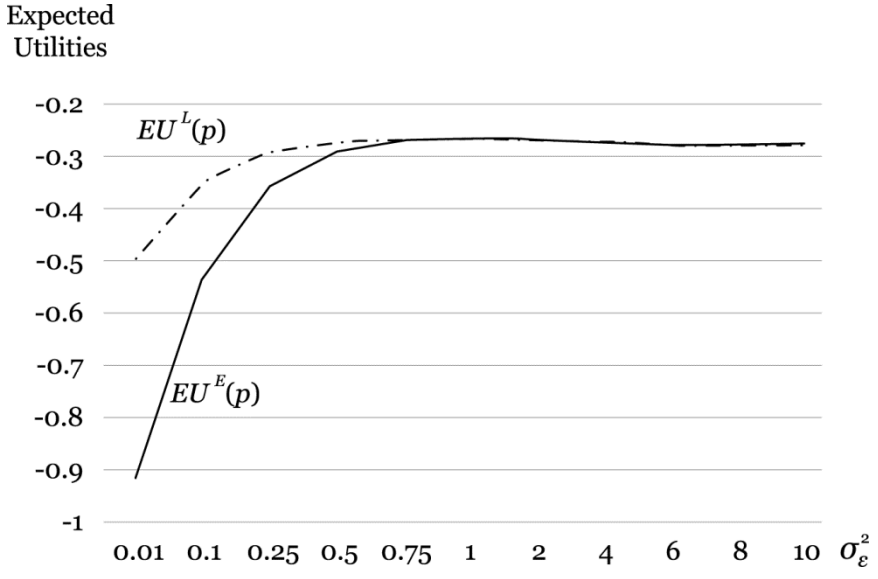


M	0.01	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	0.99
EU^{E}	-0.202	-0.216	-0.232	-0.250	-0.267	-0.286	-0.304	-0.322	-0.340	-0.358	-0.373
EU^{L}	-0.234	-0.242	-0.251	-0.260	-0.270	-0.280	-0.289	-0.299	-0.309	-0.318	-0.326

Figure 3. The Impact of the Proportion of Institutions (M) on the Timing of Informed Trading

This figure presents the numerical results of the impact of the proportion of institutions on the timing of informed trading. The standard parameters are $\gamma = 2.5, \sigma_{\varepsilon}^{2} = 2, M = 0.4$, and $\sigma_{Z}^{2} = 0.4$. The parameter γ represents the risk aversion coefficient; M represents the proportion of institutions; σ_{ε}^{2} and σ_{Z}^{2} represent the variances of signal error term and liquidity shock, respectively. EU^{E} and EU^{L} represents the expected utilities of the institutions when all choose to acquire at date 1 and date 2, respectively. Figure 3 indicates that when the proportion of institutions is large, all institutions tend to choose date 2, whereas, when the proportion of institutions is small, all institutions tend to choose at date 1.

for their trading, this would have substantial impacts on the market prices on both dates 1 and 2, thereby significantly influencing the expected utility of institutions. For example, as shown in Figure 4, when the precision of private information $(1/\sigma_\varepsilon^2)$ is 0.1, the expected utilities of early-use institutions (-0.279) is higher than those of late-use institutions (-0.281); when the precision of private information $(1/\sigma_\varepsilon^2)$ is 10, the expected utilities of early-use institutions (-0.536) would be lower than those of late-use institutions (-0.352). As a result, a better strategy for institutions would be to choose date 2, essentially because the huge aggregate informed trades could only influence the price at date 2.



σ_ε^2	0.01	0.1	0.25	0.5	0.75	1	2	4	6	8	10
EU^E	-0.917	-0.536	-0.361	-0.293	-0.275	-0.269	-0.267	-0.273	-0.276	-0.278	-0.279
EU^L	-0.497	-0.352	-0.293	-0.271	-0.267	-0.266	-0.270	-0.275	-0.278	-0.280	-0.281

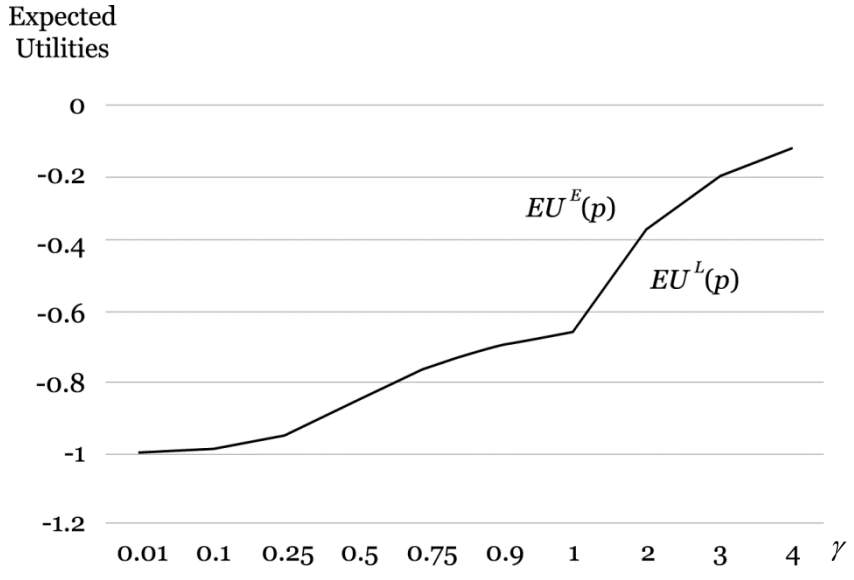
Figure 4. The Impact of the Signal Error Term's Variance (σ_ε^2) on the Timing of Informed Trading

This figure presents the numerical results of the impact of the signal error term's variance on the timing of informed trading. The standard parameters are $\gamma = 2.5, \sigma_\varepsilon^2 = 2, M = 0.4,$ and $\sigma_Z^2 = 0.4$. The parameter γ represents the risk aversion coefficient; M represents the proportion of institutions; σ_ε^2 and σ_Z^2 represent the variances of signal error term and liquidity shock, respectively. EU^E and EU^L represents the expected utilities of the institutions when all choose to acquire at date 1 and date 2, respectively. Figure 4 indicates that when the precision of private information is high, all institutions tend to choose date 2, whereas, when the precision of private information is low, all institutions tend to choose at date 1.

In contrast, when the proportion of institutions is not large or when the precision of private information is not sufficiently high, the negative impacts of the aggregate informed trades on the benefits of early trading would be lower than the

positive impacts from informed trades; therefore, all institutions could obtain a higher expected utility by choosing to trade early on their private information.

In addition, the results presented in Figures 5 and 6 provide support for Result 2c. Although the expected utility of institutions is influenced by both the risk-aversion coefficient and the variance in liquidity shocks, these two factors have no influence on the selection of the appropriate trading timing; hence, they are not determinants of the timing selection.

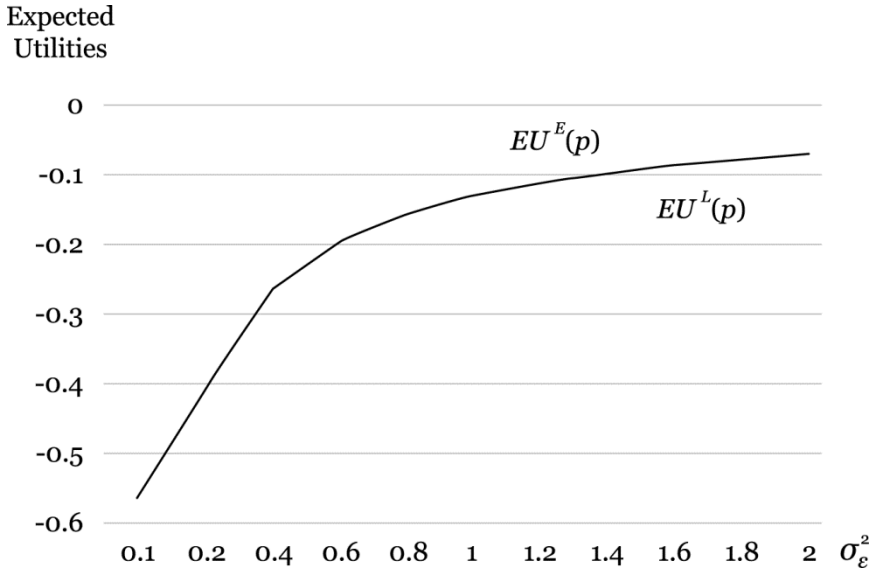


γ	0.01	0.1	0.25	0.5	0.75	0.9	1	2	3	4
EU^E	-0.999	-0.991	-0.949	-0.854	-0.753	-0.694	-0.656	-0.357	-0.205	-0.128
EU^L	-0.999	-0.990	-0.946	-0.848	-0.748	-0.690	-0.652	-0.359	-0.207	-0.130

Figure 5. The Impact of the Risk Aversion Coefficient (γ) on the Timing of Informed Trading

This figure presents the numerical results of the impact of the risk aversion coefficient on the timing of informed trading. The standard parameters are $\gamma = 2.5$, $\sigma_\varepsilon^2 = 2$, $M = 0.4$, and $\sigma_Z^2 = 0.4$. The parameter γ represents the risk aversion coefficient; M represents the proportion of institutions; σ_ε^2 and σ_Z^2 represent the variances of signal error term and liquidity shock, respectively. EU^E and EU^L represents the expected utilities of the institutions when all choose to acquire at date 1 and date 2, respectively. Figure 5 indicates that the movement in the risk-aversion coefficient is not the determinant of informed trader timing.

Summarizing this section, we find that the factor determining the timing selection is the aggregate informed trade size of all institutions (which is closely related to the proportion of institutions and the precision of private information). When the aggregate informed trade size is sufficiently large, all institutions will tend to postpone the use of the private information; conversely, when the aggregate informed trade size is not sufficiently large, all institutions will acquire and use the private information as it is available to the market.



σ_Z^2	0.1	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2
EU^E	-0.565	-0.411	-0.267	-0.198	-0.158	-0.131	-0.112	-0.097	-0.087	-0.078	-0.071
EU^L	-0.564	-0.413	-0.270	-0.201	-0.160	-0.133	-0.113	-0.099	-0.088	-0.079	-0.072

Figure 6. The Impact of the Liquidity Shock Variance (σ_Z^2) on the Timing of Informed Trading

This figure presents the numerical results of the impact of the liquidity shock variance on the timing of informed trading. The standard parameters are $\gamma = 2.5$, $\sigma_\varepsilon^2 = 2$, $M = 0.4$, and $\sigma_Z^2 = 0.4$. The parameter γ represents the risk aversion coefficient; M represents the proportion of institutions; σ_ε^2 and σ_Z^2 represent the variances of signal error term and liquidity shock, respectively. EU^E and EU^L represents the expected utilities of the institutions when all choose to acquire at date 1 and date 2, respectively. Figure 6 indicates that the variance in liquidity shocks is not the determinant of informed trader timing.

IV. Market Phenomena

The corner-type equilibrium in any investing session of our model can explain several hard-to-understand market phenomena, such as excess volatility, price momentum, higher possibility of showing price momentum for the stocks with small size or analyst less-attention, investigative herding of institutions, and the co-existing phenomenon between active arbitrage and market anomaly.

A. Excess Volatility

Shiller (1981) and LeRoy and Porter (1981) empirically find a phenomenon that stock price are “too volatile” to be justified by fundamentals. Financial economists refer this phenomenon as the excess volatility puzzle. The model of

this paper can explain this phenomenon conditionally. Here we measure the stock volatility by price variances. Denote the price variances at dates 1, 2, and 3 respectively by $var_t\,(P_1-P_0)$, $var_t\,(P_2-P_1)$, and $var_t\,(P_3-P_2)$ as all institutions choose date t (t=1, 2) to use the information. For simplicity, we assume $P_0=0$. And the unconditional price variance, $\overline{\mathrm{var}_t}$, is denoted as the arithmetical means of $var_t\,(P_1-P_0)$, $var_t\,(P_2-P_1)$, and $var_t\,(P_3-P_2)$. The comparing results of the price variances between the two timing selections are presented in the following Proposition.

PROPOSITION 5:

(a) $var_1(P_3-P_2)=var_2(P_3-P_2)$,

(b) $var_1(P_2-P_1)<var_2(P_2-P_1)$,

(c) $\overline{var_1}<\overline{var_2}$.

Proof: Shown in the appendix.

We describe the intuition of Proportion 5 as follows. Any newly-arrived informed trades at date t will influence the date t price variance through three channels. Firstly, new informed trades let the price of date t reflect more of the stock value. Secondly, new informed trades can reduce the levels of risk which individuals (uninformed traders) have to bear at date t in order to accommodate the aggregate liquidity shocks at date t (we denote this risk as "holding risk"). Thirdly, new informed trades increase the risk faced by individuals at date t when trading with institutions (we denote the risk as "adverse selection risk").

In the case where all institutions choose date 1, the new informed trades will enter into the market at date 1. Accordingly, the price variance $var_1\,(P_1-P_0)$ reflects three components, including a proportion of the stock value added to the price P_1, the adverse selection risk of individuals to trade with institutions, and the lower holding risk of both institutions and individuals to absorb Z_1. The holding risk is relatively low since the price at date 1 (P_1) already reflects some of the private information.

At date 2, $var_1\,(P_2-P_1)$ reflects the lower holding risk of both institutions and individuals to absorb Z_2. Finally, since the complete stock value is revealed at date 3, there is no need for both institutions and individuals to bear any risk at that date; thus, $var_1\,(P_3-P_2)$ reflects the unrevealed proportion of the stock value and the resolution of the total risk undertaken by institutions and individuals at date 2.

In the alternative case, where all institutions choose date 2, $var_2\,(P_1-P_0)$ reflects only the higher holding risk for both institutions and individuals to absorb Z_1; this is essentially because no informed trades are entering into the market at date 1 and P_1 does not therefore reflect any of the private information.

At date 2, $var_2\,(P_2-P_1)$ reflects some proportion of the stock value added to the price P_2, the adverse selection risk of individuals to trade with institutions,

the lower holding risk of institutions and individuals to absorb Z_2, and the adjusted term from the higher holding risk at date 1 to the lower holding risk at date 2 for both institutions and individuals to absorb Z_1. Finally, the complete stock value is revealed at date 3; therefore, $var_2\,(P_3-P_2)$ reflects both the proportion of the stock value which is not disclosed by P_2 and the resolution of the total risk that has to be assumed by both institutions and individuals at date 2.

In summary, we begin by obtaining the conclusion of $var_1\,(P_3-P_2)=var_2\,(P_3-P_2)$ since these two variances both reflect the same element of the stock value and the same risk resolution; then, we show that as compared with $var_1\,(P_2-P_1)$, $var_2\,(P_2-P_1)$ additionally reflects the partial stock values, the adverse selection risk and the adjusted term from higher holding risk to lower holding risk, which therefore leads to the conclusion of $var_1\,(P_2-P_1)<var_2\,(P_2-P_1)$. The last result of Proposition 7 is due to the higher holding risk for both institutions and individuals to absorb Z_1 when all institutions choose to acquire the private information of stock at date 2. So far we can conclude that the timing of institutions' informed trading do affect the volatility of stock prices. The later the information use, the higher the stock volatility is.

Past studies explain the excess volatility puzzle from different viewpoints. DeLong et al. (1990) assume there are positive feedback traders in the markets; Dumas, Kurshev, and Uppal (2009) suppose markets have overconfident traders; Barberis, Shleifer, and Vishny (1998) believe the traders have representative bias; Daniel, Hirshleifer, and Subrahmanyam (1998) claim the traders have self-contribution bias; and Chen et al. (2013) attribute the high stock volatility to the impact of foreign institutional ownership. These studies represent an explaining approach which describes that in the financial markets there are some traders irrational. And therefore the transactions from these irrational traders make a part of changes in prices irrelevant to the fundamental value of stocks. Different from the above-mentioned explanations, our model does not assume irrational traders existing. The excess volatility in our model is just due to the rational institutions that intentionally choose to postpone acquiring the private information for the higher expected utility.

B. Price Momentum

The anomaly noted in this section is the price momentum, the minority anomaly that still exists now. Here we discuss the serial correlation of stock prices by measuring the covariance of the adjacent price changes, denoted by $cov_t\,(P_2-P_1,\ P_3-P_2)$ for t representing the date selected by the institutions to acquire the information. Clearly, if $cov_t\,(P_2-P_1,\ P_3-P_2)>0$, then the adjacent price changes will be positively correlated (namely price momentum); if $cov_t\,(P_2-P_1,\ P_3-P_2)<0$, then the adjacent price changes will be negatively correlated (namely price reversion); and if $cov_t\,(P_2-P_1,\ P_3-P_2)=0$, then the adjacent price changes will be uncorrelated.

PROPOSITION 6:

(a) $cov_1(P_2-P_1, P_3-P_2) < 0$,

(b) $cov_2(P_2-P_1, P_3-P_2) > 0$, *if, and only if,* $M > \sigma_\varepsilon^2$.

Proof: Shown in the appendix.

Proposition 6(a) shows the following: If all institutions choose to be the early-use institutions, there is no price momentum but rather price reversion before the day of disclosing the true value. Proposition 6(b) shows the phenomenon of price momentum appears only when all institutions choose to be the late-use institutions and also the condition of $M > \sigma_\varepsilon^2$ is satisfied. The intuition behind these results is interpreted as follows. In our model, when all institutions choose date 1 using their information, according to Grossman and Miller (1988), price changes exhibit reversal as a result of standard inventory considerations. On the other hand, when all institutions use their private information at date 2, P_1 will not reflect any of this private information; hence, the conditional risk premium required to absorb Z_1 will be at the maximum value at date 1, and reducing at date 2, essentially because individuals will be better informed at date 2. Finally, this conditional risk premium ultimately reduces to zero at date 3 due to the total revelation of the stock value.

We further analyze the impact of the conditional risk premium required to absorb Z_1 on $cov_2(P_2-P_1, P_3-P_2)$. When $Z_1>0$ (indicating an increase in aggregate liquidity shocks of date 1), prices will fall, thereby providing a potentially greater return, which will attract investors to hold more positions. As above-mentioned, there are reductions in the conditional risk premium to absorb Z_1 from date 1 to date 2, and from date 2 to date 3, and thus, we have $P_2-P_1>0$ and $P_3-P_2>0$. The result for $Z_1>0$ is $cov_2(P_2-P_1, P_3-P_2)>0$. Similar analysis can be applied when $Z_1<0$, which results in $P_2-P_1<0$ and $P_3-P_2<0$, and thus, the same conclusion is obtained, that is, $cov_2(P_2-P_1, P_3-P_2)>0$.

Again, the conditional risk premium required to absorb Z_2 is produced at date 2, and then reduces to zero at date 3. The relevant impact on $cov_2(P_2-P_1, P_3-P_2)$ is described as follows. When $Z_2>0$, we then have $P_2-P_1<0$ and $P_3-P_2>0$, and thus, $cov_2(P_2-P_1, P_3-P_2)<0$. However, when $Z_2<0$, we then obtain $P_2-P_1>0$ and $P_3-P_2<0$, and thus, we get the same result; that is, $cov_2(P_2-P_1, P_3-P_2)<0$. To summarize these findings, the impact of the conditional risk premium required to absorb Z_1 contributes a positive value to $cov_2(P_2-P_1, P_3-P_2)$, whereas the impact of the premium to absorb Z_2 contributes a negative value.

There is a need for us to clarify Proposition 6(b), that the two adjacent price changes (P_2-P_1, P_3-P_2) are positively correlated, if and only if, $M > \sigma_\varepsilon^2$. If the value of M is sufficiently large or the value of σ_ε^2 is sufficiently small, more information will be disclosed at date 2. Such a P_2 with more information would reduce the conditional risk premiums required to absorb both Z_1 and Z_2. A

reduction in the premiums would subsequently lead to an increase in the positive value of $cov_2\,(P_2-P_1,\ P_3-P_2)$ for absorbing Z_1 and a reduction in the negative value of $cov_2\,(P_2-P_1,\ P_3-P_2)$ for absorbing Z_2. As a result, there would be an increase in the likelihood of two adjacent price changes (P_2-P_1 and P_3-P_2) becoming positively correlated.

C. Stock Characteristics

Some studies have indicated that different types of stocks exhibit different degrees of price momentum; for example, Jegadeesh and Titman (1993, 2001) and Rouwenhorst (1998) find that small-sized stocks exhibit more significant phenomena of returns continuation (price momentum) than large-sized stocks. Hong, Lim, and Stein (2000) and Zhang (2006) also find that those stocks which attract relatively little attention amongst analysts exhibit stronger positive serial correlation (price momentum) than those which attract much greater analyst attention. These studies attribute the discovered empirical evidence to the biased behavior of agents. While in the following we confirm that our rational model can also explain this phenomenon.

The first example relates to small- and large-sized stocks. In our model, the parameter M, which represents the proportion of institutions, can also represent the proportion of informed trades to all trades (comprising all informed trades plus all uninformed trades). Since all trades of small-sized stocks are far smaller than those of large-sized stocks, it is reasonable to think that the average value of M for small-sized stocks will be greater than the average value of M for large-sized stocks.[7] Based upon Propositions 6 and 8, we have proven that with a greater value of M, all institutions will tend to select date 2, and thus the stock prices will display strong continuation. Therefore, our model predicts that small-sized stocks will have much greater potential for exhibiting price momentum than large-sized stocks. This provides a rational explanation for the empirical findings of Jegadeesh and Titman (1993, 2001) and Rouwenhorst (1998).

The second example involves a comparison of the price momentum between those stocks attracting low and high levels of attention amongst analysts. Zhang (2006) depicts the information periodically announced by analysts as public information within the market, and greater analyst coverage is likely to correspond to those firms on which there is greater availability of public information and less uncertainty about the fundamental values of such firms. Our model regards public information as being readily available to both institutions and individuals. If this commonly-known information is relatively precise (due to

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7 In previous studies, the empirical works of Easley et al. (1996), Easley, Hvidkjaer, and O'Hara (2002), and Bushee and Goodman (2007) show that smaller firms will correspond to higher probability of informed trading. Moreover, Hasbrouck (1991) and Holden and Subrahmanyam (2002) argue that the magnitude of informativeness of trades is a positive function of the proportion of informed traders in the population.

the greater analyst coverage), there will be a decrease in the informational advantage of those institutions in possession of additional private information. In our model, such an informational advantage is characterized by the level of precision of their private information, which corresponds to the parameter $1/\sigma_{\varepsilon}^{2}$. Specifically, the higher the value of $1/\sigma_{\varepsilon}^{2}$, the greater the informational advantage enjoyed by institutions. Hence, it follows that those stocks which attract relatively little attention amongst analysts will correspond to those stocks with the higher level of precision of private information in our model.

Similarly, Propositions 4 and 6 have also proven that when the precision of private information is high, all institutions will tend to choose date 2, and thus the stock prices will display strong continuation. Therefore, our model predicts that those stocks with a lower level of analyst attention will display stronger price momentum. This provides support for the findings of Hong, Lim, and Stein (2000) and Zhang (2006).

D. Investigative Herding Behavior

In this section, we use an example to clarify the corner-type equilibrium in any investing session of our model which can explain the investigative herding of institutions to some extent. Consider the following scenario: Institutions can choose one from two stocks, called stocks A and B. These two stocks have exactly the same properties except the time of disclosing the liquidation value. Suppose the time-point that investors currently stand on is close to the date 2 of stock A and the date 1 of stock B. That is, for investors, the time to disclose the liquidation value of stock A is earlier than the time of stock B. According to the conclusion of Section III, under some market parameters where the aggregate informed trade size is large enough, all institutions will choose to the late time-point (i.e., close to the time of disclosing the liquidation value) to use the private information of stock. This implies all institutions would together choose to use the private information of stock A, because for investors, stocks A and B are almost the same but stock A discloses the liquidation value early. Conversely, under the other market parameters where the aggregate trade size is not large, all institutions would together choose to acquire the private information of stock B. Therefore, no matter what the market parameters are, all institutions in our model would together choose to use the private information of the same stock, and such a strategy is similar to the "investigative herding" behavior of institutions proposed by Hirshleifer, Subrahmanyam, and Titman (1994).

E. Arbitrage and Market Anomalies

With the trend of electronic finance (Claessens, Glaessner, and Klingebiel (2002)), recent empirical research such as Pontiff (2006), Chordia, Subrahmanyam, and Tong (2014), and McLean and Pontiff (2016) finds that

many of the most well-known anomalies are eliminated in the current era of active arbitrage activities. But, Fama and French (2012), Asness, Moskowitz, and Pedersen (2013), and Israel and Moskowitz (2013) note that some market anomalies still are robust. Traditional arbitrage literature consider these excess returns of anomalies are due to the many kinds of explicit and potential transaction costs in real market, which reduce and/or limit the arbitrage activities. Therefore, when arbitrage activities become active, it is predicted that excess returns of anomalies would be substantially reduced (or even vanished). Such a viewpoint is hard to explain the recent finding, while our results can provide the explanation to some extent.

In our model the institutions own the private information of stocks' fundamental value, so they can know which stocks are mispriced and employ this information to perform the arbitrage trading. The results of our model show that arbitrage activity is not always an immediate action, but may take the action after a period of anomalies development. Especially when the aggregate informed trades are sufficiently large (that can be regarded as being in the era of active arbitrage), all institutions would postpone acquiring the private information to carry on the arbitrage. Because the time of arbitrage trading may be delayed, the mispricing of stocks would continue to exist during the whole delaying period. Therefore, our model concludes that, even in the period of active arbitrage, some anomalies still exist in the market. However, we want to clarity that, the results do not represent that arbitrage activity cannot call the mispricing stocks back to their fundamentals. The real implication is that, the increase in arbitrage activity would strengthen the institutions' incentive to strategically choose to delay their arbitrage (in order to obtain greater profits). In other words, it is exactly that the delayed informed-trading behavior of institutions lets arbitrage activity and mispricing stock co-exist.

Our results have another interesting prediction: The eliminated or disappeared anomalies due to increased arbitrage activity can re-appear in the future. The reason is described as follows. The primary goal of arbitrage activity is to earn profits. If the profits from arbitrage trading are significantly reduced due to active arbitrage activity, arbitrageurs need to decrease the arbitrage activity or, according to the results of our model, choose to together postpone their action to enlarge the arbitrage profits. For the former, some arbitrageurs must abort the arbitrage activity. But we do not think it works as long as the arbitrage profits are not converged to zero or negative, because if someone chooses to abort, the remaining ones will obtain the gain. So everyone would wait for others abort and the final result is that no one will exit the game of arbitrage activity. Unlike the above dilemma, the results of our model indicated arbitrage profits can rise without requiring any institutional investor to exit arbitrage activities. They only need to choose to postpone their arbitrage activities. It is reasonable to expect that, in equilibrium the institutions will

select delayed arbitrage instead of decreased arbitrage activity to enlarge their arbitrage profits, and thus we expect that the disappeared anomalies will re-appear in the future.

Several prior studies such as DeLong et al. (1990) and Abreu and Brunnermeier (2002, 2003) also acquire the results of delayed arbitrage. In the presence of the positive feedback investors, DeLong et al. (1990) claim that, when the good news came to the market, the arbitrager would wait the positive feedback investors driving up the price higher than its fundamental value to get the higher profits. The delayed arbitrage activities in the DeLong et al. (1990) model is because it is assumed there are positive feedback investors. But it is needed to verify the market always has irrational traders and these irrational traders are exactly the positive feedback traders. Without saying, this point is difficult to prove. The main difference between DeLong et al. (1990) and this paper is that our model does not assume any traders to be irrational. The delayed arbitrage activities of institutions in our model are entirely the results of rational choice based on their motive of maximum profit.

In addition, Abreu and Brunnermeier (2002, 2003) declare arbitrage activities require the coordination of arbitragers, but each of them faces the uncertainty about the time of the others taking actions (called "the synchronization risk"). These articles prove that arbitrageurs will time the market rather than correcting the mispricing right away, finally leading to the delayed arbitrage. It is approved for infrequent events (such as the tech bubble or the financial crisis), the synchronization risk plays a significant role because the evolution of asset prices during these accidental events are quite strange to all traders. Conversely, for the frequent or periodic occurrence of market anomalies discussed here, we believe that the synchronization problem will not have much impact. To sum up, our model is more suitable to explain the market anomalies than the above-mentioned models.

V. Conclusion

In the real market, the institutions do continue investing in the financial market, i.e., they will participate in many, rather than one, investing sessions. Considering this realistic prospection, this paper examines how the institutions decide their informed trading strategy in any investing session and how this trading strategy would influence the behavior of stock prices by employing a noisy rational expectations model.

Research results find that our model has no interior equilibrium, but alternative corner-type equilibrium. In some situation where the aggregate informed trades of institutions are sufficiently large, all institutions will choose the late date; and under the other situation where the aggregate informed trades

are not large, they will choose the early date. This type of trading strategy can be understood as follows. All institutions choose early date mainly due to the essence of competition among institutions. Everyone wants to use the information earlier than others to obtain higher trading profits. However, if considering they will participate in many investing sessions, the institutions are proved to form the alliance substituting the competition.

In light of the corner-type equilibrium in this model, the behavior of institutions is similar to investigative herding. When the aggregate informed trades of institutions are sufficiently large, stock prices will show excess volatility and the returns will exhibit continuation. Additionally, our model also proves that the stocks which are small or receive less attention from analysts have a greater tendency for price momentum than those which are large or receive more attention from analysts. Finally, we can provide the explanation for the co-existing phenomenon of arbitrage activities and market anomalies to some extent.

A main contribution of this paper is that it adopts the assumption of real operation of financial market. It is helpful to understand the informed trading behavior of institutions in the real market, and the influence of such behavior on stock prices. Another contribution is that the rational expectations model of this paper can explain some market phenomena to some extent. Most of these familiar market phenomena are explained by the behavior of irrational investors in the past.

Appendix

The following lemma is a standard result for multivariate normal random variables (see, for example, Bray (1981)).

LEMMA A1:

Let $\chi \in R^n$ denote a normally-distributed random vector with mean vector μ and covariance matrix Σ. Define $Q(\chi)$ as a quadratic function of the random vector $\chi : Q(\chi) = C + B^T \chi - \chi^T A \chi$, where A is a symmetric matrix, B is an n-vector, and C is a scalar; thus:

$$E\left[\exp(Q(\chi))\right]$$
$$= \left|\Sigma\right|^{\frac{-1}{2}} \left|2A + \Sigma^{-1}\right|^{\frac{-1}{2}} \exp\left[C + B^T \mu - \mu^T A \mu + \frac{1}{2}(B^T - 2\mu^T A^T)(2A + \Sigma^{-1})^{-1}(B - 2A\mu)\right].$$

Proof of Proposition 1: The proof presents the optimal demand of traders as follows. Section (a) is for the institutions that choose date 1, Section (b) is for the institutions that choose date 2, and Section (c) is for the individuals.

(a) The Optimal Demand of Early-Use Institutions

At dates 1 and 2, institutions select their demand for the risky asset conditional on their own information set. The date 1 information set for each early-use institution is denoted by $\phi_{i1}^E = \{S, P_1\}$, while the date 2 information set is denoted by $\phi_{i2}^E = \{S, P_1, P_2\}$. Using these information sets, the optimal demand of each institution at dates 1 and 2 can be determined via backward dynamic programming, which we describe as follows.

The final wealth of each early-use institution is represented by

$$W^E = x_1^E (V - P_1) + x_2^E (V - P_2).$$

Since at date 2 the wealth is conditionally normally distributed (the only primitive random variable unknown to institutions is V, which is normally distributed), we can use the standard mean-variance analysis to show that the optimal date 2 demand for each early-use institution is equal to:

$$x_1^E + x_2^E = \frac{E\left(V \mid \phi_{i2}^E\right) - P_2}{\gamma \cdot Var\left(V \mid \phi_{i2}^E\right)}. \tag{A1}$$

In Equation (A1), the expected value and variance of V, conditional on ϕ_{i2}^E, can be calculated based upon the project theorem. They are provided as follows:

$$E\left(V \mid \phi_{i2}^E\right) = \frac{1}{1 + \sigma_\varepsilon^2} S \quad \text{and} \quad Var\left(V \mid \phi_{i2}^E\right) = \frac{\sigma_\varepsilon^2}{1 + \sigma_\varepsilon^2}.$$

Define $\lambda \equiv \frac{1}{1+\sigma_\varepsilon^2}$ and $\tau_t \equiv \frac{\sigma_\varepsilon^2}{1+\sigma_\varepsilon^2}$. Therefore, the optimal date 2 demand of each early-use institution is presented as

$$x_1^E + x_2^E = \frac{\lambda S - P_2}{\gamma \tau_i}.$$

Equation (3) thus obtains.

Next, we analyze the optimal date 1 demand of the early-use institutions. Substitute $x_1^E + x_2^E$ into the expression for W^E, which yields:

$$W^E = x_1^E (P_2 - P_1) + \frac{\lambda S - P_2}{\gamma \tau_i}(V - P_2).$$

Since at date 2 the wealth is normally distributed and the utility is negative exponential function, the expected utility at date 2 wealth is given by

$$E\left[U(W_i^E) \mid \phi_{i2}^E\right] = -\exp\left(-\gamma\left[x_1^E (P_2 - P_1) + \frac{(\lambda S - P_2)^2}{2\gamma \tau_i}\right]\right).$$

Accordingly, at date 1, the early-use institution would expect his/her utility over the wealth at date 2, which is given by

$$E\left[-\exp\left(-\gamma\left[x_1^E (P_2 - P_1) + \frac{(\lambda S - P_2)^2}{2 \cdot \gamma \cdot \tau_i}\right]\right) \middle| \phi_{i1}^E\right]. \tag{A2}$$

The expression within the above exponential is a quadratic function of a random variable P_2. This expression can be rearranged as:

$$C + B\chi - \chi A \chi$$

where $\chi \equiv P_2$, $C \equiv \gamma x_1^E P_1 - \frac{\lambda^2 S^2}{2\tau_i}$, $B \equiv -\gamma x_1^E + \frac{\lambda S}{\tau_i}$, and $A \equiv \frac{1}{2\tau_i}$. From Lemma A1, Equation (A2) is transformed as follows:

$$\begin{aligned}
&-1 \cdot \left|Var\left(P_2 \mid \phi_{i1}^E\right)\right|^{\frac{-1}{2}} \cdot \left|\frac{1}{\tau_i} + Var^{-1}\left(P_2 \mid \phi_{i1}^E\right)\right|^{\frac{-1}{2}} \cdot \exp\left\{\left(\gamma x_1^E P_1 - \frac{\lambda^2 S^2}{2\tau_i}\right)\right. \\
&+\left(-\gamma x_1^E - \frac{\lambda S}{\tau_i}\right) E\left(P_2 \mid \phi_{i1}^E\right) - \left(\frac{1}{2\tau_i}\right) \cdot E\left[\left(P_2 \mid \phi_{i1}^E\right)\right]^2 + \frac{1}{2}\left[\frac{1}{\tau_i} + Var^{-1}\left(P_2 \mid \phi_{i1}^E\right)\right]^{-1} \\
&\left.\left[\left(-\gamma x_1^E + \frac{\lambda S}{\tau_i}\right) - \frac{1}{\tau_i}\left[E\left(P_2 \mid \phi_{i1}^E\right)\right]\right]^2\right\}.
\end{aligned} \tag{A3}$$

Solving for the optimal demand by maximizing the objective function (A3) as follows,

$$\frac{d}{dx_1^E} \Rightarrow \left\{ \left(\gamma x_1^E P_1 - \frac{\lambda^2 S^2}{2\tau_i} \right) + \left(-\gamma x_1^E - \frac{\lambda S}{\tau_i} \right) E\left(P_2 \mid \phi_{i1}^E\right) - \left(\frac{1}{2\tau_i} \right) \cdot \left[E\left(P_2 \mid \phi_{i1}^E\right) \right]^2 \right.$$

$$\left. + \frac{1}{2} \left[\frac{1}{\tau_i} + Var^{-1}\left(P_2 \mid \phi_{i1}^E\right) \right]^{-1} \left[\left(-\gamma x_1^E - \frac{\lambda S}{\tau_i} \right) - \frac{1}{\tau_i} \left[E\left(P_2 \mid \phi_{i1}^E\right) \right] \right]^2 \right\} = 0,$$

yields

$$x_1^E = \frac{\left[E\left(P_2 \mid \phi_{i1}^E\right) - P_1 \right]}{\gamma} \cdot \left(\frac{1}{\tau_i} + \frac{1}{Var\left(P_2 \mid \phi_{i1}^E\right)} \right) + \frac{\lambda S - E\left(P_2 \mid \phi_{i1}^E\right)}{\gamma \tau_i}.$$

Applying the project theorem, the expected value and variance of random variable P_2 conditional on ϕ_{i1}^E are provided as follows,

$$E\left(P_2 \mid \phi_{i1}^E\right) = cS + dZ_1 \text{ and } Var\left(P_2 \mid \phi_{i1}^E\right) = e^2 \sigma_Z^2.$$

Therefore, the optimal date 1 demand of early-use institution can also be represented as:

$$x_1^E = \left(\frac{\lambda}{\gamma \tau_i} + \frac{c}{\gamma e^2 \sigma_Z^2} \right) S + \left(\frac{d}{\gamma e^2 \sigma_Z^2} \right) Z_1 - \left(\frac{1}{\gamma \tau_i} + \frac{1}{\gamma e^2 \sigma_Z^2} \right) P_1. \tag{A4}$$

Equation (4) thus obtains.

(b) The Optimal Demand of Late-Use Institutions

This paper assumes the late-use institutions await the date 2 to use their information. Therefore, the date 1 information set for each late-use institution is denoted by $\phi_{i1}^L - \{P_1\}$, while the date 2 information set is denoted by $\phi_{i2}^L = \{S, P_1, P_2\}$. For convenience of following deriving, we transform the ϕ_{i1}^L to τ_1 which has informational equivalence to P_1,

$$\tau_1 \equiv \frac{P_1}{a} = S + \frac{b}{a} \cdot Z_1.$$

Similar to the derivation in Section (a), the optimal date 2 demand for each late-use institution is equal to

$$x_1^L + x_2^L = \frac{E\left(V \mid \phi_{i2}^L\right) - P_2}{\gamma Var\left(V \mid \phi_{i2}^L\right)},$$

where the expected value and variance of V, conditional on ϕ_{i2}^L, are provided as follows,

$$E\left(V \mid \phi_{i2}^L\right) = \frac{1}{1+\sigma_\varepsilon^2} S \text{ and } Var\left(V \mid \phi_{i2}^L\right) = \frac{\sigma_\varepsilon^2}{1+\sigma_\varepsilon^2}.$$

Finally, we obtain $x_1^L + x_2^L = \dfrac{\lambda S - P_2}{\gamma \tau_i}$, which is Equation (5) in Proposition 1.

Next, for late-use institution, the expected utility over date 2's wealth at date 1 is given by

$$E\left[-\exp\left(\gamma x_1^L P_1 - \gamma x_1^L P_2 - \frac{(\lambda S - P_2)^2}{2\tau_i}\right)\middle|\phi_{i1}^L\right]. \tag{A5}$$

Define $\chi \equiv \begin{bmatrix} P_2 \\ \lambda S \end{bmatrix}$, $C \equiv \gamma x_1^L P_1$, $B \equiv \begin{bmatrix} -\gamma x_1^L \\ 0 \end{bmatrix}$, and $A \equiv \frac{1}{2\tau_i}\begin{pmatrix} 1 & -1 \\ -1 & 1 \end{pmatrix}$. From Lemma A1, Equation (A5) is transformed as follows:

$$\begin{aligned}
&-1\cdot\left|Var\left(P_2,\lambda S\,|\,\phi_{i1}^L\right)\right|^{\frac{-1}{2}}\cdot\left|\frac{1}{\tau_i}\begin{pmatrix} 1 & -1 \\ -1 & 1 \end{pmatrix}+Var^{-1}\left(P_2,\lambda S\,|\,\phi_{i1}^L\right)\right|^{\frac{-1}{2}}\cdot \\
&\exp\left\{\left(\gamma x_1^L P_1\right)+\begin{bmatrix} -\gamma x_1^L & 0 \end{bmatrix}\cdot E\left(\begin{bmatrix} P_2 \\ \lambda S \end{bmatrix}\middle|\phi_{i1}^L\right)-\left(\frac{1}{2\tau_i}\right)\cdot E\left(\begin{bmatrix} P_2 & \lambda S \end{bmatrix}|\,\phi_{i1}^L\right)\cdot\right. \\
&\begin{pmatrix} 1 & -1 \\ -1 & 1 \end{pmatrix}\cdot E\left(\begin{bmatrix} P_2 \\ \lambda S \end{bmatrix}\middle|\phi_{i1}^L\right)+\frac{1}{2}\left[\begin{bmatrix} -\gamma x_1^L & 0 \end{bmatrix}-\frac{1}{\tau_i}\cdot E\left(\begin{bmatrix} P_2 & \lambda S \end{bmatrix}|\,\phi_{i1}^L\right)\cdot\begin{pmatrix} 1 & -1 \\ -1 & 1 \end{pmatrix}\right]\cdot \\
&\left[\frac{1}{\tau_i}\begin{pmatrix} 1 & -1 \\ -1 & 1 \end{pmatrix}+Var^{-1}\left(P_2,\lambda S\,|\,\phi_{i1}^L\right)\right]^{-1}\cdot \\
&\left.\left[\begin{bmatrix} -\gamma x_1^L & 0 \end{bmatrix}^T-\frac{1}{\tau_i}\begin{pmatrix} 1 & -1 \\ -1 & 1 \end{pmatrix}\cdot E\left(\begin{bmatrix} P_2 \\ \lambda S \end{bmatrix}\middle|\phi_{i1}^L\right)\right]\right\}.
\end{aligned} \tag{A6}$$

Solving for the optimal demand by maximizing the objective function (A6) as follows,

$$\begin{aligned}
&\frac{d}{dx_1^L}\Rightarrow \\
&\left\{\left(\gamma x_1^L P_1\right)+\begin{bmatrix} -\gamma x_1^L & 0 \end{bmatrix}\cdot E\left(\begin{bmatrix} P_2 \\ \lambda S \end{bmatrix}\middle|\phi_{i1}^L\right)-\left(\frac{1}{2\tau_i}\right)\cdot E\left(\begin{bmatrix} P_2 & \lambda S \end{bmatrix}|\,\phi_{i1}^L\right)\cdot\begin{pmatrix} 1 & -1 \\ -1 & 1 \end{pmatrix}\cdot E\left(\begin{bmatrix} P_2 \\ \lambda S \end{bmatrix}\middle|\phi_{i1}^L\right)\right. \\
&+\frac{1}{2}\left[\begin{bmatrix} -\gamma x_1^L & 0 \end{bmatrix}-\frac{1}{\tau_i}\cdot E\left(\begin{bmatrix} P_2 & \lambda S \end{bmatrix}|\,\phi_{i1}^L\right)\cdot\begin{pmatrix} 1 & -1 \\ -1 & 1 \end{pmatrix}\right]\cdot\left[\frac{1}{\tau_i}\begin{pmatrix} 1 & -1 \\ -1 & 1 \end{pmatrix}+Var^{-1}\left(P_2,\lambda S\,|\,\phi_{i1}^L\right)\right]^{-1}\cdot \\
&\left.\left[\begin{bmatrix} -\gamma x_1^L & 0 \end{bmatrix}^T-\frac{1}{\tau_i}\begin{pmatrix} 1 & -1 \\ -1 & 1 \end{pmatrix}\cdot E\left(\begin{bmatrix} P_2 \\ \lambda S \end{bmatrix}\middle|\phi_{i1}^L\right)\right]\right\}=0.
\end{aligned}$$

yields

$$x_1^L=\frac{E\left(P_2\,|\,\phi_{i1}^L\right)-P_1}{\gamma G_{11}^L}+\frac{G_{11}^L-G_{12}^L}{G_{11}^L}\cdot\left(\frac{E\left(\lambda S\,|\,\phi_{i1}^L\right)-E\left(P_2\,|\,\phi_{i1}^L\right)}{\gamma\tau_i}\right),$$

where $E\left(P_2 \mid \phi_{i1}^L\right) = \dfrac{c\left(1+\sigma_\varepsilon^2\right)+\left(\frac{b}{a}\right)d\sigma_Z^2}{1+\sigma_\varepsilon^2+\left(\frac{b}{a}\right)^2\sigma_Z^2}\cdot\tau_1 \equiv c^L\tau_1$ and

$$E\left(\lambda S \mid \phi_{i1}^L\right) = \frac{1}{1+\sigma_\varepsilon^2+\left(\frac{b}{a}\right)^2\sigma_Z^2}\cdot\tau_1 \equiv k^L\tau_1.$$

The coefficients, G_{11}^L and G_{12}^L, are calculated in the following procedures:

$$Var\left(P_2,\lambda S \mid \phi_{i1}^L\right) = \begin{pmatrix} Var\left(P_2 \mid \phi_{i1}^L\right) & Cov\left(P_2,\lambda S \mid \phi_{i1}^L\right) \\ Cov\left(P_2,\lambda S \mid \phi_{i1}^L\right) & Var\left(\lambda S \mid \phi_{i1}^L\right) \end{pmatrix}$$

$$= \begin{pmatrix} c^2(1+\sigma_\varepsilon^2+(d^2+e^2)\sigma_Z^2 - \dfrac{\left[c(1+\sigma_\varepsilon^2)+d(b/a)\sigma_Z^2\right]^2}{(1+\sigma_\varepsilon^2)+(b/a)^2\sigma_Z^2} & c\lambda\left[(1+\sigma_\varepsilon^2)-\dfrac{(1+\sigma_\varepsilon^2)^2}{(1+\sigma_\varepsilon^2)+(b/a)^2\sigma_Z^2}\right] \\ c\lambda\left[(1+\sigma_\varepsilon^2)-\dfrac{(1+\sigma_\varepsilon^2)^2}{(1+\sigma_\varepsilon^2)+(b/a)^2\sigma_Z^2}\right] & \lambda^2(1+\sigma_\varepsilon^2)-\dfrac{\lambda^2(1+\sigma_\varepsilon^2)}{(1+\sigma_\varepsilon^2)+(b/a)^2\sigma_Z^2} \end{pmatrix}$$

$$\equiv \begin{pmatrix} a_{11}^L & a_{21}^L \\ a_{12}^L & a_{22}^L \end{pmatrix},$$

$$Var^{-1}\left(P_2,\lambda S \mid \phi_{i1}^L\right) = \begin{pmatrix} \dfrac{a_{22}^L}{a_{11}^L a_{22}^L-\left(a_{12}^L\right)^2} & \dfrac{-a_{12}^L}{a_{11}^L a_{22}^L-\left(a_{12}^L\right)^2} \\ \dfrac{-a_{12}^L}{a_{11}^L a_{22}^L-\left(a_{12}^L\right)^2} & \dfrac{a_{11}^L}{a_{11}^L a_{22}^L-\left(a_{12}^L\right)^2} \end{pmatrix} \equiv \begin{pmatrix} b_{11}^L & -b_{12}^L \\ -b_{12}^L & b_{22}^L \end{pmatrix},$$

$$2A+Var^{-1}\left(P_2,\lambda S \mid \phi_{i1}^L\right) = \begin{pmatrix} \dfrac{1}{\tau_i}+b_{11}^L & \dfrac{-1}{\tau_i}-b_{12}^L \\ \dfrac{-1}{\tau_i}-b_{12}^L & \dfrac{1}{\tau_i}+b_{22}^L \end{pmatrix} \equiv \begin{pmatrix} c_{11}^L & c_{12}^L \\ c_{12}^L & c_{22}^L \end{pmatrix},$$

$$\left[2A+Var^{-1}\left(P_2,\lambda S \mid \phi_{i1}^L\right)\right]^{-1} = \begin{pmatrix} \dfrac{c_{22}^L}{c_{11}^L c_{22}^L-\left(c_{12}^L\right)^2} & \dfrac{-c_{12}^L}{c_{11}^L c_{22}^L-\left(c_{12}^L\right)^2} \\ \dfrac{-c_{12}^L}{c_{11}^L c_{22}^L-\left(c_{12}^L\right)^2} & \dfrac{c_{11}^L}{c_{11}^L c_{22}^L-\left(c_{12}^L\right)^2} \end{pmatrix} \equiv \begin{pmatrix} G_{11}^L & G_{12}^L \\ G_{12}^L & G_{22}^L \end{pmatrix}.$$

Finally, substituting $E\left(P_2 \mid \phi_{i1}^L\right)$ and $E\left(\lambda S \mid \phi_{i1}^L\right)$, the optimal date 1 demand of late-use institution can also be represented as:

$$x_1^L = \left(\frac{c^L}{\gamma G_{11}^L}+\frac{G_{11}^L-G_{12}^L}{G_{11}^L}\cdot\frac{k^L-c^L}{\gamma\tau_i}\right)\cdot S+\left(\frac{b}{a}\right)\left(\frac{c^L}{\gamma G_{11}^L}+\frac{G_{11}^L-G_{12}^L}{G_{11}^L}\cdot\frac{k^L-c^L}{\gamma\tau_i}\right)\cdot Z_1+\left(\frac{-1}{\gamma G_{11}^L}\right)\cdot P_1.$$

Thus, Equation (6) obtains.

(c) The Optimal Demand of Individuals

The individuals do not observe the private information signal, S, at any time, but they can observe the respective equilibrium prices, P_1 and P_2, at dates 1 and 2. Therefore, their date 1 information set is $\{P_1\}$ or the informational equivalence, τ_1. And the date 2 information set is $\{P_1, P_2\}$.

Define $\tau_2 \equiv S - \frac{\gamma\sigma_\varepsilon^2}{M}(Z_1 + Z_2)$, and thus $\{P_1, P_2\}$ and $\{\tau_1, \tau_2\}$ are informational equivalence. That is, $\phi_{u1} = \{P_1\} = \{\tau_1\}$ and $\phi_{u2} = \{P_1, P_2\} = \{\tau_1, \tau_2\}$.

Similar to the derivation in Sections (a) and (b), the optimal date 2 demand for each individual is equal to

$$x_1^U + x_2^U = \frac{E(V \mid \phi_{u2}) - P_2}{\gamma \cdot Var(V \mid \phi_{u2})},$$

where

$E(V \mid \phi_{u2}) = k_1^U \cdot \tau_1 + k_2^U \cdot \tau_2$ and $\tau_u \equiv Var(V \mid \phi_{u2}) = 1 - k_1^U - k_2^U$. The coefficients, k_1^U and k_2^U, are

$$k_1^U = \left[\left(1 + \sigma_\varepsilon^2 + \left(\frac{b}{a}\right)^2 \sigma_Z^2\right) \cdot \left[\left(1 + \sigma_\varepsilon^2\right) + \frac{2\gamma^2\sigma_\varepsilon^2}{M^2}\sigma_Z^2\right] - \left[\left(1 + \sigma_\varepsilon^2\right) - \left(\frac{b}{a}\right)\frac{\gamma\sigma_\varepsilon^2}{M}\sigma_Z^2\right]^2\right]^{-1} \cdot$$
$$\left(\frac{2\gamma^2\sigma_\varepsilon^4}{M^2}\sigma_Z^2 + \left(\frac{b}{a}\right)\frac{\gamma\sigma_\varepsilon^2}{M}\sigma_Z^2\right),$$

and

$$k_2^U = \left[\left(1 + \sigma_\varepsilon^2 + \left(\frac{b}{a}\right)^2 \sigma_Z^2\right) \cdot \left[\left(1 + \sigma_\varepsilon^2\right) + \frac{2\gamma^2\sigma_\varepsilon^4}{M^2}\sigma_Z^2\right] - \left[\left(1 + \sigma_\varepsilon^2\right) - \left(\frac{b}{a}\right)\frac{\gamma\sigma_\varepsilon^2}{M}\sigma_Z^2\right]^2\right]^{-1} \cdot$$
$$\left(\left(\frac{b}{a}\right)^2 \sigma_Z^2 + \left(\frac{b}{a}\right)\frac{\gamma\sigma_\varepsilon^2}{M}\sigma_Z^2\right).$$

Thus,

$$x_1^U + x_2^U = \left(\frac{k_1^U + k_2^U}{\gamma\tau_u}\right) \cdot S\left(\frac{\left(\frac{b}{a}\right)k_1^U}{\gamma\tau_u} - \frac{\sigma_\varepsilon^2 k_2^U}{M\tau_u}\right) \cdot Z_1 + \left(\frac{-\sigma_\varepsilon^2 k_2^U}{M\tau_u}\right) \cdot Z_2 + \left(\frac{-1}{\gamma\tau_u}\right) \cdot P_2,$$

which is Equation (7) in Proposition 1.

To derive the optimal date 1 demand of individual, we starts with the expected utility of individual over date 2's wealth at date 1, which is given by

$$E\left[-\exp\left(\gamma x_1^U P_1 - \gamma x_1^U P_2 - \frac{(k_1^U \tau_1 + k_2^U \tau_2 - P_2)^2}{2\tau_u}\right) \middle| \phi_{u1}\right]. \tag{A7}$$

Define $\chi \equiv \begin{bmatrix} P_2 \\ k_1^U \tau_1 + k_2^U \tau_2 \end{bmatrix}$, $C \equiv \gamma x_1^U P_1$, $B \equiv \begin{bmatrix} -\gamma x_1^U \\ 0 \end{bmatrix}$, and $A \equiv \frac{1}{2\tau_u}\begin{pmatrix} 1 & -1 \\ -1 & 1 \end{pmatrix}$.

From Lemma A1, Equation (A7) is transformed as follows:

$$
\begin{aligned}
&-1 \cdot \left| Var\left(P_2, k_1^U \tau_1 + k_2^U \tau_2 \mid \phi_{u1}\right)\right|^{\frac{-1}{2}} \cdot \left| \frac{1}{\tau_i}\begin{pmatrix} 1 & -1 \\ -1 & 1 \end{pmatrix} + Var^{-1}\left(P_2, k_1^U \tau_1 + k_2^U \tau_2 \mid \phi_{u1}\right)\right|^{\frac{-1}{2}} \cdot \\
&\exp\left\{ \left(\gamma x_1^U P_1\right) + \begin{bmatrix} -\gamma x_1^U & 0 \end{bmatrix} \cdot E\left(\begin{bmatrix} P_2 \\ k_1^U \tau_1 + k_2^U \tau_2 \end{bmatrix} \middle| \phi_{u1} \right) \right. \\
&\quad - \left(\frac{1}{2\tau_i}\right) \cdot E\left(\begin{bmatrix} P_2 & k_1^U \tau_1 + k_2^U \tau_2 \end{bmatrix} \mid \phi_{u1} \right) \cdot \begin{pmatrix} 1 & -1 \\ -1 & 1 \end{pmatrix} \cdot E\left(\begin{bmatrix} P_2 \\ k_1^U \tau_1 + k_2^U \tau_2 \end{bmatrix} \middle| \phi_{u1} \right) \\
&\quad + \frac{1}{2}\left[\begin{bmatrix} -\gamma x_1^U & 0 \end{bmatrix} - \frac{1}{\tau_i} \cdot E\left(\begin{bmatrix} P_2 & k_1^U \tau_1 + k_2^U \tau_2 \end{bmatrix} \mid \phi_{u1} \right) \cdot \begin{pmatrix} 1 & -1 \\ -1 & 1 \end{pmatrix} \right] \cdot \\
&\quad \left[\frac{1}{\tau_i}\begin{pmatrix} 1 & -1 \\ -1 & 1 \end{pmatrix} + Var^{-1}\left(P_2, k_1^U \tau_1 + k_2^U \tau_2 \mid \phi_{u1}\right) \right]^{-1} \cdot \\
&\quad \left. \left[\begin{bmatrix} -\gamma x_1^U & 0 \end{bmatrix}^T - \frac{1}{\tau_i}\begin{pmatrix} 1 & -1 \\ -1 & 1 \end{pmatrix} \cdot E\left(\begin{bmatrix} P_2 \\ k_1^U \tau_1 + k_2^U \tau_2 \end{bmatrix} \middle| \phi_{u1} \right) \right] \right\}.
\end{aligned}
$$

Solving for the optimal demand by maximizing the objective function as follows,

$$
\begin{aligned}
\frac{d}{dx_1^U} \Rightarrow &\left\{ \left(\gamma x_1^U P_1\right) + \begin{bmatrix} -\gamma x_1^U & 0 \end{bmatrix} \cdot E\left(\begin{bmatrix} P_2 \\ k_1^U \tau_1 + k_2^U \tau_2 \end{bmatrix} \middle| \phi_{u1} \right) \right. \\
&- \left(\frac{1}{2\tau_u}\right) \cdot E\left(\begin{bmatrix} P_2 & k_1^U \tau_1 + k_2^U \tau_2 \end{bmatrix} \middle| \phi_{u1} \right) \cdot \begin{pmatrix} 1 & -1 \\ -1 & 1 \end{pmatrix} \cdot E\left(\begin{bmatrix} P_2 \\ k_1^U \tau_1 + k_2^U \tau_2 \end{bmatrix} \middle| \phi_{u1} \right) \\
&+ \frac{1}{2}\left[\begin{bmatrix} -\gamma x_1^U & 0 \end{bmatrix} - \frac{1}{\tau_i} \cdot E\left(\begin{bmatrix} P_2 & k_1^U \tau_1 + k_2^U \tau_2 \end{bmatrix} \mid \phi_{u1} \right) \cdot \begin{pmatrix} 1 & -1 \\ -1 & 1 \end{pmatrix} \right] \cdot \\
&\left[\frac{1}{\tau_i}\begin{pmatrix} 1 & -1 \\ -1 & 1 \end{pmatrix} + Var^{-1}\left(P_2, k_1^U \tau_1 + k_2^U \tau_2 \mid \phi_{u1}\right) \right]^{-1} \cdot \\
&\left. \left[\begin{bmatrix} -\gamma x_1^U & 0 \end{bmatrix}^T - \frac{1}{\tau_u}\begin{pmatrix} 1 & -1 \\ -1 & 1 \end{pmatrix} \cdot E\left(\begin{bmatrix} P_2 \\ k_1^U \tau_1 + k_2^U \tau_2 \end{bmatrix} \middle| \phi_{u1} \right) \right] \right\} = 0.
\end{aligned}
$$

The result is

$$
x_1^U = \frac{E\left(P_2 \mid \phi_{u1}\right) - P_1}{\gamma G_{11}^U} + \frac{G_{11}^U - G_{12}^U}{G_{11}^U} \cdot \left(\frac{E\left(k_1^U \tau_1 + k_2^U \tau_2 \mid \phi_{u1}\right) - E\left(P_2 \mid \phi_{u1}\right)}{\gamma \tau_u} \right),
$$

where $E\left(P_2 \mid \phi_{u1}\right) = \dfrac{c\left(1+\sigma_\varepsilon^2\right)+(b/a)d\sigma_Z^2}{1+\sigma_\varepsilon^2+(b/a)^2\sigma_Z^2}\cdot\tau_1 \equiv c^U\tau_1$,

and $E\left(k_1^U\tau_1+k_2^U\tau_2 \mid \phi_{u1}\right) = k_1^U\tau_1+k_2^U\cdot\dfrac{\left(1+\sigma_\varepsilon^2\right)-(b/a)\dfrac{\gamma\sigma_\varepsilon^2}{M}\sigma_Z^2}{1+\sigma_\varepsilon^2+(b/a)^2\sigma_Z^2}\cdot\tau_1 \equiv k^U\tau_1$.

The coefficients, G_{11}^U and G_{12}^U, are calculated in the following procedures:

$$Var\left(P_2,k_1^U\tau_1+k_2^U\tau_2 \mid \phi_{u1}\right) = \begin{pmatrix} Var\left(P_2 \mid \phi_{u1}\right) & Cov\left(P_2,k_1^U\tau_1+k_2^U\tau_2 \mid \phi_{u1}\right) \\ Cov\left(P_2,k_1^U\tau_1+k_2^U\tau_2 \mid \phi_{u1}\right) & Var\left(k_1^U\tau_1+k_2^U\tau_2 \mid \phi_{u1}\right) \end{pmatrix}$$

$$\equiv \begin{pmatrix} a_{11}^U & a_{21}^U \\ a_{12}^U & a_{22}^U \end{pmatrix},$$

$$a_{11}^U = c^2(1+\sigma_\varepsilon^2)+(d^2+e^2)\sigma_Z^2 - \frac{\left[c(1+\sigma_\varepsilon^2)+d(b/a)\sigma_Z^2\right]^2}{c(1+\sigma_\varepsilon^2)+d(b/a)^2\sigma_Z^2},$$

$$a_{12}^U = c\cdot(k_1^U+k_2^U)\cdot\frac{(b/a)^2(1+\sigma_\varepsilon^2)\sigma_Z^2}{(1+\sigma_\varepsilon^2)+(b/a)^2\sigma_Z^2}$$

$$+d\cdot\left(k_1^U(b/a)-k_2^U\frac{\gamma\sigma_\varepsilon^2}{M}\right)\cdot\frac{(1+\sigma_\varepsilon^2)\sigma_Z^2}{(1+\sigma_\varepsilon^2)+(b/a)^2\sigma_Z^2}+e\cdot\left(-k_2^U\frac{\gamma\sigma_\varepsilon^2}{M}\sigma_Z^2\right),$$

$$a_{22}^U = (k_2^U)^2\cdot\left[1+\sigma_\varepsilon^2+2\frac{\gamma^2\sigma_\varepsilon^4\sigma_Z^2}{M^2}-\frac{\left[(1+\sigma_\varepsilon^2)-(b/a)\dfrac{\gamma^2\sigma_\varepsilon^2\sigma_Z^2}{M^2}\right]^2}{(1+\sigma_\varepsilon^2)+(b/a)^2\sigma_Z^2}\right];$$

$$Var^{-1}\left(P_2,k_1^U\tau_1+k_2^U\tau_2 \mid \phi_{u1}\right) = \begin{pmatrix} \dfrac{a_{22}^U}{a_{11}^Ua_{22}^U-\left(a_{12}^U\right)^2} & \dfrac{-a_{12}^U}{a_{11}^Ua_{22}^U-\left(a_{12}^U\right)^2} \\ \dfrac{-a_{12}^U}{a_{11}^Ua_{22}^U-\left(a_{12}^U\right)^2} & \dfrac{a_{11}^U}{a_{11}^Ua_{22}^U-\left(a_{12}^U\right)^2} \end{pmatrix} \equiv \begin{pmatrix} b_{11}^U & -b_{12}^U \\ -b_{12}^U & b_{22}^U \end{pmatrix},$$

$$2A+Var^{-1}\left(P_2,k_1^U\tau_1+k_2^U\tau_2 \mid \phi_{u1}\right) = \begin{pmatrix} \dfrac{1}{\tau_u}+b_{11}^U & \dfrac{-1}{\tau_u}-b_{12}^U \\ \dfrac{-1}{\tau_u}-b_{12}^U & \dfrac{1}{\tau_u}+b_{22}^U \end{pmatrix} \equiv \begin{pmatrix} c_{11}^U & c_{12}^U \\ c_{12}^U & c_{22}^U \end{pmatrix},$$

$$\left[2A+Var^{-1}\left(P_2,k_1^U\tau_1+k_2^U\tau_2 \mid \phi_{u1}\right)\right]^{-1} = \begin{pmatrix} \dfrac{c_{22}^U}{c_{11}^Uc_{22}^U-\left(c_{12}^U\right)^2} & \dfrac{-c_{12}^U}{c_{11}^Uc_{22}^U-\left(c_{12}^U\right)^2} \\ \dfrac{-c_{12}^U}{c_{11}^Uc_{22}^U-\left(c_{12}^U\right)^2} & \dfrac{c_{11}^U}{c_{11}^Uc_{22}^U-\left(c_{12}^U\right)^2} \end{pmatrix} \equiv \begin{pmatrix} G_{11}^U & G_{12}^U \\ G_{12}^U & G_{22}^U \end{pmatrix}.$$

Finally, substituting $E\left(P_2 \mid \phi_{u1}\right)$ and $E\left(k_1^U \tau_1 + k_2^U \tau_2 \mid \phi_{u1}\right)$, the optimal date 1 demand of individual can also be represented as:

$$x_1^U = \left(\frac{c^U}{\gamma G_{11}^U} + \frac{G_{11}^U - G_{12}^U}{G_{11}^U} \cdot \frac{k^U - c^U}{\gamma \tau_u}\right) S + \left(\frac{b}{a}\right)\left(\frac{c^U}{\gamma G_{11}^U} + \frac{G_{11}^U - G_{12}^U}{G_{11}^U} \cdot \frac{k^U - c^U}{\gamma \tau_u}\right) Z_1 + \left(\frac{-1}{\gamma G_{11}^U}\right) P_1.$$

Thus, Equation (8) obtains.

Proof of Proposition 2: Proposition 2 is the presentation of the coefficients in the price function. Substitute the optimal demands of traders at date 2 ($x_1^E + x_2^E, x_1^L + x_2^L$, and $x_1^U + x_2^U$) into the market-clearing condition at that date,

$$p \cdot M \cdot \left(x_1^E + x_2^E\right) + (1-p) \cdot M \cdot \left(x_1^L + x_2^L\right) + (1-M) \cdot \left(x_1^U + x_2^U\right) = Z_1 + Z_2.$$

Compare the price function at date 2, $P_2 = cS + dZ_1 + eZ_2$, and we can obtain the following three coefficients.

$$c = \frac{\frac{M\lambda}{\gamma \tau_i} + \frac{1-M}{\gamma \tau_u}\left(k_1^U + k_2^U\right)}{\frac{M}{\gamma \tau_i} + \frac{1-M}{\gamma \tau_u}}, \quad d = \frac{\frac{1-M}{\gamma \tau_u}\left(\left(\frac{b}{a}\right) k_1^U - \frac{\gamma \sigma_\varepsilon^2}{M} k_2^U\right) - 1}{\frac{M}{\gamma \tau_i} + \frac{1-M}{\gamma \tau_u}},$$

and $$e = \frac{\frac{1-M}{\gamma \tau_u}\left(\frac{\gamma \sigma_\varepsilon^2}{M} k_2^U\right) - 1}{\frac{M}{\gamma \tau_i} + \frac{1-M}{\gamma \tau_u}}.$$

Next, Substitute the optimal demands at date 1 (x_1^E, x_1^L, and x_1^U) into the market-clearing condition,

$$pM\left(x_1^E\right) + (1-p)M\left(x_1^L\right) + (1-M)\left(x_1^U\right) = Z_1.$$

Then, transform to the price function at date 1, $P_1 = aS + bZ_1$, and thus the coefficients are obtained as follows,

$$a = \frac{pM\left(\frac{\lambda}{\gamma \tau_i} + \frac{c}{\gamma e^2 \sigma_z^2}\right) + (1-p)M\left(\frac{c^L}{\gamma G_{11}^L} + \frac{G_{11}^L - G_{12}^L}{G_{11}^L} \cdot \frac{k^L - c^L}{\gamma \tau_i}\right) + (1-M)\left(\frac{c^U}{\gamma G_{11}^U} + \frac{G_{11}^U - G_{12}^U}{G_{11}^U} \cdot \frac{k^U - c^U}{\gamma \tau_u}\right)}{pM\left(\frac{1}{\gamma \tau_i} + \frac{1}{\gamma e^2 \sigma_z^2}\right) + (1-p)M\left(\frac{1}{\gamma G_{11}^L}\right) + (1-M)\left(\frac{1}{\gamma G_{11}^U}\right)},$$

$$b = \frac{pM\left(\frac{d}{\gamma e^2 \sigma_z^2}\right) + (1-p)M\left(\frac{b}{a}\right)\left(\frac{c^L}{\gamma G_{11}^L} + \frac{G_{11}^L - G_{12}^L}{G_{11}^L} \cdot \frac{k^L - c^L}{\gamma \tau_i}\right) + (1-M)\left(\frac{b}{a}\right)\left(\frac{c^U}{\gamma G_{11}^U} + \frac{G_{11}^U - G_{12}^U}{G_{11}^U} \cdot \frac{k^U - c^U}{\gamma \tau_u}\right) - 1}{pM\left(\frac{1}{\gamma \tau_i} + \frac{1}{\gamma e^2 \sigma_z^2}\right) + (1-p)M\left(\frac{1}{\gamma G_{11}^L}\right) + (1-M)\left(\frac{1}{\gamma G_{11}^U}\right)}.$$

Proof of Proposition 3: Proposition 3 presents the closed-form solution to the accompanying trading equilibrium when all institutions choose date 1, which is the special case of Proposition 2 (p=1). Avoiding the redundant derivation, here focus on the difference. Complete derivation is provided by the author for request.

When all institutions choose date 1 (i.e., p=1), for each institution, the information set at dates 1 and 2 are $\phi_{i1}=\{S,P_1\}$ and $\phi_{i2}=\{S,P_1,P_2\}$. Employing the ϕ_{i2} information set, the optimal date 2 demand of institution is as follows:

$$x_1+x_2=\frac{\lambda S-P_2}{\gamma\tau_i},$$

where $\lambda\equiv\frac{1}{1+\sigma_\varepsilon^2}$ and $\tau_i\equiv\frac{\sigma_\varepsilon^2}{1+\sigma_\varepsilon^2}$.

Employing the ϕ_{i1} information set, the optimal date 1 demand of institution is as follows:

$$x_1=\left(\frac{\lambda}{\gamma\tau_i}+\frac{c_1}{\gamma e_1^2\sigma_z^2}\right)\cdot S+\left(\frac{d_1}{\gamma e_1^2\sigma_z^2}\right)\cdot Z_1-\left(\frac{-1}{\gamma\tau_i}+\frac{-1}{\gamma e_1^2\sigma_z^2}\right)\cdot P_1.$$

For individuals, their information set at dates 1 and 2 are

$$\phi_{u1}=\{\tau_1\},\quad \tau_1\equiv\frac{P_1}{a_1}=S+\phi Z_1,\ \text{ where }\ \phi\equiv\frac{b_1}{a_1}.$$

and

$$\phi_{u2}=\{\tau_1,\tau_2\},\quad \tau_2\equiv S-\frac{\gamma\sigma_\varepsilon^2}{M}\left(Z_1+Z_2\right).$$

Hence, the optimal date 2 demand of individual is

$$y_1+y_2=\frac{k_1\tau_1+k_2\tau_2-P_2}{\gamma\tau_u}.$$

where

$$k_1=\frac{(\gamma\sigma_\varepsilon^2+\phi)^2\sigma_z^2+(\gamma\sigma_\varepsilon^2)^2\sigma_z^2}{(1+\sigma_\varepsilon^2+\phi^2\sigma_z^2)\left[(\gamma\sigma_\varepsilon^2+\phi)^2\sigma_z^2+(\gamma\sigma_\varepsilon^2)^2\sigma_z^2\right]-\left[-\phi\left(\gamma\sigma_\varepsilon^2+\phi\right)\sigma_z^2\right]^2},$$

$$k_2=\frac{\phi\cdot(\gamma\sigma_\varepsilon^2+\phi)\sigma_z^2}{(1+\sigma_\varepsilon^2+\phi^2\sigma_z^2)\left[(\gamma\sigma_\varepsilon^2+\phi)^2\sigma_z^2+(\gamma\sigma_\varepsilon^2)^2\sigma_z^2\right]-\left[-\phi\left(\gamma\sigma_\varepsilon^2+\phi\right)\sigma_z^2\right]^2},$$

and $\tau_u=1-k_1$.

Before calculating the optimal date 1 demand of individual, here first solve the variable ϕ. Substituting the date 2 optimal demands of institutions and individuals into the date 2 market-clearing condition,

$$M(x_1+x_2)+(1-M)(y_1+y_2)=z_1+z_2,$$

yields:

$$P_2=c_1S+d_1Z_1+e_1Z_2.$$

where the coefficients are as follows:

$$c_1=\frac{\dfrac{M\lambda}{\gamma\tau_i}+\dfrac{k_1(1-M)}{\gamma\tau_u}}{\dfrac{M}{\gamma\tau_i}+\dfrac{1-M}{\gamma\tau_u}},$$

$$d_1=\frac{\dfrac{\phi k_1(1-M)}{\gamma\tau_u}+\left(\dfrac{k_2(1-M)}{\gamma\tau_u}\right)\left(-\dfrac{\gamma\sigma_\varepsilon^2}{M}-\phi\right)-1}{\dfrac{M}{\gamma\tau_i}+\dfrac{1-M}{\gamma\tau_u}},$$

$$e_1=\frac{\left(\dfrac{k_2(1-M)}{\gamma\tau_u}\right)\left(-\dfrac{\gamma\sigma_\varepsilon^2}{M}\right)-1}{\dfrac{M}{\gamma\tau_i}+\dfrac{1-M}{\gamma\tau_u}}.$$

Since the individuals only observe P_1 at date 1, it is expected that the optimal date 1 demand of individual can be expressed as:

$$y_1=\varphi P_1,$$

where φ is a coefficient. Substituting the date 1 optimal demands x_1 and y_1 into the market-clearing condition of date 1 $(Mx_1+(1-M)y_1=Z_1)$ and arranging the form of market price at date 1 $(P_1=a_1S+b_1Z_1)$, we yield:

$$a_1=\frac{-M\left(\dfrac{\lambda}{\gamma\tau_i}+\dfrac{c_1}{\gamma e_1^2\sigma_z^2}\right)}{-M\left(\dfrac{1}{\gamma\tau_i}+\dfrac{1}{\gamma e_1^2\sigma_z^2}\right)+\varphi(1-M)} \quad \text{and} \quad b_1=\frac{-\left(M\dfrac{d_1}{\gamma e_1^2\sigma_z^2}-1\right)}{-M\left(\dfrac{1}{\gamma\tau_i}+\dfrac{1}{\gamma e_1^2\sigma_z^2}\right)+\varphi(1-M)}.$$

Hence,

$$\phi\equiv\frac{b_1}{a_1}=\frac{-\left(M\dfrac{d_1}{\gamma e_1^2\sigma_z^2}-1\right)}{-M\left(\dfrac{\lambda}{\gamma\tau_i}+\dfrac{c_1}{\gamma e_1^2\sigma_z^2}\right)}. \tag{A8}$$

Substituting the coefficients $c_1, d_1,$ and e_1, Equation (A8) can be rearranged as $\left(\phi+\dfrac{\gamma\sigma_\varepsilon^2}{M}\right)\cdot F(\phi)=0$, where $F(\phi)$ is a complicated non-linear function of ϕ.

There is only one simple linear solution to this equation, that is, $\phi = \frac{\gamma\sigma_\varepsilon^2}{M}$. Using this linear solution of ϕ, we continue to calculate the optimal date 1 demand of individual, as follows:

$$y_1 = \left(\frac{k_1}{\gamma\tau_u} + \frac{c_1}{\gamma e_1^2 \sigma_Z^2}\right)\tau_1 - \left(\frac{1}{\gamma\tau_u} + \frac{1}{\gamma e_1^2 \sigma_Z^2}\right)P_1.$$

Finally, substituting the linear solution of ϕ into all the optimal demand, and also substituting into the market-clearing condition, we obtain the price coefficients as follows:

$$a_1 = \frac{M(M+\gamma^2\sigma_Z^2\sigma_\varepsilon^2)}{M^2 + M(M+\gamma^2\sigma_Z^2)\sigma_\varepsilon^2 + \gamma^2\sigma_Z^2\sigma_\varepsilon^4},$$

$$b_1 = \frac{-\gamma\sigma_\varepsilon^2(M+\gamma^2\sigma_Z^2\sigma_\varepsilon^2)}{M^2 + M(M+\gamma^2\sigma_Z^2)\sigma_\varepsilon^2 + \gamma^2\sigma_Z^2\sigma_\varepsilon^4},$$

$$c_1 = \frac{M(M+\gamma^2\sigma_Z^2\sigma_\varepsilon^2)}{M^2 + M(M+\gamma^2\sigma_Z^2)\sigma_\varepsilon^2 + \gamma^2\sigma_Z^2\sigma_\varepsilon^4},$$

$$d_1 = \frac{-\gamma\sigma_\varepsilon^2(M+\gamma^2\sigma_Z^2\sigma_\varepsilon^2)}{M^2 + M(M+\gamma^2\sigma_Z^2)\sigma_\varepsilon^2 + \gamma^2\sigma_Z^2\sigma_\varepsilon^4},$$

$$e_1 = \frac{-\gamma\sigma_\varepsilon^2(M^2+\gamma^2\sigma_Z^2\sigma_\varepsilon^2)}{M^2 + M(M+\gamma^2\sigma_Z^2)\sigma_\varepsilon^2 + \gamma^2\sigma_Z^2\sigma_\varepsilon^4}.$$

This is the accompanying trading equilibrium when all institutions choose date 1 (p=1). It is noted the solution is in closed-form.

Proof of Proposition 4: Proposition 4 presents the closed-form solution to the accompanying trading equilibrium when all institutions choose date 2, which is also the special case of Proposition 2 (p=0). Similar with the proof of Proposition 4, here focus on the description of difference.

Since all institutions choose date 2, for each institution, the information set at dates 1 and 2 are $\phi_{i1} = \{P_1\} = \{Z_1\}$ and $\phi_{i2} = \{S, P_1, P_2\}$. Employing the ϕ_{i2} information set, the optimal date 2 demand of institution is as follows:

$$x_1 + x_2 = \frac{\lambda S - P_2}{\gamma\tau_i},$$

where $\lambda \equiv \frac{1}{1+\sigma_\varepsilon^2}$ and $\tau_i \equiv \frac{\sigma_\varepsilon^2}{1+\sigma_\varepsilon^2}$.

Employing the ϕ_{i1} information set, the optimal date 1 demand of institution is as follows:

$$x_1 = \frac{d_2 Z_1 - P_1}{\gamma G_{11}^i} + \frac{G_{11}^i - G_{12}^i}{G_{11}^i}\left(\frac{-d_2 Z_1}{\gamma \tau_i}\right).$$

The expression of the coefficients G_{11}^i and G_{12}^i are computed as follows. Define

$D \equiv \left(\frac{1}{e_2^2\sigma_Z^2} + \frac{1}{\tau_i}\right)\cdot\left(\frac{c_2^2(1+\sigma_\varepsilon^2)+e_2^2\sigma_Z^2}{e_2^2\sigma_Z^2\lambda^2(1+\sigma_\varepsilon^2)} + \frac{1}{\tau_i}\right) - \left(\frac{c_2^2\lambda(1+\sigma_\varepsilon^2)}{e_2^2\sigma_Z^2\lambda^2(1+\sigma_\varepsilon^2)} + \frac{1}{\tau_i}\right)^2$, and therefore,

$G_{11}^i = \frac{1}{D}\cdot\left(\frac{c_2^2(1+\sigma_\varepsilon^2)+e_2^2\sigma_Z^2}{e_2^2\sigma_Z^2\lambda^2(1+\sigma_\varepsilon^2)} + \frac{1}{\tau_i}\right)$ and $G_{12}^i = \frac{1}{D}\cdot\left(\frac{c_2^2\lambda(1+\sigma_\varepsilon^2)}{e_2^2\sigma_Z^2\lambda^2(1+\sigma_\varepsilon^2)} + \frac{1}{\tau_i}\right)$.

For individuals, their information set at dates 1 and 2 are

$$\phi_{u1} = \{P_1\} = \{Z_1\}$$

and

$$\phi_{u2} = \{P_1, P_2\} = \{\tau, Z_1\},$$

where

$$\tau \equiv \frac{1}{c_2}\left(P_2 - \frac{d_2}{b_2}P_1\right).$$

Hence, the optimal date 2 demand of individual is $y_1 + y_2 = \frac{k\tau - P_2}{\gamma\tau_u}$,

where $k = \frac{1}{1+\sigma_\varepsilon^2 + \left(\frac{e_2}{c_2}\right)^2\sigma_Z^2}$ and $\tau_u = k\left(\sigma_\varepsilon^2 + \left(\frac{e_2}{c_2}\right)^2\sigma_Z^2\right)$.

The optimal date 1 demand of individual is

$$y_1 = \frac{d_2 Z_1 - P_1}{\gamma G^u} + (1-\alpha_2)\left(\frac{-d_2 Z_1}{\gamma G^u}\right),$$

where $\alpha_2 = \frac{\frac{1}{c_2}}{1+\sigma_\varepsilon^2 + \left(\frac{e_2}{c_2}\right)^2\sigma_Z^2}$ and $G^u = \left(\frac{1}{c_2^2(1+\sigma_\varepsilon^2)+e_2^2\sigma_Z^2} + \frac{(\alpha_2-1)^2}{\tau_u}\right)^{-1}$.

Substituting all the optimal demand into the market-clearing condition $(P_1 = b_2 Z_1, P_2 = c_2 S + d_2 Z_1 + e_2 Z_2)$, we obtain the price coefficients as follows:

$$b_2 = -\gamma,$$

$$c_2 = \frac{M(M+\gamma^2\sigma_Z^2\sigma_\varepsilon^2)}{M^2 + M(M+\gamma^2\sigma_Z^2)\sigma_\varepsilon^2 + \gamma^2\sigma_Z^2\sigma_\varepsilon^4},$$

$$d_2 = \frac{-\gamma\sigma_\varepsilon^2(M^2+\gamma^2\sigma_Z^2\sigma_\varepsilon^2)}{M^2 + M(M+\gamma^2\sigma_Z^2)\sigma_\varepsilon^2 + \gamma^2\sigma_Z^2\sigma_\varepsilon^4},$$

$$e_2 = \frac{-\gamma\sigma_\varepsilon^2(M+\gamma^2\sigma_Z^2\sigma_\varepsilon^2)}{M^2+M(M+\gamma^2\sigma_Z^2)\sigma_\varepsilon^2+\gamma^2\sigma_Z^2\sigma_\varepsilon^4}.$$

This is the accompanying trading equilibrium when all institutions choose date 2 (p=0). Similarly, it is noted the solution is in closed-form.

Proof of Proposition 5: Let P_0=0 and P_3=V. When all institutions choose date 1, the variance of the date 1 price change is given by:

$$var(P_1-P_0) = var_1(a_1S+b_1Z_1) = a_1^2(1+\sigma_\varepsilon^2)+b_1^2\sigma_Z^2.$$

The variance of the date 2 price change is given by:

$$var_1(P_2-P_1) = var_1\left[(c_1-a_1)S+(d_1-b_1)Z_1+e_1Z_2\right].$$

From Proposition 4, $c_1=a_1$ and $d_1=b_1$, and thus

$$var_1(P_2-P_1) = var_1(e_1Z_2) = e_1^2\sigma_Z^2.$$

The variance of the date 3 price change is given by:

$$var_1(P_3-P_2) = (1-c_1)^2+c_1^2\sigma_\varepsilon^2+d_1^2\sigma_Z^2+e_1^2\sigma_Z^2.$$

Finally, the unconditional price variance $\overline{var_1}$ is given by the average of $var(P_1-P_0)$, $var_1(P_2-P_1)$, and $var_1(P_3-P_2)$, which is:

$$\overline{var_1} = \frac{1}{3}\left[a_1^2+(1-c_1)^2+(a_1^2+c_1^2)\sigma_\varepsilon^2+(b_1^2+d_1^2+2e_1^2)\sigma_Z^2\right].$$

In the other case, when all institutions choose date 2, the price change variances and unconditional volatility are given by:

$$var_2(P_1-P_0) = b_2^2\sigma_Z^2,$$

$$var_2(P_2-P_1) = c_2^2(1+\sigma_\varepsilon^2)+(d_2-b_2)^2\sigma_Z^2+e_2^2\sigma_Z^2,$$

$$var_2(P_3-P_2) = (1-c_2)^2+c_2^2\sigma_\varepsilon^2+d_2^2\sigma_Z^2+e_2^2\sigma_Z^2,$$

and $\overline{var_2} = \frac{1}{3}\left[c_2^2+(1-c_1)^2+2c_2^2\sigma_\varepsilon^2+\left((d_2-b_2)^2+b_2^2+d_2^2+2e_2^2\right)\sigma_Z^2\right].$

Substituting the price coefficients of Propositions 4 and 5, and then calculating $var_2(P_3-P_2)-var_1(P_3-P_2)$, $var_2(P_2-P_1)-var_1(P_2-P_1)$, and $\overline{var_2}-\overline{var_1}$, yields:

$$var_2(P_3-P_2)-var_1(P_3-P_2)=0,\ var_2(P_2-P_1)-var_1(P_2-P_1)>0,$$

and $\overline{var_2}-\overline{var_1} = \frac{2\gamma^2}{3}\left(1-\frac{M^2\sigma_\varepsilon^2+\gamma^2\sigma_Z^2\sigma_\varepsilon^4}{M^2\sigma_\varepsilon^2+\gamma^2\sigma_Z^2\sigma_\varepsilon^4+M^2+M\gamma^2\sigma_Z^2\sigma_\varepsilon^2}\right)>0.$

Thus, Proposition 5 is demonstrated.

Proof of Proposition 6: Let P_0=0 and P_3=V. When all institutions choose date 1, the prices of the asset at dates 1 and 2 are presented as,

$$P_1 = a_1 S + b_1 Z_1$$

and

$$P_2 = c_1 S + d_1 Z_1 + e_1 Z_2.$$

Hence, the price changes across dates 1 and 2, and dates 2 and 3 are given by:

$$P_2 - P_1 = (c_1 - a_1)V + (c_1 - a_1)\varepsilon + (d_1 - b_1)Z_1 + e_1 Z_2$$

and

$$P_3 - P_2 = (1 - c_1)V - c_1\varepsilon - d_1 Z_1 - e_1 Z_2.$$

The serial covariance of adjacent price changes prior to date 3 is given by:

$$cov_1(P_2 - P_1, P_3 - P_2) = (1 - c_1)(c_1 - a_1) - c_1(c_1 - a_1)\sigma_\varepsilon^2 - d_1(d_1 - b_1)\sigma_Z^2 - e_1^2\sigma_Z^2.$$

From Proposition 3, $c_1 = a_1$ and $d_1 = b_1$, and thus

$$cov_1(P_2 - P_1, P_3 - P_2) = -e_1^2\sigma_Z^2 < 0.$$

This proves part 1 of Proposition 6.

In the other case, when all institutions choose date 2, the prices of the asset at dates 1 and 2 are presented as,

$$P_1 = b_2 Z_1$$

and

$$P_2 = c_2 S + d_2 Z_1 + d_2 Z_2.$$

The price changes across dates 1 and 2, and dates 2 and 3 are given by:

$$P_2 - P_1 = c_2 V + c_2\varepsilon + (d_2 - b_2)Z_1 + e_2 Z_2$$

and

$$P_3 - P_2 = (1 - c_2)V - c_2\varepsilon - d_2 Z_1 - e_2 Z_2.$$

The serial covariance of adjacent price changes prior to date 3 is:

$$cov_1(P_2 - P_1, P_3 - P_2) = c_2(1 - c_2) - c_2^2\sigma_\varepsilon^2 - d_2(d_2 - b_2)\sigma_Z^2 - e_2^2\sigma_Z^2.$$

Substituting the price coefficients $b_2, c_2, d_2,$ and e_2 from Proposition 4 yields:

$$cov_1(P_2 - P_1, P_3 - P_2) = \frac{\gamma^2\sigma_Z^2\sigma_\varepsilon^2(M - \sigma_\varepsilon^2)\left[M^3 + M\gamma^2\sigma_Z^2\sigma_\varepsilon^2 + M^2\gamma^2\sigma_Z^2\sigma_\varepsilon^2\sigma_\varepsilon^2 + \gamma^4\sigma_Z^4\sigma_\varepsilon^4\right]}{\left[M^2 + M^2\sigma_\varepsilon^2(M + \gamma^2\sigma_Z^2) + \gamma^2\sigma_Z^2\sigma_\varepsilon^4\right]^2}$$

This covariance is positive if, and only if, $M - \sigma_\varepsilon^2 > 0$, proving part 2 of Proposition 6.

Expressions for the Elements of the Matrices of Institutions' Final Wealth:

(a) For the Early-Use Institutions (I_1-I_{10})

$$I_1 = \frac{(\lambda-c)(1-c)}{\tau_i} + \frac{(c-a)}{e^2\sigma_z^2} + \frac{(\lambda-a)(c-a)}{\tau_i},$$

$$I_2 = \frac{(\lambda-c)(1-c_1)+(\lambda-c)(-c)}{\tau_i} + \frac{2(c-a)^2}{e^2\sigma_z^2} + \frac{2(\lambda-a)(c-a)}{\tau_i},$$

$$I_3 = \frac{(-d)(1-c)+(-d)(\lambda-c)}{\tau_i} + \frac{2(c-a)(d-b)}{e^2\sigma_z^2} + \frac{(-b)(c-a)+(\lambda-a)(d-b)}{\tau_i},$$

$$I_4 = \frac{(-e)(1-c)+(-e)(\lambda-c)}{\tau_i} + \frac{e(c-a)}{e^2\sigma_z^2} + \frac{e(\lambda-a)}{\tau_i},$$

$$I_5 = \frac{(-c)(\lambda-c)}{\tau_i} + \frac{(c-a)^2}{e^2\sigma_z^2} + \frac{(\lambda-a)(c-a)}{\tau_i},$$

$$I_6 = \frac{dc+(-d)(\lambda-c)}{\tau_i} + \frac{2(c-a)(d-b)}{e^2\sigma_z^2} + \frac{(-b)(c-a)+(\lambda-a)(d-b)}{\tau_i},$$

$$I_7 = \frac{ec+(-e)(\lambda-c)}{\tau_i} + \frac{e(c-a)}{e^2\sigma_z^2} + \frac{e(\lambda-a)}{\tau_i},$$

$$I_8 = \frac{(d)^2}{\tau_i} + \frac{(d-b)^2}{e^2\sigma_z^2} + \frac{(d-a)(-b)}{\tau_i},$$

$$I_9 = \frac{2ed}{\tau_i} + \frac{e(d-b)}{e^2\sigma_z^2} + \frac{e(-b)}{\tau_i},$$

$$I_{10} = \frac{(e)^2}{\tau_i}.$$

(b) For the Late-Use Institutions (J_1-J_{10})

$$J_1 = \frac{(\lambda-c)(1-c)}{\tau_i} + \frac{(c^L-a)(c-a)}{G_{11}^L} + \frac{G_{11}^L-G_{12}^L}{G_{11}^L} \cdot \frac{(k^L-c^L)(c-a)}{\tau_i},$$

$$J_2 = \frac{(\lambda-c)(1-c_1)+(\lambda-c)(-c)}{\tau_i} + \frac{2(c^L-a)(c-a)}{G_{11}^L} + \frac{G_{11}^L-G_{12}^L}{G_{11}^L} \cdot \frac{2(k^L-c^L)(c-a)}{\tau_i},$$

$$J_3 = \frac{(-d)(1-c)+(-d)(\lambda-c)}{\tau_i} + \frac{(c^L-a)(d-b)+(c^L\cdot\phi-b)(c-a)}{G_{11}^L} + \frac{G_{11}^L-G_{12}^L}{G_{11}^L} \cdot \frac{(k^L-c^L)(d-b)+(k^L-c^L)\cdot\phi\cdot(c-a)}{\tau_i},$$

$$J_4 = \frac{(-e)(1-c)+(-e)(\lambda-c)}{\tau_i} + \frac{e(c^L-a)}{G_{11}^L} + \frac{G_{11}^L-G_{12}^L}{G_{11}^L} \cdot \frac{e(k^L-c^L)}{\tau_i},$$

$$J_5 = \frac{(-c)(\lambda-c)}{\tau_i} + \frac{(c^L-a)(c-a)}{G_{11}^L} + \frac{G_{11}^L-G_{12}^L}{G_{11}^L} \cdot \frac{(k^L-c^L)(c-a)}{\tau_i},$$

$$J_6 = \frac{dc+(-d)(\lambda-c)}{\tau_i} + \frac{(c^L-a)(d-b)+(c^L\cdot\phi-b)(c-a)}{G_{11}^L} + \frac{G_{11}^L-G_{12}^L}{G_{11}^L} \cdot \frac{(k^L-c^L)(d-b)+(k^L-c^L)\cdot\phi\cdot(c-a)}{\tau_i},$$

$$J_7 = \frac{ec+(-e)(\lambda-c)}{\tau_i} + \frac{e(c^L-a)}{G_{11}^L} + \frac{G_{11}^L-G_{12}^L}{G_{11}^L} \cdot \frac{e(k^L-c^L)}{\tau_i},$$

$$J_8 = \frac{(d)^2}{\tau_i} + \frac{(c^L\cdot\phi-b)(d-b)}{G_{11}^L} + \frac{G_{11}^L-G_{12}^L}{G_{11}^L} \cdot \frac{(k^L-c^L)\cdot\phi\cdot(d-b)}{\tau_i},$$

$$J_9 = \frac{2ed}{\tau_i} + \frac{e(c^L\cdot\phi-b)}{G_{11}^L} + \frac{G_{11}^L-G_{12}^L}{G_{11}^L} \cdot \frac{(k^L-c^L)\cdot\phi\cdot e}{\tau_i},$$

$$J_{10} = \frac{(e)^2}{\tau_i}.$$

(c) For the Institutions when All Institutions Choose Date 1 $(I_1^1 - I_{10}^1)$

$$I_1^1 = \frac{(\lambda - c_1)\cdot(1-c_1)}{\tau_i},$$

$$I_2^1 = \frac{(\lambda - c_1)\cdot(1-c_1)+(\lambda - c_1)\cdot(-c_1)}{\tau_i},$$

$$I_3^1 = \frac{(-d_1)\cdot(1-c_1)+(-d_1)\cdot(\lambda - c_1)}{\tau_i},$$

$$I_4^1 = \frac{(-e_1)\cdot(1-c_1)+(-e_1)\cdot(\lambda - c_1)}{\tau_i} + \frac{e_1\cdot(\lambda - a_1)}{\tau_i},$$

$$I_5^1 = \frac{(-c_1)\cdot(\lambda - c_1)}{\tau_i},$$

$$I_6^1 = \frac{(d_1)\cdot(c_1)+(-d_1)\cdot(\lambda - c_1)}{\tau_i},$$

$$I_7^1 = \frac{(e_1)\cdot(c_1)+(-e_1)\cdot(\lambda - c_1)}{\tau_i} + \frac{e_1\cdot(\lambda - a_1)}{\tau_i},$$

$$I_8^1 = \frac{(d_1)\cdot(d_1)}{\tau_i},$$

$$I_9^1 = \frac{2\cdot(e_1)\cdot(d_1)}{\tau_i} + \frac{e_1\cdot(-b_1)}{\tau_i},$$

$$I_{10}^1 = \frac{(e_1)\cdot(e_1)}{\tau_i}.$$

(d) For the Institutions when All Institutions Choose Date 2 $(J_1^2 - J_{10}^2)$

$$J_1^2 = \frac{(\lambda - c_2)(1-c_2)}{\tau_i},$$

$$J_2^2 = \frac{(\lambda - c_2)(1-c_2)+(\lambda - c_2)(-c_2)}{\tau_i},$$

$$J_3^2 = \frac{(-d_2)(1-c_2)+(-d_2)(\lambda - c_2)}{\tau_i} + \frac{(c_2)(d_2 - b_2)}{G_{11}^i} + \frac{G_{11}^i - G_{12}^i}{G_{11}^i}\cdot\frac{(-d_2)(c_2)}{\tau_i},$$

$$J_4^2 = \frac{(-e_2)(1-c_2)+(-e_2)(\lambda - c_2)}{\tau_i},$$

$$J_5^2 = \frac{(-c_2)(\lambda - c_2)}{\tau_i},$$

$$J_6^2 = \frac{d_2 c_2 + (-d_2)(\lambda - c_2)}{\tau_i} + \frac{(c_2)(d_2 - b_2)}{G_{11}^i} + \frac{G_{11}^i - G_{12}^i}{G_{11}^i}\cdot\frac{(-d_2)(c_2)}{\tau_i},$$

$$J_7^2 = \frac{e_2 c_2 + (-e_2)(\lambda - c_2)}{\tau_i},$$

$$J_8^2 = \frac{(d_2)^2}{\tau_i} + \frac{(d_2 - b_2)^2}{G_{11}^i} + \frac{G_{11}^i - G_{12}^i}{G_{11}^i}\cdot\frac{(-d_2)(d_2 - b_2)}{\tau_i},$$

$$J_9^2 = \frac{2 e_2 d_2}{\tau_i} + \frac{(d_2 - b_2)(e_2)}{G_{11}^i} + \frac{G_{11}^i - G_{12}^i}{G_{11}^i}\cdot\frac{(-d_2)(d_2 - b_2)}{\tau_i},$$

$$J_{10}^2 = \frac{(e_2)^2}{\tau_i}.$$

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機構法人資訊交易與股價行為

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摘 要

本文模型設定法人決策行為並非僅關注當下的利得，而是考量未來多期交易的利潤總合。結果顯示當資訊交易總量較大時，機構法人將私下協議共同延後使用資訊。此一結果與過往文獻認為機構法人在取得資訊後會立即使用的結論迥然不同。機構法人共同延後使用資訊的行為可解釋部分市場異象。

關鍵詞：資訊交易、機構法人、多期交易、市場異象

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