Information Diffusion and Speed Competition

Abstract
Do increasing information transparency and trading speed competition improve market quality? By introducing heterogeneous information diffusion and trading speed hierarchies in an otherwise standard Kyle model, we examine the joint impact of information transparency and trading speed competition on strategic trading and market quality. With faster information diffusion, the speed hierarchies create first-mover advantage and intensify fast trading, re-shaping the trade-off between the weakening effect on information asymmetry and the crowding-out effect on fast and informed trading. We identify strategic complementarities in informed and fast trading in the sense that aggressive trading of (partially informed) fast traders encourages more aggressive informed trading. This strategic complementarity, together with the learning of (partially informed) slow traders and market maker, tends to abate significantly the negative crowding-out effect of fast information diffusion on market quality. Therefore greater information transparency and trading speed competition can improve market quality even though the crowding-out effect can be very significant.

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1. Introduction

Recent regulatory efforts (the Sarbanes-Oxley and Dodd-Frank Acts) have brought disclosure of information in financial markets to the forefront of market regulation. A distinguish feature of publicly available information is that traders receive heterogeneous and partial information, which then diffuses gradually among traders. In other words, instead of receiving full information promptly, traders receive distinct and scattered pieces of information initially due to varying locations, different industry or product specific knowledge of traders, and increasing corporate diversification and globalization of firms. When information becomes more transparent through faster information diffusion, it is easier for traders to interpret the public information, which speeds up information transmission. This generates a “weakening effect” that reduces information asymmetry among traders and benefits market quality with respect to market liquidity and price efficiency. However, this weakening effect can also demote the incentive for informed trading, generating a “crowding-out effect”, and impede market quality. Therefore, the impact of faster information diffusion on market quality depends on the trade-off between the weakening and crowding-out effects.

The rise of technology investment on computer hardware, algorithms and connection to exchange servers has witnessed the development of high-frequency trading (HFT) and speeded up information acquisition and dissemination. This trading speed hierarchy creates the “first-mover advantage” and intensifies fast trading competition, leading to a speed arms race and (inter-temporal) competition among fast and slow traders. The information diffusion among partially informed traders provide an incentive for some traders to trade earlier on their partial (and less precise) information. With faster information diffusion, fast trading can re-shape the trade-off between the weakening and crowding-out effects. On the one hand, the equilibrium price in earlier period can provide additional information source, amplifying the weakening effect and significantly reducing information uncertainty for slow traders and market maker. On the other hand, it can further reduce the information rent for informed trading, amplifying the crowding-out effect on the informed and fast trading. There is a growing literature on both information disclosure/transparency and high-frequency trading respectively, however how they jointly affect price efficiency and market liquidity has not been well understood and become an intensive and heated debate.
To understand the joint effect of increasing information disclosure requirements from market regulators and the development of fast trading technology, we introduce information diffusion (as in Hong and Stein, 1999) to a two-period Kyle (1985) model with partially informed fast traders who trade in early period and partially informed slow traders who trade in late period, in addition to fully informed traders who also trade in late period. The information diffusion captures the transparency of incomplete and heterogeneous information among partially informed traders, while the speed hierarchies facilitate trading speed competition. With the changing market structure due to fast information diffusion, market equilibrium can be characterized by informed trading based on information production and fast trading competition based on speed acquisition. We then examine how information diffusion and speed competition jointly affect the strategic trading among different types of traders, the trade-off mechanism between the weakening and crowding-out effects, and market quality. Our analysis sheds some lights on the debate about the effect of increasing information transparency and fast trading competition, in particular in the context of HFT.

In this paper, we first consider an exogenous economy in which traders are endowed with the speed or information and characterize the strategic trading among traders in equilibrium. On the strategic interaction between informed and slow traders, when slow traders trade more aggressively, more fundamental information is released through their trading. This generates two opposite effects on informed trading. On the one hand, the price impact decreases due to the reduction in the adverse selection, generating an “asymmetry reduction effect” that favours strategic complementarities. On the other hand, the more aggressive slow trading reduces pricing error, leading to a “competition effect” that favours strategic substitutability. Overall, we show that the competition effect always dominates the weakening effect. Therefore an increase in the slow traders’ trading intensity weakens informed traders’ trading intensity, generating strategic substitutability. On the strategic interaction between informed and fast traders, the presence of more aggressive fast trading implies that more fundamental information is released through the equilibrium price in early period, reducing the adverse selection for (long-lived) market maker. This leads to a similar weakening effect that favours strategic complementarities. However, due to the first mover advantage, there is no inter-temporal competition effect between fast and informed traders. Therefore, as opposite to the previous situation, an increase in fast traders’ trading intensity strengthens informed traders’ trading intensity, generating strategic complementarity.
We then extend the model to endogenize the decisions of information production and speed acquisition with respect to the equilibrium fractions of informed and fast traders, respectively. When the fraction of informed traders increases, the competition among informed traders becomes more intensified in the late period. This increases the first-mover advantage in the early period, leading more traders to trade fast. Therefore, acquiring speed is a complement to producing information. The implication of the increase in the fast trading is however ambiguous. More aggressive fast trading impounds more information into the equilibrium price in early period and makes slow traders be more informative. This implies that, on the one hand, slow traders rely relatively more on the equilibrium price instead of their own information. This reduces their relative trading sensitivity and increases the difference in the revenue between informed and slow traders, which then increases the incentive to produce information. On the other hand, fast trading can make the price more informative and reduce the information rent of informed and therefore the incentive to become informed. We identify conditions for informed trading under which whether the complementarity or substitutability dominates the trade-off.

We further examine how fast information diffusion affects information production and speed acquisition. Directly, faster information diffusion reduces the incentive to be fast and informed due to the reduction in the first-mover advantage for fast traders and the information advantage for informed traders respectively. Indirectly, the interdependence of values of speed and information generates a multiplier that changes the direct effect of faster information diffusion in equilibrium. For fast trading, acquiring speed decidedly shows a complement to producing information in the sense that as less traders become informed, the value of the speed also decreases. As the result, the decrease of informed trading amplifies the crowding-out effect for speed acquisition, reducing the fraction of fast traders. For informed traders, however, producing information can be either a substitute or complement to acquiring the speed. When there are strategic substitutions, with faster information diffusion, less traders choose to be the fast, which increases the incentive to be informed and demotes the crowding-out effect. Nevertheless, we show that, with faster information diffusion, the equilibrium fraction of informed traders decreases no matter it is substitute or complement. In general, faster information diffusion reduces the fractions of both informed and fast traders in equilibrium.
Finally, by linking the results of information production and speed acquisition to trading intensities, we analyze how faster information diffusion impacts market quality. In the baseline case without trading speed hierarchies, similar to the existing literature on information disclosure (Diamond, 1985; Gao and Liang, 2013), we show that the crowding-out effect dominates the weakening information asymmetry effect; thus, faster information diffusion impedes market quality. With the trading speed hierarchies, we would expect the amplified and significant crowding-out effect for both informed and fast traders to impede market quality. Surprisingly, with faster information diffusion, greater information transparency and trading speed competition can actually improve market quality. Essentially, the overall market quality depends not only on the population of informed and fast traders, but more importantly on how much of fundamental information leak to slow informed via fast trading and equilibrium price in early period, how the informed trading reacts to more aggressive fast trading, and how aggressively fast traders, as a group, trade on their information with faster information diffusion.

[Figure 1]

With the speed hierarchies, the baseline trade-off can be affected differently (as illustrated in Figure 1 and discussed in Section 6). On the one hand, due to the strategic complementarities in informed and fast trading, the aggressive fast trading abates the negative effect on informed trading; informed trading is decreasing insignificantly or even increasing with faster information diffusion. On the other hand, more fast traders not only leak more fundamental information to slow traders through the equilibrium price in early period, but also decrease the rate at which the fraction of slow traders increases with faster information diffusion. This can either amplify or shrink the positive effect on slow trading, depending on the relatively strength of different impacts. Our analysis shows that the negative effect on informed trading abates significantly; therefore, with trading speed hierarchies, the weakening effect dominates the trade-off.

In sum, we identify strategic complementarities in informed and fast trading so that the aggressive fast trading encourages more aggressive informed trading. Together with the learning of slow traders and market maker, this strategic complementarity tends to abate significantly the negative crowding-out effect of fast information diffusion on market quality. Therefore, even with the significant crowding-out effect on fast and informed trading, greater information transparency and trading speed competition can improve market quality. Besides, the trading complementarities
between informed and fast trading and the significant crowding-out effect on fast and informed trading have important implications for information transparency and fast trading competition. For example, in an equilibrium economy with faster information diffusion, trading speed competition can reduce fast and informed trading, but improve market liquidity and price efficiency.

1.1 Related Literature

The current modeling framework builds on the literature of endogenous information production in financial market and extends to endogenous trading speed acquisition. The static endogenous information equilibrium model of Grossman and Stiglitz (1980) has been extended in the literature from different perspectives by considering: a) dynamic trading (Mendelson and Tunca, 2004; Avdis, 2016); b) traders to condition their information acquisition decision on public signals (Foster and Viswanathan, 1993); and c) traders to pre-commit to receiving signals at particular dates (Back and Pedersen, 1998; Holden and Subrahmanyam, 2002). A distinguishing feature of our model from this literature is that (partially informed) speculators can endogenously acquire faster trading speed\(^1\), which captures fast trading speed competition. In this aspect, our model is more closely related to Huang and Yueshen (2018) who separate speed from information and show that speed and information can be either substitute or complement, leading to potential dysfunction of price discovery. Different from Huang and Yueshen (2018), we follow Hong and Stein (1999) to model the speed of information transparency through information diffusion among speculators who have partial and heterogonous information in a two-period Kyle (1985) model. Our analysis points out that trading speed hierarchies, which generate the interaction between informed and fast trading competition, play a very important role in how greater information transparency can affect market quality. To our knowledge, this is the first paper to examine the joint effect of improving information transparency and fast trading competition on speculators’ strategic trading behavior and market quality.

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\(^1\) Similar to our two period model, asymmetry information models based on two trading rounds (Grundy and McNichols (1989), Froot, Scharfstein, and Stein, 1992; Hirshleifer, Subrahmanyam, and Titman, 1994; Holden and Subrahmanyam, 1996; Brunnermeier, 2005; Banerjee, Davis, and Gondhi, 2017) assume that speculators cannot choose their speed; they either trade in both rounds or are assigned with speed exogenously.
This paper contributes to the literature on strategic trading behavior including strategic substitutability and complementarity. Apart from the standard substitution effect in Grossman and Stiglitz (1980) that acquiring fundamental information becomes less valuable as the number of informed traders increases, there is a rapidly growing literature focusing on different channels of strategic complementarity. By extending Grossman and Stiglitz (1980), Advis (2016) develops a theory of dynamic information acquisition and shows that, in the presence of persistent noise trading, learning more about fundamentals makes the price more informative about noisy trading. By assuming different traders are informed about different fundamentals that affect the security value, Goldstein and Yang (2015) show that acquiring information about different components of fundamentals can be complementary due to that aggressive trading on information about one fundamental reduces the uncertainty in trading on the information about another fundamental. Due to information diffusion and speed competition, the nature of complementarity and the underlying mechanism in Goldstein and Yang (2015) are very different from this paper. With information diffusion among partially informed traders, increasing in informed trading intensifies the competition in late period and increases the first-mover advantage, resulting in more fast trading. In addition, more aggressively fast trading reduces the relative trading sensitivity of the slow traders and increases traders’ incentive to become the informed. In general, we contribute to the existing literature by characterizing the strategic complementarity and substitutability between information production and speed acquisition and the trade-off mechanism on market quality through the weakening and crowding-out effects of fast information diffusion.

This paper also contributes to the literature on information disclosure and transparency (surveyed in Verrecchia, 2001; Bond, Edmans and Goldstein, 2012 and Goldstein and Yang, 2017) and provides information diffusion as a new channel for improving market quality. The literature has theoretically explored implications of information transparency from different aspects, including the cost of capital (Hughes, Liu and Liu, 2007); informative prices about fundamentals (Banerjee, Davis and Gondhi, 2017); endogenous liquidity trading (Han, Tang and Yang, 2016); inefficient coordination on public information (Morris and Shin, 2002); and learning of manager or regulator (Goldstein and Yang, 2017). However, none of these studies has examined the positive price-efficiency consequences of public information through the channel of inducing strategic

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substitution or complementarity among fast and informed trading. In fact, without fast trading competition, the existing literature shows that faster information diffusion impedes price efficiency through the crowding-out channel. We show however that, with fast information diffusion and trading speed competition, more information transparency can improve market quality through the dominance of the weakening information asymmetry effect channel.

Finally, this paper contributes to a broad literature that studies the influence of HFT (see Menkveld (2016) for an excellent survey on both theoretical and empirical research about HFT). This growing literature mainly focuses on three questions: (a) what information do high-frequency traders trade on (Hu, Pan and Wang, 2017; Van Kerveland and Menkveld, 2017); (b) how does HFT incorporate information (O’Hara, Yao and Ye, 2014; Brogaard, Hendershott and Riordan, 2017); and (c) what is the impact of HFT on market quality (Budish, Cramton and Shim, 2015; Yang and Zhu, 2016 and Weller, 2016)? By introducing the information diffusion (with respect to question (a)), this paper addresses questions (b) and (c). We characterize the strategic substitutability and complementarity through the trade-off between the weakening and crowding-out effects. In particular, we highlight the effect of increasing information transparency on market quality. Our results provide a better understanding of how the effect of information transparency explored in the literature can be changed under this “new environment”, which has not been addressed in the existing literature.

The rest of the paper is organized as follows. Section 2 develops the model of information diffusion and speed competition and characterizes the equilibrium in the trading stage. In an exogenous economy, Section 3 analyses the strategic trading behaviour among different types of traders. We show that informed traders’ trading intensity is a substitute to slow informed traders’ trading intensity, but a complement to fast traders’ trading intensity. Section 4 examines the endogenous equilibrium on information production and speed acquisition and characterizes strategic substitutability and complementarity. Section 5 shows how the faster information diffusion impacts equilibrium information production and speed acquisition. Section 6 studies the effect of faster information diffusion on market quality though the trade-off between the weakening and crowding-out effects, together with some implications for empirical predictions. Discussions on model assumptions, robustness and extensions are collected in Section 7. Section 8 concludes and all the proofs are presented in the Appendix.
2. Model

In this section, we first introduce information diffusion process and different trading speed into a two-period Kyle model. We then present the perfect Bayesian equilibrium results when the information production and speed acquisition decisions are exogenous. For convenience, the model variables are tabulated and explained in Table A1 of the appendix.

2.1 Setup

Consider the market for a risky asset with normally distributed payoff $V \sim N(0, \sigma^2)$. There are three types of traders who trade over two periods $t=1, 2$: (i) $N$ speculators who are sophisticated and trade strategically in either the first or second period (no speculator can trade for both periods; we relax this assumption by examining an extended economy where fast traders can trade in both early and late period in Section 7); (ii) a represent liquidity trader who trades randomly $x_t \sim N(0, \sigma^2)$ shares in both periods (at time $t=1, 2$); and (iii) long-lived competitive market-makers who absorb the net trading flow and set the market prices over the two periods. As in Kyle (1985), all traders are risk neutral.

Timeline: There are four dates in the model: $\tau \in \{-1, 0, 1, 2\}$. Figure 2 illustrates the timeline of the information structure, trading actions and events in general. At time $-1$, all traders independently invest in either information or speed technologies (to be discussed in Section 4). At time 0, informed traders receive the full information of the fundamental value, while partially informed traders receive partially and heterogeneous information about the fundamental value from an information diffusion process (to be introduced next). There are two trading rounds at time $\tau \in \{1,2\}$. Based on their information set, traders trade strategically; fast traders trade in the first period while informed and slow traders trade in the second period.

[Figure 2: Timeline]

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3 Although liquidity traders on average make a loss in trading, they trade for some other reason, such as hedging.
4 Competitive market makers mean that, in equilibrium, the market makers set the price to have zero expected profit. Li (2014) describes these market makers as “They do not, however, act like specialists or designated market makers in a dealer market. These market makers represent the large population of traders who have no information or speed advantage, and also no incentives to initiate trades”.

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**Information Diffusion Structure**: Before trading, each speculator receives a private, partial and heterogeneous but the same amount of information about the risky payoff according to an information diffusion process. This captures the idea that heterogeneous information diffuses gradually across speculators. More precisely, we follow Hong and Stein (1999) and decompose the information about the fundamental value $V$ that is normally distributed with mean of zero and variance of $\sigma^2$ into $n$ ($2 \leq n \leq N$) independent sub-innovations with the same variance,

$$V = \sum_{i=1}^{n} v_i,$$

where $v_i$ ($i=1,\ldots,n$) are independent and identical random variables with normal distribution $v_i \sim N(0, \sigma^2/n)$. At time 0, the information starts to spread across the traders. Each trader randomly receives the information about one of the sub-innovations $v_i$. We divide the traders evenly into $n$ groups according to the sub-innovations they have received. Traders in group $i$ receive the same information $v_i$ at time 0. The information diffusion process in our model captures the ideas that “Financial market and commodity markets can be characterized by a number of informed traders, each with different information” (Foster and Viswanathan, 1996).

To better understand the information structures and trading environment captured by the model and the novelty of the results, we consider the following scenario. There is a market for trading shares of a firm whose operations reflect different aspects of the firm. The firm may disclosure information today, but information diffuses gradually among traders due to different locations and knowledge to interpret the public available information. Suppose that the information diffuses at a speed of $n=4$, then investors can learn about one-fourth information of potentially observable uncertainty in the firm’s value. For example, if firm’s fundamental is related to corporate acquisitions, Federal Reserve policy, patent filings and marketing policy, donated as $\{A,B,C,D\}$, each investor only observes one of $\{A\},\{B\},\{C\},\{D\}$ that she is familiar with. Suppose that information becomes more transparency and diffuses faster than before at a speed of, say, $n=2$ now. Then each investor learns one-half information and observes $\{A,B\}$ or $\{C,D\}$. Because of the more transparent information, it becomes easier for investors to interpret unfamiliar information, which speeds up information transmission.

**Speed Technology**: Traders can invest in a speed technology by paying a cost of $c_F$ at time -1 to become a fast trader (see the “Timeline” in Figure 2). The speed technology creates a first-
mover advantage for the fast trader who can trade early at time 1 after receiving heterogeneous public information from the information diffusion process. Without investing in the speed, all traders are slow and can only trade at time 2. Therefore the fast traders are not only faster-acting but also partially informed. Empirically, Jovanovic and Menkveld (2016) find that high-frequency market makers can use index futures information to update their quotes; and Hu, Pan and Wang (2017) show that high-frequency traders are quick in processing public information. Our assumption is consistent with these empirical evidences and the argument that “the investment decision to become HFT is often modeled as a ‘bundle’ – once invested, the investor is both informed and fast” (Huang and Yueshen, 2018).

**Information Technology:** Similarly, traders can also spend $C_I$ on an information technology at time -1 to receive the additional information to be fully informed about the fundamental value $V$ at time 0 (in addition to the partial information received from the information diffusion process). In order to disentangle the effects of the speed and information, we assume that traders can be either informed or fast, but not both. Comparing the fast and slow traders, they have the same amount of information but are different in their trading speed, reflecting the effect of the fast trading. Similarly, comparing the informed and slow traders, they have the same trading speed but with different information, illustrating the effect of the information.

**Trader Type:** In the basic model setup described in this section and analyzed in the next three sections, there are three types of rational traders: (1) a fraction of $I_F (> \frac{n}{N})$ traders are “fast traders” who pay a cost of $C_F (> 0)$ to trade at time $t = 1$; (2) a fraction of $I_I (> \frac{N}{1})$ traders are “informed traders” who pay a cost of $C_I(n) (> 0)$ to be fully informed at time $t = 0$ and trade at time $t = 2$; and (3) the remaining fraction of $1 - I_F - I_I (> \frac{n}{N})$ of the traders are “slow informed traders” who only receive information from the information diffusion process at time $t = 0$ and trade at time $t = 2$. While the masses of the fast and informed traders, $I_F$ and $I_I$, are given exogenously in this section and Section 3, they are endogenized in Section 4.

**Trading Strategy:** With the information described above, we now introduce the trading decision of the three types of traders. For the fast traders in group $i$, they receive (partial)
information $v_i$ and submit market orders $x_F(v_i)$ at time 1. Hence, the aggregate trading volume at time 1 is given by

$$w_1 = \frac{l_F N}{n} \sum_{i=1}^{n} x_F(v_i) + z_1,$$

where $z_1$ is the order submitted by the liquidity trader. Conditional on price $p_1$ at time 1, for the informed traders, they submit market orders $x_I(V, p_1)$ at time 2. For the slow informed traders in group $i$, after receiving the information $v_i$ from the information diffusion process, they submit market orders $x_S(v_i, p_1)$ at time 2. Hence, the aggregate trading volume at time 2 becomes

$$w_2 = l_I N x_I(V, p_1) + \frac{(1 - l_F - l_I)N}{n} \sum_{i=1}^{n} x_S(v_i, p_1) + z_2,$$

where $z_2$ is the order submitted by the liquidity trader at time 2.

### 2.2 Equilibrium Definition and Characterization

The equilibrium concept introduced in the following is the perfect Bayesian equilibrium, as in Kyle (1985). In equilibrium, traders maximize their expected trading profit conditional on their information. After receiving the total trading volume, the market maker sets the price based on the zero-expected-profit criteria.

**Definition 1**: Given the fractions of the fast and informed traders $l_F$ and $l_I$, respectively, a perfect Bayesian equilibrium is defined by traders’ strategy profile and market makers’ pricing rules $(x_F(v_i), x_I(V, p_1), x_S(v_i, p_1), p_1(w_1), p_2(p_1, w_2))$ that satisfy the following conditions,

1) **Profit maximization:**

   $$x_F^*(v_i) = \arg\max_{x_F} E[x_F(V - p_1)|v_i];$$

   $$x_I^*(V, p_1) = \arg\max_{x_I} E[x_I(V - p_2)|V, p_1];$$

   $$x_S^*(v_i, p_1) = \arg\max_{x_S} E[x_S(V - p_2)|v_i, p_1].$$

2) **Market efficiency**: the price functions $p_1(w_1)$ and $p_2(p_1, w_2)$ are determined by the rules that the market maker clears the security market in each period for an expected zero profit:

   $$E[w_2(p_2 - V)|p_1, w_2] = 0;$$

   $$E[w_1(p_1 - V) + w_2(p_2 - V)|w_1] = 0.$$
3) All the traders have rational expectations in that each trader’s belief about the others’ strategies is correct in the equilibrium.

The equilibrium definition implies that traders and market maker are strategic in their trading and pricing, characterizing “forecast the forecasts of others” (Foster and Viswanathan, 1996). Indeed, in the model, a trader’s trading strategy depends on the trading strategies of the others and market maker’s pricing rules, which in turn also depend on the trader’s trading strategies. This endogenous feedback of “one agent’s strategy affects other agents’ strategies that affect himself own strategy” (Foster and Viswanathan, 1996) can be characterized by a fixed-point problem that considerably complicates the analysis in general. Following the literature, we consider a linear equilibrium, where the price linearly depends on the aggregate trading volume:

\[ p_1 = \lambda_1 w_1, \quad p_2 = p_1 + \lambda_2 w_2, \]  

(4)

where the coefficients \( \lambda_1 \) and \( \lambda_2 \) are endogenously determined. Based on the linear price assumption, similar to Kyle (1985), the trading strategies of fast and informed traders are also linear,

\[ x_F(v_i) = \beta_F v_i; \]  

(5)

\[ x_I(V, p_1) = \beta_I (V - p_1). \]  

(6)

Equations (5) and (6) simply say that the fast traders trade on their speed advantage and the informed trade on their information advantage. The coefficients \( \beta_F \) and \( \beta_I \) measure how sensible the fast and informed traders trade to their information. From equation (5), the fast traders trade in advance and thus face a better quote. Equation (6) captures how aggressively the informed traders trade on the pricing error in the expected fundamental value (based on their information about \( V \)) from the equilibrium price in period-one. The trading strategy for the slow traders becomes more complicated,

\[ x_S(v_i, p_1) = \beta_S (v_i - p_1) + \gamma_S p_1. \]  

(7)

While the first term has the similar meaning as in the informed traders’ trading strategy; the second term captures the learning of the slow traders from the equilibrium price in the first period.

In the equilibrium to be characterized, the strategy in equation (7) can also be written alternatively as

\[ x_S(v_i, p_1) = \alpha (E(V) - p_1). \]  

(8)
for some constant $\alpha > 0$. This implies that the order of the slow traders is proportional to his information advantage relative to the market maker. With the linear price, $E(V)$ is also linear in the slow traders’ private information and equilibrium price. We nonetheless work with (7) since it is the most general form and does not impose any structure as in (8).

The procedure of obtaining the equilibrium follows the standard Kyle model. Based on the market maker’s linear pricing functions, we first solve the speculator’s optimal investment problem. We then characterize the fixed-point problem of the strategic and optimal trading among the traders who are “forecasting the forecasts of others”. Finally, with the speculator’s strategy, we determine the pricing functions of the market makers. Consequently, we obtain the following linear equilibrium result.

THEOREM 1: For given $l_F > 0$ and $l_I > 0$, there exists a linear Bayesian equilibrium specified by equations (2)-(7). The coefficients ($\lambda_1, \lambda_2, \beta_F, \beta_I, \beta_S, \gamma_S$) are the functions of parameters $(N, n, l_F, l_I, \sigma, \sigma_z)$ given by (A-1) to (A-4) in Appendix A1.

2.3 Model Discussion

We make several remarks regarding the model assumptions. First, we assume that the fast traders are not only faster-acting but also partially informed. Most observations associate HFT with extremely fast computer running algorithms coded by traders who trade for their own account, which means that fast traders are faster-acting. We also assume that fast traders receive partial information through the information diffusion process. What information HFT trades on is always a heated debate. Empirical evidences show that HFTs are informed, but without being adversely selected completely on their quotes (Menkveld, 2013; Brogaard, Hendershott and Riordan, 2014). By studying the trading around local price trends, Fishe, Haynes and Onur (2017) find that those who best predict either the start or the end of such trends are typically not the fastest traders. These results tend to support our assumption that fast traders are partially informed about the fundamental information.

Second, in the analysis above, we focus on the case in which the information is equally split among the $n$ groups of traders. This assumption provides a consistent allocation scheme for
comparing aggregate results when information diffuses at different speed. With faster information diffusion speed, the fast (or slow) traders, as a group, still hold the full information about the fundamental value. Also, the relative allocation of each piece of information remains uniform, which simplifies the “forecast the forecasts of others” problem.

Third, the information diffusion process in our model affects intra-temporal competition through re-shaping the information structure. Unlike the traditional Kyle-based models which assume that the informed traders have the full (and homogenous) information about the payoff promptly, the fast traders in our model receive partial and heterogeneous information about the payoff. With faster information diffusion, there are fewer information groups and more traders share the same information within each group. This intensifies the competition not only within the group but also among different groups, leading to hyper intra-temporal competition. This results in some different trading behaviour comparing to the normal information structure.

To disentangle the effect of the competition within each group and among heterogeneous groups of fast traders, in Appendix A4, we consider an alternative scenario in which all the fast traders receive partial but homogeneous information $v_i$. In this case, there is no competition among groups with different information. We show that faster information diffusion reduces fast traders’ revenue when fast traders receive heterogeneous information, but increases faster traders’ revenue under homogenous information scenario. The difference comes from the fact that faster information diffusion intensifies the intra-temporal competition under the heterogeneous case; while it has no influence on the intra-temporal competition under the homogenous case. We also show that the price efficiency is better under the heterogeneous information than under the homogeneous information, though the difference is reduced with fast information diffusion. This reflects the benefit of intensified competition to market quality and the collective information advantage of the fast traders with heterogeneous information. The results illustrate a significant impact of information diffusion on intra-competition among the fast traders.

Furthermore, to disentangle the effect of speed and information, we assume that fast traders only trade in the first period, not in the second period. In Section 7, we show that the main results remain the same by allowing the fast traders to trade in both periods.
3. Trading Intensities and Market Quality

To understand the trading behaviour of the fast, informed and slow traders, we examine their trading intensities $\Phi_F, \Phi_I$ and $\Phi_S$ in terms of how aggressively different groups of traders trade on the information about the fundamental.

Due to the first-mover advantage, fast trading is not influenced by informed and slow trading in the late period. Therefore, we start with examining fast trader’s trading intensity $\Phi_F$. When the fundamental value $V$ increases by one unit, the fast traders, as a group, will buy

$$\frac{I_F}{n} \frac{\partial}{\partial V} \left( \sum_{i=1}^{n} x_F(v_i) \right)$$

more stock, representing the trading intensity $\Phi_F$ of the fast traders. By substituting the expression of $\beta_F$, we have

$$\Phi_F = \frac{I_F}{n} \frac{\sigma_z}{\sigma}$$

Similarly, for the informed and slow traders, their trading intensities are given by, respectively,

$$\Phi_I = I_I \frac{\sigma_z}{\sigma}$$

$$\Phi_S = \frac{(1 - I_I - I_F)N}{n} \beta_S.$$  \hspace{1cm} (10)

Different from the fast traders, the informed and slow traders’ trading intensities are interconnected due to the intra-temporal competition. They are also affected by the fast traders’ trading intensity caused by the inter-temporal competition. We examine how the trading intensities interact with each other to generate trading complementarity and substitutability in subsection 3.1.

The overall market quality, mainly the price efficiency\(^6\), depends on the trading intensities. We use the conditional variance to measure the price efficiency about the payoff, which reflects how much residual uncertainty market maker faces after conditioning on the price. It can be shown that

$$VAR(V|w_1) = \frac{\sigma^2 \sigma_z^2}{\Phi_F^2 \sigma^2 + \sigma_z^2}; \quad VAR(V|w_1,w_2) = \frac{\sigma^2 \sigma_z^2}{(\Phi_F^2 + (\Phi_I + \Phi_S)^2) \sigma^2 + \sigma_z^2}.$$  \hspace{1cm} (11)

Note that all three trading intensities positively affect the price efficiency. This is intuitive; when traders trade more aggressively, they reveal more information to the market makers who then

---

\(^6\) As in Kyle (1985), parameter $\lambda_1$ measures the liquidity, characterizing the price impact of the liquidity traders in the market. Note that

$$\lambda_1 = \frac{\Phi_F \sigma^2}{\Phi_F^2 \sigma^2 + \sigma_z^2}; \quad \lambda_2 = \frac{(\Phi_I + \Phi_S) \sigma^2}{(\Phi_I + \Phi_S)^2 \sigma^2 + \sigma_z^2},$$

the trading intensities affect the market liquidity in the same way to the price efficiency as in Equation (11). Since the impact and mechanism of information diffusion on market liquidity and price efficiency are the same, we focus on price efficiency in the following context.
impound more information to the equilibrium price. Therefore price efficiency is affected by the strategic trading of different types of traders, characterized by the trading intensities.

3.1. Trading Complementarity and Substitutability

We now examine the interaction of the strategic trading among different types of traders. In the late period, the two best response functions about the informed and slow traders’ trading intensities jointly determine the trading intensities in market equilibrium. We use \( \phi_i = h_i(\phi_j; \phi_F, N, n, I_i, I_F, \sigma, \sigma_z) \) to represent the best response functions of the informed (with \( i=I, j=S \)) and slow (with \( i=S, j=F \)) traders. We are interested in the slope of the response function. If \( h_i \) is increasing (decreasing) with respect to \( \phi_i \) (or \( \phi_F \)), then we say that trading of type \( i \) traders is a complement (substitute) to trading of type \( -i \) traders, meaning that type \( i \) traders also trade more (less) aggressively on their information when type \( -i \) traders trade more aggressively.

To derive the informed traders’ best response function, for given trading intensities of the fast and slow traders, the informed trader \( k \) maximizes his expected profit,

\[
\max_{x} \mathbb{E}[x_k(V - p_1 - \lambda_2(x_k + (I_iN - 1)X_i + \Phi_S V + \Omega_5 p_1 + z_2))|V, w_1].
\]

From the first-order condition and (9), we obtain

\[
\phi_i = \frac{I_iN((\phi_F^2 + (\phi_i + \phi_S)^2)\sigma^2 + \sigma_z^2)}{(\phi_i + \phi_S)(I_iN + 1)\sigma^2} - \frac{I_iN}{I_iN + 1} \phi_S. \tag{12}
\]

Equation (12) shows that an increase in the fundamental value affects the informed traders’ demand in two ways. First, there is a direct effect; an increase in the signal of the fundamental value increases the expected revenue given the price, leading the informed traders to increase their demand. This positive effect is represented by the first term \( \phi_{i,\text{Direct}} \) of the best response functions in equation (12). Second, there is an indirect effect generating from the forecasting the forecasts of others. With the given fundamental value, an increase in the slow traders’ trading intensity reduces the pricing error and, thus, the revenue of the informed traders, reducing their demands. This indirect and negative effect is represented by the second term \( \phi_{i,\text{Indirect}} \) of the best response functions in (12). Similarly, given the fast and informed traders’ trading intensities, the slow
trader’s trading intensity can be decomposed as $\phi_s = \phi_{S,\text{Direct}} - \phi_{S,\text{Indirect}}$. The same argument applies to the trading intensity of the slow traders.

To explore how the trading intensities affect each other, we focus on the informed traders’ trading intensity in this and next subsections; the analysis and result for the slow traders are similar. Rearranging equation (12) and calculating the quadratic function, we have

$$
\phi_I = h_I(\phi_S; \Phi_F, N, n, I_I, I_F, \sigma, \sigma_z) = -\frac{\phi_S}{2} + \sqrt{\frac{\phi_S^2}{4} + I_IN\phi_F^2 + I_IN \sigma_z^2}.
$$

(13)

To better understand the strategic trading between the informed and slow traders and the trade-off between the direct and indirect effects in equation (12), we substitute equation (13) into equation (12) and obtain

$$
\phi_I = \frac{\frac{I_IN}{2(I_IN + 1)} 4\phi_F^2 \sigma^2 + 4\sigma_z^2 + \left(\phi_S \sigma + \sqrt{(\phi_S^2 + 4I_IN\phi_F^2) \sigma^2 + 4I_IN \sigma_z^2}\right)^2}{\phi_S \sigma^2 + \sqrt{(\phi_S^2 + 4I_IN\phi_F^2) \sigma^2 + 4I_IN \sigma_z^2}}
- \frac{I_IN}{I_IN + 1} \phi_S
$$

(14)

Thus, we can express the informed traders’ trading intensity as the direct and indirect effects of the fast and slow trader’s trading intensities.

Due to the intra-temporal competition between the informed and slow traders, the informed and slow traders’ trading intensities are interconnected. We first look at how the slow trading affects the direct effect of the informed trading. An increase in $\phi_s$ strengthens positively the direct effect (as showed in Appendix B1) of the signal received by the informed traders on their demand. This is because a higher level of $\phi_s$ implies that there is more information about the fundamental value in the trading volume, which reduces the market maker’s adverse selection and price impact, making the informed traders trade more aggressively. Therefore, when the slow traders trade more aggressively, the informed traders also trade more aggressively. This “asymmetry reduction effect” generates strategic complementarity in trading, that is,

$$
\frac{\partial \phi_{I,\text{Direct}}(\phi_F, \phi_S)}{\partial \phi_S} > 0.
$$

(15)

asymmetry reduction effect
We then examine how the slow trading affects the indirect effect of the informed trading. An increase in $\phi_s$ also strengthens the indirect effect, which negatively affects the trading intensity of the informed traders. It captures how the informed and slow traders compete each other. Holding the fundamental value, an increase of slow informed traders’ trading intensity reduces the pricing error and, thus, revenue of the informed traders, making them trade less aggressively. Therefore when the slow traders trade more aggressively, the informed traders trade less aggressively. This “competition effect” generates strategic substitutability in trading, that is, 

$$
\frac{\partial \Phi_{I,\text{Indirect}}(\Phi_F, \Phi_S)}{\partial \Phi_S} = \frac{l_iN}{l_iN + 1} > 0.
$$

Equations (14), (15) and (16) imply that the slope of the best response function is jointly determined by the asymmetry reduction and competition effects,

$$
\frac{\partial h_i(\Phi_S; \Phi_F, N, n, I_1, I_F, \sigma, \sigma_z)}{\partial \Phi_S} = \text{asymmetry reduction effect} - \text{competition effect}.
$$

Based on the relative strength of these two effects, either the strategic complementarity or strategic substitutability dominates (depending on the best response function with a positive or negative slope). We show in Appendix B1 that the competition effect always dominates the asymmetry reduction effect. Therefore, the informed trading is a substitute to the slow informed trading; an increase in the slow traders’ trading intensity weakens the informed traders’ trading intensity.

Instead, due to the first-mover advantage, the fast traders trade earlier than the informed and slow traders. Hence, the fast traders’ trading intensity has no influence on the indirect effect due to no competition between them, that is $\partial \Phi_{I,\text{Indirect}}(\Phi_F, \Phi_S)/\partial \Phi_F = 0$. However, the early period equilibrium price provides information for market maker and weakens the information asymmetry. Consequently, fast traders’ trading intensity works in a similar way as the weakening effect of slow traders’ trading intensity and favours strategic complementarities, that is $\partial \Phi_{I,\text{Direct}}(\Phi_F, \Phi_S)/\partial \Phi_F > 0$. Therefore, the fast traders’ trading intensity strengthens the informed traders’ trading intensity. Similar analysis applies to the trading intensity of slow traders. We summarize the above analysis on the strategic trading among different groups of traders in the following proposition.

**PROPOSITION 1**: The informed traders’ trading intensity is a substitute to the slow informed traders’ trading intensity but a complement to the fast traders’ trading intensity. The slow traders’
trading intensity is a substitute to the informed traders’ trading intensity, but a complement to the fast traders’ trading intensity.

3.2. Implications of Strategic Trading

The trading intensities \( \Phi_i \) and \( \Phi_S \) are determined by the system of functions of the underlying parameters of the model, in particular, the market fractions of different type of traders and the speed of the information diffusion. To understand the effect of changes in these parameters on strategic trading and market quality, we introduce the concept of trading intensity multiplier to characterize how the trading intensities \( \Phi_i \) and \( \Phi_S \) are affected by the model parameters.

**PROPOSITION 2:** Let \( Q \) be one of the six exogenous parameters \((N, n, l_i, l_F, \sigma, \sigma_z)\) that determine \( \Phi_i \) and \( \Phi_S \). Then the effect of \( Q \) on the trading intensity is given by

\[
\frac{d\Phi_i}{dQ}_{\text{total effect}} = M \left( \frac{\partial h_i}{\partial Q} + \frac{\partial h_i}{\partial \Phi_i} \frac{\partial \Phi_i}{\partial Q} + \left( \frac{\partial h_i}{\partial \Phi_F} + \frac{\partial h_i}{\partial \Phi_j} \frac{\partial \Phi_j}{\partial \Phi_F} \right) \frac{d\Phi_F}{dQ} \right),
\]

where the three terms in the bracket capture the direct effects of changing in \( Q \) that come from type-\( i \), type-\( j \) speculators and the fast traders respectively, while the coefficient \( M \) is a multiplier given by

\[
M = \left( 1 - \frac{\partial h_i}{\partial \Phi_i} \frac{\partial h_i}{\partial \Phi_j} \right)^{-1} \geq 1.
\]

Furthermore, \( M=1 \) with either no informed traders \((l_i = 0)\) or no slow traders \((l_i + l_F = 1)\); otherwise, \( M>1 \) and therefore the effect of \( Q \) is amplified in the equilibrium.

The direct effect of \( Q \) on \( \Phi_i \) characterizes the initial impact before considering the interdependence among the trading intensities. The interdependence then creates a multiplier \((M)\) that changes the direct effect in equilibrium. It shows (in Appendix B2) that, when both the informed and slow traders are active in the market, the multiplier \( M \) is greater than one, which means that the interaction between the two trading intensity measures tends to amplify the initial effect. In general, the two trading intensity measures reinforce each other and the initial effect due to the change in the exogenous parameters is amplified in the equilibrium.
3.2.1 The Effect of Market Fraction

Following Proposition 2, we now consider the influence of the fraction of different traders. An increase in \( I_F \) (\( I_l \)) indicates an increase in the fast (informed) traders and a decrease in the slow traders at the same time\(^7\). On the effect of changing in the fraction of informed traders on the informed traders’ trading intensity, we have from (18) that

\[
\frac{d\Phi_i}{dI_l} = M \left( \frac{\partial h_i}{\partial I_l} + \frac{\partial h_s}{\partial \Phi_i} \frac{\partial \Phi_i}{\partial I_l} \right).
\]  

(20)

From Proposition 1, \( \partial h_i/\partial \Phi_S \) is negative. In addition, \( \partial h_i/\partial I_l \) is positive by the expressions of \( h_i \) in equation (13), while \( \partial h_s/\partial I_l \) is negative as shown by (B-4) in Appendix B1. These observations lead to the following results on the effect of increasing in \( I_l \). First, given the individual fast trader’s trading sensitivity, when the fraction of the informed increases, the informed trader, as a group, trade more aggressively due to more informed. Second, more informed trading reduces the slow traders’ trading intensity, which, in turn, increases the informed traders’ trading intensity due to the strategic substitution. In addition, the effect becomes more significant due to the amplified trading intensity multiplier (in Eq. (19)) through the interconnection between the informed and slow traders’ trading intensities. Therefore, with more informed traders, they trade more aggressively. On the effect of changing in the fraction of the fast traders on the informed traders’ trading intensity, the analysis is similar; with an increase in the fast traders’ fraction, the informed traders trade more aggressively.

A similar analysis can be conducted to examine the effect of the slow trader’s trading behaviour. In summary, we show (in Appendix B3) the following result on the effect of the fast and informed traders on the interaction of strategic trading behaviour.

**PROPOSITION 3:** With either more informed or fast traders, the informed traders’ trading intensity \( \Phi_i \) increases, while the slow traders’ trading intensity \( \Phi_S \) decreases.

On the price efficiency, from (11), we see that it is the aggregate trading intensity of the informed and slow traders, \( \Phi_k = \Phi_i + \Phi_S \), that determines the price efficiency in the late period. Given the fraction of the fast traders, based on Proposition 3, more informed traders increases their

\(^7\) Note that here we assume that the increase in \( I_l \) is exogenous and study the trading implications for a fixed \( I_l \). In Section 4, we endogenize information production and speed acquisition and examine how an increase in \( I_l \) leads to the change in \( I_l \), resulting in an additional effect on trading intensity.
trading intensity, but decreases the slow traders’ trading intensity at the same time. The net effect depends on whether the trading intensity of informed or slow traders dominates the trade-off. From Theorem 1 and equations (9) and (10), we have

\[
\Phi_L = \Phi_I + \Phi_S = \sqrt{\frac{I_F N + n}{n} \left( I_F N + \frac{(1 - I_I - I_F)Nn}{(n - 1)I_F N + n^2} \right) \frac{\sigma_z}{\sigma}}.
\]

This indicates that the informed traders’ trading intensity dominates the trade-off; therefore an increase in the informed trading increases the aggregate trading intensity in the late period. This implies that, when the information production and speed acquisition are exogenous, an increase in the informed trading improves market quality in the late period.

The analysis on the effect of the fast traders becomes more complicated. From Proposition 3, the similar trade-off applies to the effect of the fast traders: more fast trading increases informed traders’ trading intensity, but decreases the slow traders’ trading intensity at the same time. Different from the above analysis, in this case, whether the informed or slow traders’ trading intensity dominates the trade-off depends on the market fractions of the fast and informed traders. We show (in Appendix B4) that, when the market fraction of the informed traders is low, the slow traders’ trading intensity can dominate the trade-off, reducing the trading intensity in the late period; otherwise the effect becomes positive. The effect on market quality can be summarized as follows (see the proof in Appendix B4).

**COROLLARY 1**: In the exogenous equilibrium, more informed traders increases the market quality in the late period but has no impact on the market quality in the early period; while more fast traders improves the market quality in the early period and benefits market quality in the late period unless the market fraction of the informed traders is low.

### 3.2.2 The Effect of Faster Information Diffusion

Finally, we consider the effect of information diffusion on traders’ trading intensity and provide a comprehensive framework to examine several key channels analytically. From Proposition 2, we have

\[
\frac{d\Phi_I}{dn} = M \left( \frac{\partial h_I}{\partial \Phi_I} \frac{\partial h_I}{\partial \Phi_F} \frac{\partial \Phi_F}{\partial n} + \frac{\partial h_I}{\partial \Phi_S} \frac{\partial h_I}{\partial n} \right)_{\text{direct effect through fast trader}} + \frac{\partial h_I}{\partial \Phi_S} \frac{\partial h_I}{\partial n} \right)_{\text{direct effect through slow informed}}
\]
The direct effect becomes negative through the fast traders’ trading intensity, generating strategic complementarity in trading; but becomes positive through the slow traders’ trading intensity, generating strategic substitutability in trading, leading to ambiguous net effect as discussed in Proposition 4. Instead, faster information diffusion always increases the slow traders’ trading intensity, making them trade more aggressively. We summarize the results as follows (see Appendix B5 for the proof).

**PROPOSITION 4**: When the fractions of the fast and informed traders satisfy,

$$n < I_F N < \frac{n + \sqrt{n^2 + 4n^3(n - 2)}}{2n - 4},$$

and

$$1 < I_I N < \max \left\{ N - I_F N, \frac{-(1 - I_F)Nn[(n - 2)I_F N + n(-I_F N - n^2)]}{I_F N[(n - 1)I_F N + n^2] - n[(n - 2)I_F N - n(2 - n^2)]} \right\},$$

$$\frac{d\Phi_I}{dn}$$ is positive; otherwise, it is negative. Instead, $$\frac{d\Phi_S}{dn}$$ is always negative. Therefore, as information diffuses faster, the slow traders always trade more aggressively, while the informed traders trade less (more) aggressively when condition (22) and (23) (do not) hold.

From (9), faster information diffusion intensifies the fast traders’ trading intensity, which benefits market quality in the early period. On market quality in late period, similar to the effect of changing in the fractions of different traders, it is the aggregate traders’ trading intensity $$\Phi_L$$ of the informed and slow traders that matters. Proposition 4 shows that, with faster information diffusion, the slow traders’ trading intensity increases; while the informed traders’ trading intensity can either increase or decrease, depending on the fractions of the fast and informed traders. From (21), we can show that, with faster information diffusion, the aggregate trading intensity $$\Phi_L$$ in the late period increases, contributing positively to the market quality in the late period. In summary, we have the following result.

**COROLLARY 2**: In the exogenous equilibrium, faster information diffusion benefits market quality in both trading periods.
4. Endogenous Information Production and Speed Acquisition

The analysis so far focuses on exogenous equilibrium in which the fractions of different type of traders are given exogenously. In this section we introduce costs of information production and speed acquisition into an endogenous equilibrium and examine how market composition of different types of traders is determined and how their strategic trading behavior and market quality are affected differently from the exogenous equilibrium economy. We show that there are strategic complementarities in both information production and speed acquisition, whereby an increase in acquiring speed results in producing more information and vice versa.

4.1 Information Production and Speed Acquisition in Equilibrium

Under risk neutral assumption, our analysis on the endogenous information production and speed acquisition follows closely Foster and Viswanathan (1993). To model the information production and speed acquisition, traders simultaneously decide whether to become the fast, informed or slow traders at the information production and speed acquisition stage \((t = -1)\)\(^8\). For now, we assume that each trader has an opportunity to become either the informed or fast (but not both).

On the information production and speed acquisition decisions, traders can pay a cost, \(c_F\) or \(c_I\), to become the fast or informed traders in the trading model described in the previous section, while those who choose not to acquire speed and not to produce information are the slow traders. To examine the joint impact of the information and speed, we do not consider the corner scenarios. In another word, all three types of speculators (the informed, fast and slow traders) are active in the market \((I_F > 0, I_I > 0, 1 - I_F - I_I > 0)\). By computing the difference between the unconditional expected revenues of being the fast and being the slow traders, the value of the speed \(\Gamma_F\) is determined by the trading intensities,

\[
\Gamma_F = \frac{\sigma^2 \sigma_z^2}{\Phi_F^2 \sigma^2 + \sigma_z^2} \left( \Phi_F - \Phi_I^2 \left( \frac{\Phi_I}{I_F N} \right)^2 \right) + \frac{(\Phi_I + \Phi_S) \sigma^2}{(\Phi_I^2 + (\Phi_I + \Phi_S)^2) \sigma^2 + \sigma_S^2 (n - 1) \Phi_F^2 \sigma^2 + n \sigma_S^2}.
\]

\(^8\)The events for the information production and speed acquisition stage \((t = -1)\) are described as follows: 1) the information diffusion speed and hence the information transparency level are revealed, 2) traders simultaneously decide whether to produce information to be the informed or acquire speed to be the fast with certain costs, and 3) the market fractions of the fast and informed traders are announced and traders trade accordingly. Correspondingly, the market makers and speculators adjust their pricing and trading decision rules according to the trading of the fast, informed and slow traders.
Similarly, by computing the difference between the unconditional expected revenue of being the informed trader and being the slow trader, the value of information $\Gamma_i$ is given by,

$$
\Gamma_i = \frac{\phi_i^2}{(I_iN)^2} \frac{(\phi_i + \phi_N) \sigma^2}{(\phi_i + \phi_N)^2 \sigma^2 + \sigma_z^2} (n-1) \sigma^2 \sigma_z^2 \frac{\sigma_z^2}{n \sigma_z^2}.
$$

Note that, as the functions of the trading intensities, the values of the information and speed depend indirectly on the fractions of the informed and fast traders.

In the equilibrium, a trader chooses to become the fast or informed only when his expected payoff from the trading is sufficient to cover the cost of acquiring the speed or information, comparing to a slow trader. When a trader chooses to acquire the speed (produce the information), then the value of the speed (information) must be equal to its cost; that is, the trader is indifferent between acquiring the speed (producing the information) and being a slow trader. Formally, we have the following definition about the equilibrium conditions.

**DEFINITION 2:** For given speed cost $C_F$ and information cost $C_I$, the market equilibrium fractions of the fast and informed traders $(I^*_F, I^*_I)$ are determined by either (a) $\Gamma_i = C_i$ if $I_i^* > 0$ for some $i = F, I$; or (b) $\Gamma_i \leq C_i$ if $I_i^* = 0$ for some $i = F, I$.

Following Proposition 1, the value of the speed can be expressed as a function of the fractions of the fast and informed traders,

$$
\Gamma_F(I_F, I_I, n) = \frac{n}{(I_FN + n)^2} \sigma \sigma_z - \frac{n}{I_FN + n} \Psi(I_F, I_I, n), \tag{24}
$$

while the value of the information becomes

$$
\Gamma_I(I_F, I_I, n) = (n-1) \Psi(I_F, I_I, n), \tag{25}
$$

where

$$
\Psi(I_F, I_I, n) = \frac{\sqrt{(I_FN + n)n}}{\left( (I_FN + 1) (n-1)I_FN + n^2 \right) + (1 - I_I - I_F)NN} \frac{\sigma \sigma_z}{\sqrt{I_FN + (1 - I_I - I_F)NN}}.
$$

By characterizing the values of the speed and information, we can analyze the endogenous information acquisition.
4.2 Strategic Complementarity and Substitutability

We now analyze the strategic interactions among traders in their decisions to produce information or acquire speed. In particular, we show that these two decisions can be either complementary or substitutable. Formally, we examine how the information and speed values $\gamma_i$ change with the market fractions $(I_F, I_I)$ of the fast and informed traders. When $\gamma_i$ is increasing in $I_I$, we say that acquiring speed (producing information) exhibits a strategic complementarity to producing information (acquiring information), meaning that more traders produce information (acquire speed) when more traders acquire speed (produce information). When $\gamma_i$ is decreasing in $I_I$, acquiring speed (producing information) exhibits a strategic substitutability to producing information (acquiring information). Similarly, when $\gamma_i$ is increasing (decreasing) in $I_I$, there is a strategic complementarity (substitutability) among traders acquiring the speed or producing the information.

From (24), we have $\frac{\partial \gamma_F(I_F, I_I, n)}{\partial I_I} > 0$, which means that acquiring the speed is complement to producing the information. The value of the speed is the difference between the unconditional expected revenues of being the fast and being the slow traders. The informed traders have no influence on the fast traders’ revenue since the fast traders have the first-mover advantage and trade in advance. However, an increase in the fraction of the informed traders $I_I$ has a negative effect on the slow traders’ revenue due to the intensified intra-temporal competition in the late period. Thus, with more informed traders, the value of the speed increases. In general, we find that more informed traders increase trader’s incentive to acquire the speed. Intuitively, with more informed traders, the competition in the late period becomes more intensified and therefore the first-mover advantage becomes more significant. As the result, traders are more willing to trade fast in the early period so that they can avoid the competition in the late period. Therefore, this positive net effect leads to a complementarity.

Similarly, from (25), we have

$$
\frac{\partial \gamma_I(I_F, I_I, n)}{\partial I_F} = \frac{\partial}{\partial I_F} \left[ \frac{(n-1)(I_FN+n)}{(n-1)I_FN+n^2} \right] \frac{(n-1)I_FN+n^2}{I_FN+n} \psi 
+ \frac{(n-1)(I_FN+n)}{(n-1)I_FN+n^2} \frac{\partial}{\partial I_F} \left[ \frac{(n-1)I_FN+n^2}{I_FN+n} \psi \right].
$$

(26)
More fast traders, in general, bring more information to market through their trading, making the equilibrium price more informative about the fundamental value in the early period. Equation (26) indicates that this can have two opposite effects. First, it decreases how sensitive the slow traders trade relatively with the information comparing to the informed traders \( \frac{\beta_s}{\beta_i} \). With more informative equilibrium price, the slow traders rely relatively more on the price instead of their own signals, reducing the individual slow trader’s trading sensitivity. This increases the difference in the revenues between the informed and slow traders, increasing traders’ incentive to invest in the information. We label this effect as “competition effect”, referring to the first term in (26).

Second, an increase in the fast traders reduces the information rent for the informed due to more informative equilibrium price provides slow traders more precise signals about the fundamental value. This reduces the difference in the revenues between the informed and slow traders, leading to a negative effect for the informed traders. We label this effect as “asymmetry reduction effect”, referring to the second term in (26).

The total effect depends on the trade-off between the competition and asymmetry reduction effects. When the negatively asymmetry reduction effect dominates the positive competition effect, an increase in the fast traders reduces the information value, leading to substitutability. We can show that this is the case when

\[
\min\{1 - I_F, \{I_t|G(I_t) = 0, I_t > 0\}\} < I_t < 1 - I_F, \quad (27)
\]

in which the expression of function \( G \) is given by equation (C-2) in Appendix C1. Intuitively, with more informed traders, the competition among the informed is intensified; even with the decreasing in the competition with the slow traders. Under this situation, more fast traders reduce the revenues for both the informed and slow traders due to the fact that the fast traders provide more information to the market makers. With full information, the informed traders are affected more significantly. On the other hand, when

\[
0 < I_t < \min\{1 - I_F, \{I_t|G(I_t) = 0, I_t > 0\}\}, \quad (28)
\]

the positive competition effect dominates the negative asymmetry reduction effect, leading to complementarity.

Finally, we examine how the fraction of the fast (informed) traders affects the value of the speed (information). Consistent with the standard Grossman-Stiglitz substitution effect, investing in the same technology (either the information or speed) is always a strategic substitute; having
more informed (fast) traders reduce trader’s incentive to become the informed (fast). This substitution effect exists not only for the information production but also for the speed acquisition. We summarize these results in the following proposition.

**PROPOSITION 5:** When both the informed and fast traders are active in the market: a) both producing information and acquiring speed are strategic substitute, meaning that the value of the information (speed) decreases as more traders become informed (fast); b) acquiring speed is a complement to producing information, meaning that the value of speed increases as more traders become informed; c) producing information can be either a substitute or a complement to acquiring speed, meaning that, as more traders become fast, the value of the information decreases when condition (27) holds but increases when condition (28) holds.

To illustrate the implications of the strategic interactions in the information acquisition, we conduct a comparative-statics analysis by examining the impact of changing in the exogenous cost of acquiring the speed (producing the information) on the equilibrium fractions of the informed and fast traders in the equilibrium. This analysis is based on the equilibrium conditions $I_F(I_F, I_I, n) = C_F$ and $I_I(I_F, I_I, n) = C_I$ in the information production and speed acquisition stage. The cost of the information (speed) represents a measure of the easiness of producing the information (acquiring the speed). A proliferation of sources of information about the firm (say, abundant disclosure, large analyst/media coverage, and advanced communication technologies) leads to easier access to information, corresponding to a low information cost (Fishman and Hagerty (1989), Kim and Verrecchia (1994)). Similarly, a significant improvement in modern technology (say, investments in computational hardware and connection to exchange servers) reduces the expenses to trade fast and hence the cost of the speed. From Proposition 5, we have the following corollary on the impact of the information and speed costs.

**COROLLARY 3:** When both informed and fast traders are active in market equilibrium: a) an increase in the cost of acquiring the speed reduces the fraction of the fast traders, and increases the fraction of the informed traders when condition (27) is satisfied but decreases the fraction of the informed traders when condition (28) is satisfied; b) an increase in the cost of producing information reduces the fractions of the informed and fast traders.
5. Faster Information Diffusion on Information Production and Speed Acquisition

In this section, we conduct an analysis of comparative statics with respect to parameter \( n \) to examine the implications of faster information diffusion on endogenous equilibrium decisions about speed acquisition and information production, which can be used to measure information transparency and disclosure in financial markets. The analysis in Section 4 shows that the information diffusion plays an important role in determining the equilibrium level of information production and speed acquisition. Intuitively, faster information diffusion reduces both the first-mover advantage of the fast trading and the information advantage of the informed trading. When both fast and informed traders are active in the market, the strategic interactions between acquiring speed and producing information can lead to very different implications comparing to the situations with only the speed acquisition or information production\(^9\).

5.1 Speed Acquisition

We firstly consider how faster information diffusion affects the equilibrium fraction of fast trading. In order to provide an insight on how different effects interact with each other, we observe from the equilibrium condition, \( \gamma_F(l_F, l_i, n) = C_F \), that the optimal response of \( l_F^* \) for a given value of \( l_i^* \) (and \( n \)) can be described as \( l_F^* = \gamma_F(l_i^*, n) \). Similarly, given the fraction \( l_F^* \), the optimal response function for the informed trader can be described as \( l_i^* = \gamma_i(l_F^*, n) \). The two unknowns \( l_F^* \) and \( l_i^* \), which define the endogenous equilibrium of information production and speed acquisition, are pinned down by these two best response functions, creating a fixed-point problem. To solve this problem, we insert the equilibrium condition for the informed trader into the equilibrium condition for the fast trader \( l_F^* = \gamma_F(\gamma_i(l_F^*, n), n) \). Taking the total differentiation with respect to \( n \) in the above equation yields (we formally prove (29) in Appendix C3)

\(^9\) When there is no informed trader, with faster information diffusion, on the one hand, the slow traders become more informative; on the other hand, the intra-temporal competition among the fast traders becomes intensified, reducing fast trader’s revenue. Consequently, the first-mover advantage of the fast traders tends to decrease, leading to fewer fast traders. Similarly, when there is no fast trader, consistent with the existing literature of public information, faster information diffusion makes the slow traders more informative, reducing informed trader’s information advantage and hence the number of informed traders.
\[
\frac{dI^*_F}{dn} = \frac{\partial Y_F(I^*_F, n)}{\partial n} + \frac{\partial Y_F(I^*_F, n)}{\partial I_F} \frac{\partial Y_F(I^*_F, n)}{\partial n} > 0,
\]

where the total differentiation is based on that both \(I^*_F\) and \(I^*_I\) are endogenous.

In (29), the term \(\partial Y_F(I^*_F, n)/\partial n\) therefore captures the crowding-out effect of faster information diffusion to the fast traders. We can show that \(\partial Y_F(I^*_F, n)/\partial n > 0\). Intuitively, faster information diffusion reduces fast trader’s first-mover advantage. That is, with faster information diffusion, the intra-temporal competitions for both fast and slow traders become intensified. Due to the speed hierarchies, the fast can trade more aggressively and, thus, be affected more significantly by the intensified competition. This reduces the difference in the expected revenues between the fast and slow traders and thus trader’s incentive to invest in the speed technology.

The term \(\frac{\partial Y_F(I^*_F, n)}{\partial I_F} \frac{\partial Y_F(I^*_F, n)}{\partial n}\) represents a new channel in our model. Specifically, faster information diffusion reduces the information advantage of the informed traders and hence their equilibrium fraction (i.e., \(\frac{\partial Y_F(I^*_F, n)}{\partial n} > 0\)). It also makes the slow traders more informative, improving their trading gains, and reducing the incentive to become fast traders (i.e., \(\frac{\partial Y_F(I^*_F, n)}{\partial I_F} > 0\)). This result is also consistent with Proposition 5 that acquiring speed is complement to producing information in the sense that, as less traders become informed, the value of speed decreases. Therefore, faster information diffusion tends to demote speed acquisition through this informed trading channel (i.e., \(\frac{\partial Y_F(I^*_F, n)}{\partial I_F} \frac{\partial Y_F(I^*_F, n)}{\partial n} > 0\)). This new channel amplifies the crowding-out effect on speed acquisition. Therefore the overall effect of faster information diffusion is determined jointly by the crowding-out and informed trading effects.

### 5.2 Information Production

We now examine the effect of faster information diffusion on the information production in equilibrium. Similarly, we have \(I^*_F = Y_F(I^*_F, n, n)\). Taking a total differentiation with respect to \(n\) yields
\[
\frac{d l_i^*}{d n} = \frac{\frac{\partial Y_i(l_F^*, n)}{\partial n}}{1 - \frac{\partial Y_F(l_F^*, n)}{\partial l_F} \frac{\partial Y_i(l_F^*, n)}{\partial l_F}} + \frac{\frac{\partial Y_F(l_F^*, n)}{\partial n}}{\frac{\partial Y_i(l_F^*, n)}{\partial l_F} \frac{\partial Y_F(l_F^*, n)}{\partial l_F}}.
\]

On the equilibrium fraction of the informed traders, the crowding-out effect works similarly, captured by \( \frac{\partial r_i(l_F^*, n)}{\partial n} > 0 \) and faster information diffusion also decreases the equilibrium fraction of the fast traders due to the decrease in their information advantage, captured by \( \frac{\partial r_F(l_F^*, n)}{\partial n} > 0 \). The only difference from the previous analysis is that the crowding-out effect and the fast trading effect can either strengthen or weaken each other, depending on the learning complementarity and substitutability.

When producing information is complement to acquiring speed (i.e., \( \frac{\partial r_i(l_F^*, n)}{\partial l_F} > 0 \)), faster information diffusion tends to demote information acquisition through the fast trading channel (i.e., \( \frac{\partial r_F(l_F^*, n)}{\partial l_F} \frac{\partial r_i(l_F^*, n)}{\partial n} > 0 \)), which makes the overall effect of the faster information diffusion on the informed traders similar to that on the fast traders. Instead, when producing information is substitute to acquiring information (i.e., \( \frac{\partial r_F(l_F^*, n)}{\partial l_F} < 0 \)), faster information diffusion tends to promote information acquisition through the fast trading channel (i.e., \( \frac{\partial r_F(l_F^*, n)}{\partial l_F} \frac{\partial r_i(l_F^*, n)}{\partial n} < 0 \)). Therefore the total effect of faster information diffusion on the informed traders depends on the relative strength of these three effects.

Proposition 5 suggests that only when the fraction of the informed traders is sufficiently high, information production is substitute to speed acquisition. Since the crowding-out effect of informed trading also increases in the fraction of informed traders, we expect that, although the substitution between information production and speed acquisition demotes the crowding-out effect, the equilibrium fraction of fast traders also decreases due to the dominance of the significant crowding-out effect on the trade-off. Figure 3 illustrates these intuitions.

[Figure 3]

In Figure 3, we choose two different values of information production cost \( (C_i = 0.1, 0.2) \) and keep the speed acquisition cost \( (C_F = 6) \) fixed for all the scenarios. We plot the equilibrium fraction
of the informed traders against the speed of information diffusion for the combinations of information production and speed acquisition costs. In addition, by substituting the equilibrium outcomes into condition (27), we show that all equilibria satisfy the condition for the information production to be substitute to information acquisition. In both panels of Figure 3, the numerical results confirm our analysis that the trade-off of the faster information diffusion is dominated by the crowding-out effect, meaning that, with faster information diffusion, the equilibrium fraction of informed traders decreases. In general, although the crowding-out effect and the fast trading effect can either strengthen or weaken each other, depending on the learning complementarity and substitutability, the significant crowding-out effect dominates the trade-off in both scenarios, leading to a decrease in informed traders with faster information diffusion. Lastly, we summarize the results in the following corollary.

**COROLLARY 4**: In the endogenous economy, faster information diffusion decreases both information production and speed acquisition.

### 6. Implication of Faster Information Diffusion

#### 6.1 Price efficiency without speed hierarchies

To disentangle the effect of speed competition from information diffusion on market quality, we first consider a baseline case without the trading speed hierarchies. By comparing with our equilibrium with the speed hierarches, we examine how fast trading re-shapes the trade-off in the baseline case. Theorem 2 provides the equilibrium outcomes without speed hierarches.

**THEOREM 2**: Without the speed technology, when traders can pay information cost $C_i$ to receive the full information, there exists a linear Bayesian equilibrium, in which the speculators’ strategies $\beta_i$ and $\beta_s$, and the pricing rule $\lambda_1$ of the market maker are the functions of parameters $(N, n, l, \sigma, \sigma_z)$ given by (A-5) in Appendix A2. While the fraction of the informed traders is determined by (A-6) in Appendix A2.

In the baseline case without the trading speed hierarchies (i.e., $l_F = 0$ in our model), the price efficiency is jointly determined by the trade-off between a direct and positive effect of weakening
information asymmetry and an indirect and negative effect of crowding out private information. To better understand how fast trading re-shapes this trade-off, we consider the following decomposition about the aggregate trading intensity of informed and slow trading \( \Phi_L = \Phi_I + \Phi_S \),

\[
\frac{d\Phi_L}{dn} = \frac{d\Phi_I}{dn} + \frac{d\Phi_S}{dn} = \frac{\partial I_I N}{\partial n} \beta_I + \frac{\partial I_S}{\partial I_I N} \beta_I + \frac{\partial (1 - I_F - I_I) N}{\partial n} \beta_S + \frac{\partial}{\partial n} \left( \frac{\beta_S}{n} \right) (1 - I_F - I_I) N.
\]

(31)

Equation (31) shows that the aggregate trading intensity is jointly affected by the net effect between informed and slow trading intensities, which are further determined through the equilibrium factions of the fast and slow traders and their relative trading sensitivity.

Following this decomposition, with faster information diffusion (smaller \( n \)), on the one hand, individual informed and slow trader trade aggressively (meaning that the relative trading sensitivity is higher; i.e., \( \frac{\partial I_I N}{\partial n} < 0 \) and \( \frac{\partial}{\partial n} \left( \frac{\beta_S}{n} \right) < 0 \)). On the other hand, the fraction of the informed traders decreases due to the crowding-out effect (i.e., \( \frac{\partial}{\partial n} I_I N > 0 \)); while the fraction of the slow traders increases (i.e., \( \frac{\partial}{\partial n} \left( 1 - I_F - I_I \right) N < 0 \)). Therefore, for the slowing trading, both the relative trading sensitivity and market fraction increase in information diffusion, intensifying the slowing trading. However, for the informed trading, there is a trade-off between the positive effect from the higher relative trading sensitivity and the negative effect from the lower market fraction of the informed traders, which is dominated by latter effect and leads to reducing informed trading. These analysis can be described by the Equation (32),

\[
\begin{align*}
\frac{d\Phi_I}{dn} &= \beta_I \frac{\partial I_I N}{\partial n} + I_I N \frac{\partial \beta_I}{\partial I_I N} ; \\
\frac{d\Phi_S}{dn} &= \beta_S \frac{\partial (1 - I_F - I_I) N}{\partial n} + \frac{\partial}{\partial n} \left( \frac{\beta_S}{n} \right) (1 - I_F - I_I) N.
\end{align*}
\]

(32)

For the market quality, price efficiency is determined by decreasing informed trading and increasing slow trading. As illustrated by Panel A in Figure 1, we can show that the trade-off is dominated by the decrease in the informed trading, impeding price efficiency in the baseline case, which has been documented in most information disclosure literature (Diamond, 1985; Gao and Liang, 2013). The result is summarized in the following corollary.

**COROLLARY 5:** Without the speed technology, faster information diffusion decreases price efficiency.
6.2 Early period price efficiency

We now examine our model with trading speed hierarchies. We start the discussion with fast trading in the early period, then examine how it re-shapes the baseline trade-off between the crowding-out and weakening effects in the late period. Applying the implicit function theorem to Equation (9), we have

\[
\frac{d\Phi_F}{dn} = \frac{1}{2} \sqrt{\frac{N \sigma_z}{nl_F \sigma}} \frac{dl_F}{dn} - \frac{1}{2n} \sqrt{\frac{N \sigma_z}{\frac{n}{\sigma}}} . \tag{33}
\]

In the early trading period, faster information diffusion not only brings more information to fast traders, weakening information asymmetry, but also reduces trader’s incentive to invest in the speed technology, crowding-out fast trading. In equation (33), the first term captures the effect that faster information diffusion crowds out fast traders; while the second term captures the effect of more information for fast traders.

With the crowding-out effect discussed in Subsection 5.1.1, we now characterize the second term. The information diffusion determines the unique information structure and intra-temporal competition among the fast traders. Theorem 1 shows that, with faster information diffusion, individual fast trader reduces his trading sensitivity \( \beta_F \) to the signal, but also receives more precise information. In equilibrium, this trade-off for faster traders is dominated by more transparent information, which increases the trading intensity of the fast traders \( \Phi_F \) (given their fraction). This is essentially reflected by the second term of equation (33).

On the net effect, we show (in Appendix C3) that \( d\Phi_F/dn < 0 \). This means that, with faster information diffusion and the speed technology, the first-mover advantage makes the fast traders trade more aggressively. Comparing to the informed or slow traders, the fast traders’ trading intensity is more sensitive to the amount of the information rather than the fraction of the fast traders. Therefore, although faster information diffusion and the interaction between the fast and informed traders amplify the crowding-out effect to the fast traders (as discussed in subsection 5.1.1), the positive information effect in fact dominates the negative crowding-out effect, leading the fast traders to trade more aggressively. Following (11), this intensified fast trading directly benefits the price efficiency in both the early and late periods and, more importantly, re-shapes the baseline trade-off in the late period to be discussed next.
6.3 Late period price efficiency

We now turn to the price efficiency in the late period. The complexity of the overall equilibrium precludes a fully analytical characterization of these outcomes and we illustrate the results numerically in Figure 4. Specifically, Proposition 5 suggests that the information production can be either substitute or complement to the speed acquisition. In Figure 4, we report the late period price efficiency for two scenarios. With the information production cost $C_I = 0.1$ on the left panel and $C_I = 1$ on the right panel for a fixed speed acquisition cost $C_F = 6$, the information production is a substitute and complement to the speed acquisition, respectively. The other parameters are the same as in Figure 3. Figure 4 shows that in both panels, the market becomes more efficient, in terms of lower conditional volatility, with faster information diffusion.

[Figure 4]

Figure 4 shows that with faster information diffusion, the market quality actually improves for both early and late period. This result is surprising because the significant crowding-out effect would make informed and fast traders trade less aggressively with faster information diffusion and hence reduce market quality. Instead, it shows that information disclosure can have different implications and benefit market quality under the “new” market environment. In fact, the overall market quality, in terms of price efficiency and market liquidity, depends not only on the population of informed and fast traders, but more importantly on how much of fundamental information “leaks” to slow informed via fast trading and equilibrium price in early period, how informed trading reacts to more aggressive fast trading, and how aggressively fast traders, as a group, trade on their information. With faster information diffusion, the crux of our analysis in the following is that the fast trading affects the baseline trade-off between informed and slow trading differently.

According to equation (11), more aggressively fast trading intensity $\phi_F$ and aggregate trading intensity $\phi_L$ contribute positively to market efficiency in the late period. We have demonstrated (in Subsection 6.2) that faster information diffusion intensify fast trading. Here, we focus on the aggregate trading intensity $\phi_L$ of slow informed and fully informed traders. With the trading speed hierarchies, the baseline trade-off (in Subsection 6.1) is changed through the fast trading in the early period. In fact, the direction of the impact of the traders’ component and the relative trading
sensitivity remains the same; however, the relative strength of these effects changes, especially the relative trading sensitivity on the informed trader,

\[
\frac{d\Phi_I}{dn} = \frac{\partial l_I N}{\partial n} \beta_I + \frac{\partial l_I N}{\partial n} \ln(-) \quad ; \quad \frac{d\Phi_S}{dn} = \frac{\partial(1 - I_F - I_i) N \beta_S}{\partial n} + \frac{\partial(1 - I_F - I_i) N}{\partial n} (-) \]

(34)

This significant changes in the relative trading sensitivity for the informed trader can lead to a situation that, with faster information diffusion, the informed trading reduces less significantly, even increases, comparing to the baseline case without the speed hierarchies (in Section 6.1). We illustrate this argument as Panel B in Figure 1.

To explore how the fast trading re-shapes the trade-off, we conduct a numerical analysis under two cases, with (solid lines) or without the speed hierarchies (dashed lines), and report the results in Figure 5 (the other parameters remain the same as in Figure 3). The left and right panels show the cases that the information production is a substitute and complementary to the speed acquisition, respectively. By comparing the solid and dashed lines, we see how the increasing fast trading affects the trade-off between the informed trading and slow trading.

With faster information diffusion, on the one hand, due to strategic complementarities in the informed and fast trading, the aggressive fast trading abates the negative and indirect effect, meaning that the informed trading is decreasing slightly or, even, increasing. On the other hand, more fast trading not only leak more fundamental information to the slow traders through the equilibrium price in the early period, but can also reduce the increasing rate of the fraction of the slow traders. This can either amplify or shrink the positive effect, depending on the relatively strength of different impact. In general, the negative effect abates significantly. Therefore, with the trading speed hierarchies, the weakening effect dominates the trade-off.

[Figure 5]

To better understand how more aggressive fast trading affects the informed and slow informed trading, we first compare the red solid and dashed lines for the informed trading in both panels. The dashed lines corresponds to the baseline case without the speed hierarchies, in which the trade-off for the market quality is not affected by the fast trading. Figure 5 shows, with faster information diffusion, the informed trading becomes less aggravously in both panels mainly due to the crowding-out effect. However, when the fast trading is endogenously determined, the aggressive
trading of the fast traders reduces information uncertainty and encourages more aggressive informed trading (Proposition 1). This complementary effect makes the informed trading reduce slightly, as showed by the right panel in Figure 5, or even increase, as showed by the left panel in Figure 5. In the left panel, the information production is a substitute to the speed acquisition; therefore, the fast trading channel tends to promote information acquisition and demote the crowding-out effect. However, on the right panel, the information production is a complement to the speed acquisition; therefore, the fast trading channel tends to demote the information acquisition and promote the crowding-out effect. Therefore, on the right panel, the informed trading decreases mildly instead of increasing.

For the slow trading, as we have discussed, with faster information diffusion, the more aggressively fast trading not only leaks more fundamental information to the slow traders through the equilibrium price in the early period, but can also decrease the rate at which the fraction of the slow traders increases. It is straightforward to show that the weakening effect becomes more significant due to the reducing information disadvantage so that the relative trading sensitivity increases significantly. The net impact depends on the rate at which the fraction of the slow traders increases. On the left panel, the rate at which the fraction of the slow traders increases is not significantly affected by faster information diffusion; therefore, the more aggressive fast trading amplifies the positive effect. On the right panel, the rate at which the fraction of the slow traders increases with the speed hierarchies is lower than the case without the speed hierarchies. Therefore, the positive effect of the slow trading shrinks.

Finally, on the effect of more aggressive fast trading, the left panel show that the positive effect on the slow trading improves while the negative effect on the informed trading even increases. Therefore, the aggregate trading intensity in the late period increases. On the right panel, with faster information diffusion, both the positive and negative effects decline at different speed. The negative effect declines more rapidly, leading to more aggressively aggregate trading. Besides, the information revealed in the early period carries over to the late period. Therefore, the aggressive fast trading also contributes to market quality in the late period. The increase in the trading intensities in both periods improves market quality. We summarize the impact of information diffusion on market quality as follows.
**COROLLARY 6**: In the endogenous economy, faster information diffusion benefits the market quality in both the early and late periods.

Note that we have assumed throughout our analysis so far that the cost of producing information is fixed. Intuitively, the information cost should be decreasing in faster information diffusion since traders could receive more information from the information diffusion process and pay less to become fully informed. Nevertheless, when the cost decreases with faster information diffusion, our results on improving market quality become more significantly. In this case, the crowding-out effect becomes less significant, which benefits market quality. We have shown that, even with a constant information cost, the market quality is improving with faster information diffusion.

### 6.4 Price and Trade Patterns

In this subsection, we analyse the return and trade patterns induced by traders’ equilibrium behaviour and provide empirical predictions for the effects of faster information diffusion on the relationships between (i) different market participants, (ii) the trading at different dates and (iii) future returns and fast trading.

**Trading volume**: Trading volume provides an important indicator on the trading activity of market participants. We measure the total trading volume of all fast traders by the variance of their aggregate order flow:

\[
VAR\left(\frac{I_F N}{n} \sum_{i=1}^{n} x_{F}(v_i)\right) = \left(\frac{I_F N}{n} \beta_F\right)^2 \sigma^2. \tag{35}
\]

Similarly, for the informed and slow traders, their trading volume are measured by, respectively,

\[
VAR(I_t N \lambda_t(v_i, p_i)) = (I_t N \beta_t)^2 \left(1 - \frac{I_F N}{n} \beta_F\right)^2 \sigma^2 + \lambda_t^2 \sigma^2, \tag{36}
\]

\[
VAR\left(\frac{(1 - I_F - I_t)N}{n} \sum_{i=1}^{n} x_S(v_i, p_i)\right) = \left(\frac{(1 - I_F - I_t)N}{n}\right)^2 ((\gamma_S - \beta_S) I_F N \beta_F)^2 \sigma^2 + (n \gamma_S - \beta_S) \lambda_t^2 \sigma^2. \tag{37}
\]

Figure 6 plots the volume patterns with respect to the information diffusion speed. The left panel shows that, with faster information diffusion, trading volume monotonically increases for the fast
traders, but decreases for the informed traders (though dominated by the informed traders for the chosen costs). Intuitively, with faster information diffusion, fast traders are easier to access the information and improve their signal precision. Therefore, they trade more. At the same time, market maker infers more information from the equilibrium trading volume in the early period and therefore the informed traders lose their information advantage. This shrinks informed traders’ trading volume. The right panel plots the proportional trading volume of fast and informed trader’s, relative to the total volume. Consistent with the left panel, it is increasing for fast traders but decreasing for informed traders. This implies, with faster information speed, the high-frequency trading proportion increases, which is consistent with empirical findings and intuition.

[Figure 6]

**Trading correlation:** We now examine the trading pattern relation in the early and late periods. In equilibrium, this is measured by the correlation coefficient between the trades of fast traders who trade in early period and the trades of informed traders who trade in late period,

\[
\rho(x_F(v_i), x_I(V, p_1)) = \left(1 - \frac{l_F N}{n} \beta_F \right) \sqrt{\frac{n \beta_F \sigma^2}{(n - \lambda_F l_F N \beta_F)^2 \sigma^2 + (n \lambda_F)^2 \sigma^2}}.
\]

(38)

The left panel in Figure 7 illustrates how the correlation coefficient between individual fast and informed traders’ trades changes with faster information diffusion for two values of the cost of producing information. This correlation coefficient is always positive and increases with faster information diffusion. Moreover, holding the information diffusion speed fixed, it decreases as the cost of information production declines.

The results showed in the left panel in Figure 7 are consistent with the existing literature, such as Dugast and Foucault (2018). In their model, traders can trade either at early period with a raw signal or trade at late period with a processed signal. When the raw signal is valid, the processed and row signal command trades in the same direction. In our setup, fast trader receives partial but valid signal; therefore, the correlation coefficient is always positive. The intuition for increasing correlation coefficient with faster information diffusion is as follows. When fast traders receive more precise information, their trading contains more fundamental information. On the other hand, the informed traders receive full information. Therefore, the trading of the fast and informed traders becomes more correlated. Finally, holding the information diffusion speed constant, decreasing the cost of information production increases the fraction of informed trader. Due to
more intensified intra-temporal competition, informed traders trade less, which decreases the inter-temporal correlation coefficient.

[Figure 7]

**Trades and return relationship:** Finally, we examine how the trades and return interact with each other. In equilibrium, the covariance between trade of fast trader and the return (in the second period) follows:\(^\text{(39)}\):

\[
\text{COV}(x_F(v_t), p_2 - p_1) = \lambda_2 \beta_F \left( l_F N \beta_t + \frac{(1 - l_F - l_t)N}{n} \beta_S \right) + \left( (1 - l_F - l_t)N(y_S - \beta_S) - l_t N \beta_t \right) \sigma^2 \frac{N}{n}.
\]

The right panel in Figure 7 illustrates the changes in the covariance with respect to faster information diffusion. It shows that fast and informed trading is profitable, indicated by the positive covariance. However, the profitability is reducing with fast information diffusion, demonstrated by the decrease in the covariance. The crux for this analysis is the fact, we mentioned in Section 3, that individual fast trader trades less aggressively with faster information diffusion although, in aggregate, they trade more aggressively. On the other hand, more efficiency early period price indicates less profit opportunity. In conclude, with faster information diffusion, individual fast trader trades less and profit opportunity also decreases, which jointly determines the decreasing covariance.

Our analysis is silent on the welfare effects of faster information diffusion. Similar to Dugast and Foucault (2018), in our model, traders are risk-neutral; thus, trading is a zero sum game and information production and speed acquisition have no social value. In this setting, the total fixed costs of information production and speed acquisition are deadweight losses. In Dugast and Foucault (2018), a reduction in the cost of producing low precision signals reduces deadweight cost; however, in their case, less informative prices lead to less efficient investment decisions. Hence, the social benefit should be balanced with social cost of less efficient decisions for firms. Instead, in our economy, faster information diffusion is decidedly welfare improving since it not

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\(^{10}\) The covariance between trade of informed (or slow) trader and the first period return is zero. Market maker sets the price based on the zero-profit criterion. Therefore, the price is actually semi-strong efficient. When the informed (or slow) trader trades, they also take this into consideration. Hence, their trading has nothing to do with first period revenue.
only reduces deadweight losses through crowding out both informed and fast traders (decreasing
the total investment in the production of information and acquisition of speed) but also improves
the price efficiency (possible social gains from providing information for firm’s real investment
decision).

7. An Extension with Fast Traders Trade in Both Periods

This section discusses an extended model, the robustness of the results and some alternative
interpretations. So far, we have assumed that the fast trader only trades in the first period. We now
consider a “long-lived” fast trader scenario and explore the equilibrium when the fast trader can
trade in both periods. This allows the fast trader to trade more frequently than the informed and
slow traders. We show that our main mechanism and results remain the same.

7.1 Setup

The only departure from the benchmark model is that the fast traders can trade in both periods. All
the other features of the model remain the same. With the information diffusion process among
partially informed traders in a two-period Kyle (1985) model introduced in Section 2, the partially
informed fast traders can trade in both periods, while the fully informed and partially informed
slow traders trade in the late period.

Now, the trading strategy of the fast traders has two parts, the trading volume $x_f^1(v_i)$ in the early
period and $x_f^2(v_i)$ in the late period. Consequently, the trading volumes for the early and late periods
are given by, respectively,

$$w_1 = \frac{I_F N}{n} \sum_{i=1}^{n} x_f^1(v_i) + z_1,$$  \hfill(40)

$$w_2 = I_F N x_f^1(V, p_1) + \frac{I_F N}{n} \sum_{i=1}^{n} x_f^2(v_i, p_1) + \frac{(1 - I_F - I_L) N}{n} \sum_{i=1}^{n} x_s(v_i, p_1) + z_2.$$  \hfill(41)

Different from the model in Section 2, the fast trader now is acting like a “long-term” investor
who is also competing with the informed and slow traders in the late period. Since the fast traders
are rational and sophisticated, they make trading decision in the early period by considering their impact in the late period. Therefore, the trading behaviour for the fast traders becomes more complicated. We use a backward introduction to solve the trading behaviour in the late period first, then substitute them into the optimization problem in the early period. The market equilibrium is defined as follows.

**DEFINITION 3:** Given the fractions of the fast and informed traders $l_f$ and $l_i$, respectively, a perfect Bayesian equilibrium is defined by the speculators’ strategy profile and market makers’ pricing rules $(X^f_1(v_i), X^f_2(v_i, p_1), X_i(V, p_1), X_s(v_i, p_1), P_1(w_1), P_2(p_1, w_2))$ that satisfy the following conditions,

1) **Profit maximization in period 2:**

\[
X^f_2^*(v_i) = \arg\max_{x^f_2} E[x^f_2(V - p_2)|v_i, p_1];
\]

\[
X_i^*(V, p_1) = \arg\max_{x_i} E[x_i(V - p_2)|V, p_1];
\]

\[
X_s^*(v_i, p_1) = \arg\max_{x_s} E[x_s(V - p_2)|v_i, p_1].
\]

2) **Profit maximization in period 1:**

\[
X^f_1^*(v_i) = \arg\max_{x^f_1} E[x^f_1(V - p_1) + E[x^f_2^*(V - p_2)|v_i, p_1]|v].
\]

3) **Market efficiency:** The price functions $P_1(w_1)$ and $P_2(p_1, w_2)$ are determined by the rules that the market maker clears the security market for an expected zero profit in each period:

\[
E[w_2(p_2 - V)|p_1, w_2] = 0;
\]

\[
E[w_1(p_1 - V) + w_2(p_2 - V)|w_1] = 0.
\]

4) All the traders have rational expectations in that each trader’s belief about the others’ strategies is correct in the equilibrium.

Following the literature of linear equilibrium, the price linearly depends on the aggregate trading volume as in (4). The informed and slow traders’ trading sensitivities remain the same as in (6) and (7). The only difference now is that the fast traders’ trading sensitivities becomes

\[
x^f_1(v_i) = \beta_f v_i; \tag{42}
\]

\[
x^f_2(v_i, p_1) = \beta_s (v_i - p_1) + \gamma_s p_1. \tag{43}
\]

Note that, in the late period, by receiving the same partial information from the diffusion process, the fast traders are the same as the slow traders for the reason that they share the same information and are risk-neutral without considering the inventory.
7.2 Equilibrium Results

In the model presented in Section 2, the speed allows the fast trader to trade earlier, reflecting the speed differential among different traders. This separation between fast traders and informed and slow traders helps to obtain a closed form solution in Theorem 1. With the sophisticated and strategic fast traders trading in both periods, the financial market equilibrium becomes more complicated and does not permit an analytical solution in a closed form. To begin with, the following Theorem 3 establishes the financial market equilibrium.

THEOREM 3: For given $l_f > 0$ and $l_i > 0$, there exists a linear Bayesian equilibrium specified by equations (2), (3), (4), (6), (7) and (34) while the coefficients ($\lambda_1, \lambda_2, \beta_f, \beta_i, \beta_s, \gamma_s$) are functions of parameters ($N, n, l_f, l_i, \sigma, \sigma_z$) given by (A-7), (A-8) and (A-9) in Appendix A3.

To solve the overall equilibrium, it remains to pin down the information production and speed acquisition decisions. Meanwhile, the stage for information production and speed acquisition is the same as in the benchmark model in Section 2. More specifically, in the equilibrium of the information production and speed acquisition, a speculator chooses to become the fast or informed only when his expected payoff from the trading is sufficient to cover the cost of acquiring the speed or information, comparing to being a slow trader. Without considering the corner solution, a trader chooses to acquire the speed (produce the information) in equilibrium when the value of the speed (information) equals to its cost; that is, the trader is indifferent between acquiring the speed (producing the information) and being a slow trader. Unfortunately, this more complicated model setup limits the analysis discussed in Sections 4 and 5. Nevertheless, after conducting a numerical analysis, we find that the main results that greater information diffusion improves market quality remain the same, which is demonstrated in Figure 8.

[Figure 8]

It is worth emphasizing that allowing fast traders to trade more frequently does not affect the key mechanism that fast trading re-shapes the trade-off between the weakening information asymmetry effect and the crowding-out effect. Moreover, this extension allows us to examine other interesting interpretation, such as fast trader’s trading speed, measuring how much more the fast traders trade in the early period comparing with late period. Under this setup, fast traders trade in both early and late period. It is intuitive that fast traders would trade more in early period rather
than in late period due to their speed comparative advantage. However, we are also interested in how this trading speed varies with faster information diffusion. We demonstrate the results in Figure 9.

[Figure 9]

Figure 9 shows that, with faster information diffusion, the fast traders actually trade “slower” in the sense that their trades in the early period is relatively less comparing to trades in the late period, that is,

\[
\frac{\partial}{\partial n} \left( \frac{\text{VAR}(x_1^F(v_0))}{\text{VAR}(x_1^F(v_0)) + \text{VAR}(x_2^F(v_0, p_1))} \right) > 0. \tag{44}
\]

The fast traders have the ability to trade fast; however, there is a trade-off for the faster trading. On the one hand, when fast traders trade relatively more aggressively in the early period, they can avoid the intensified intra-temporal competition in the late period, which improves their expected total revenue. On the other hand, their price impact becomes more significant for the late period, which impedes their expected total revenue. The numerical analysis shows that, faster information diffusion actually reduces fast trader’s first-mover advantage and the fast traders tend to trade slower in order to reduce their price impact. Besides, comparing the blue solid and red dotted lines in Figure 9, with increasing cost of producing information, the fast trader’s trading speed decrease. The intuition behind this is straightforward. As information cost increases, less traders choose to be informed trader. Therefore, the intra-temporal competition in late period is weaken, which increases fast traders’ trade in the late period.

8. Conclusion

Recent developments in market practice and academic research have witnessed a significant speed heterogeneity and competition on trading speed in financial markets. A key question is that how the speeds by which information diffuses and trading competes jointly affect market quality. In this paper, we propose a theoretical framework to study this issue. Our model builds on the foundations laid by Kyle (1985) model with two distinct features: (a) speculators who receive partial and heterogeneous information from an information diffusion process, and (b) some of speculators invest in fast trading with speed hierarchies while others can acquire superior
information at certain costs. We emphasize the importance of the trading speed competition for better understanding the role of information diffusion in the trading incentive and the impact to market quality. Our approach is tractable and permits closed-form expressions to analyse trading intensities, market quality, and information and speed values.

Comparing to the equilibrium without speed heterogeneity, we find surprisingly that greater information transparency and trading speed competition can improve market quality, even though there are less informed and fast traders due to the significant crowding-out effect. This phenomenon identifies a natural economic force that attenuates the information disclosure problem in financial markets and generates several new empirical predictions and policy implication for market regulators. Based on the novel mechanism about the interaction of information diffusion and speed competition, the model also generates testable implications for how faster information diffusion should affect correlations between (i) the trading volumes among different market participants, (ii) the individual’s trading at different dates, and (iii) the future returns and fast trading. Future research could test these implications by considering market regulator or technological changes that increase the speed of information dissemination.
REFERENCES


APPENDIX: PROOFS

In this appendix, we provide proofs for Theorems, Propositions, Corollaries and key equations in the main text. We divide this section into three parts: Appendix A presents the proofs for equilibrium conditions under different model setups; while Appendices B and C include the proofs of model implications for exogenous and endogenous equilibrium, respectively.

Appendix A

In this Appendix, we provide proofs of the analytical results for the information diffusion and speed competition model. Furthermore, we discuss the influence of information diffusion structure and trading speed competition, respectively; and then illustrate an extension to allow the fast traders to trade in both periods.

A1. Proof of Theorem 1

With the speed hierarchies and the first-mover advantage, fast trader’s trading behaviour is not influenced by informed and slow traders. We first examine the fast traders’ trading behaviour in equilibrium in the early period; then consider the strategic interaction between informed and slow traders in the late period.

The Period Equilibrium in the Early Period: The equilibrium in the early period is similar to the standard one-period Kyle (1985) model. The only difference is that the homogenous information structure is replaced by the heterogeneous information structure. The procedure to derive the equilibrium in the early period is very similar to that in the late period; therefore we omit here. In the equilibrium, the price impact and fast traders’ trading intensity in the early period follows

\[
\lambda_1 = \frac{\sqrt{I_F N n}}{I_F N + n \sigma_x}; \quad \beta_F = \frac{\sqrt{n} \sigma_x}{\sqrt{I_F N} \sigma} \quad (A-1)
\]
The Equilibrium in the Late Period: With the partial information, the slow informed trader can infer the information from the early period equilibrium price. From the projection theorem, the slow traders have an expectation \( E(V|v_i, p_1) = k_1 v_i + k_2 p_1 \) about the fundamental value \( V \) with the coefficients \( k_1 \) and \( k_2 \) satisfying,

\[
  k_1 = \frac{n^2}{(n-1)I_F N + n^2}; \quad k_2 = \frac{(n-1)(I_F N + n)}{(n-1)I_F N + n^2}.
\]

The procedure of obtaining the equilibrium follows the standard Kyle model. Base on the market maker’s linear pricing functions, we first solve the speculator’s optimal investment problem. We then characterize the fixed-point problem of the strategic and optimal trading among the traders who are “forecasting the forecasts of others”. Finally, with the speculator’s strategy, we determine the pricing functions of the market makers.

Traders’ Optimal Strategies: Instead of using (6) and (7) directly, we nonetheless assume the trading strategies for slow trader and informed trader follow that \( x_S(v_i, p_1) = l_1 v_i + l_2 p_1 \) and \( x_I(V, p_1) = h_1 V + h_2 p_1 \) since they are most general forms and do not impose any structure. Under these assumptions, we have \( h_1 = -h_2 = \beta_I \), \( l_1 = \beta_S \) and \( l_2 = \gamma_S - \beta_S \). Based on the model assumptions, there are \( I_I N \) informed traders and \((1 - I_I - I_F)N \) slow informed traders \((1 - I_I - I_F)N/n \) in each information group). Therefore the equilibrium price in the late period follows

\[
  p_2 = p_1 + \lambda_2 \left( I_I N x_I + \frac{(1 - I_I - I_F)N \sum_{i=1}^n x_i^2}{n} + z_2 \right).
\]

Considering the trading strategy for the informed traders, they trade strategically (considering the price impact). Hence, they maximize their expected profits based on their information set,

\[
  \max_x \mathbb{E} \left[ x_i \left( V - \lambda_2 \left( x_i + (I_I N - 1)x_i + \frac{(1 - I_I - I_F)N \sum_{i=1}^n x_i^2}{n} + z_2 \right) - p_i \right) | V, w_i \right],
\]
given the slow informed traders’ trading strategy follows \( x_S(v_i, p_1) = l_1 v_i + l_2 p_1 \). From the first-order condition we obtain the informed trader’s trading strategy

\[
  x_i^* = \frac{n - l_1 \lambda_2 (1 - I_I - I_F)N}{\lambda_2 n (I_I N + 1)} V - \frac{1 + l_2 \lambda_2 (1 - I_I - I_F)N}{\lambda_2 (I_I N + 1)} p_i.
\]

Therefore, the informed traders’ trading intensity is the best response function of the slow informed traders’ trading intensity,
\[
  h_1(l_1, l_2) = \frac{n - l_1 \lambda_2 (1 - l_i - l_f) N}{\lambda_2 n (l_i N + 1)}; \quad h_2(l_1, l_2) = -\frac{1 + l_2 \lambda_2 (1 - l_i - l_f) N}{\lambda_2 (l_i N + 1)}.
\]

Each of the slow informed traders in speculator group \( i \) maximizes the expected profits. Similar to the informed trader, given informed traders’ trading strategy, we can calculate the first order condition and substitute the informed traders’ demand function into it and obtain

\[
  l_1(h_1, h_2) = \frac{nk_1}{\lambda_2 ((1 - l_i - l_f) N + n)} - \frac{n l_i N}{(1 - l_i - l_f) N + n} h_1 k_1 - \frac{(1 - l_i - l_f) N}{(1 - l_i - l_f) N + n} l_1 (k_1 - 1);
\]

\[
  l_2(h_1, h_2) = \frac{n (k_2 - 1)}{\lambda_2 ((1 - l_i - l_f) N + n)} - \frac{n l_i N}{(1 - l_i - l_f) N + n} (h_1 k_2 + h_2) - \frac{(1 - l_i - l_f) N}{(1 - l_i - l_f) N + n} (l_1 k_2 + (n - 1) l_2).
\]

In general, the informed traders’ trading behaviour is the best response functions of the slow traders’ behaviour, and visa versa, jointly determining the equilibrium.

**Fixed-point Problem of the Strategic:** The speculators and market maker are strategic in their trading and pricing, characterizing “forecast the forecasts of others”. Indeed, in our model, the speculator’s trading strategy depends on the trading strategies of the others and market maker’s pricing rules, which in turn also depend on the speculators’ trading strategies. This endogenous feedback of “one agent’s strategy affects other agents’ strategies that affects himself own strategy” can be characterized by a fixed-point problem that considerably complicates the analysis.

In the previous part, we generate the best response function for the informed and slow traders to jointly determine the equilibrium. With the four equations and four parameters, the linear system uniquely determines the market equilibrium. We therefore have the informed and slow informed traders’ trading strategies as the functions of fundamental parameters and market maker’s pricing rule,

\[
  h_1 = \frac{n}{\lambda_2 ((l_i N + 1)n + (1 - l_i - l_f) N k_3)}; \quad h_2 = -\frac{n (l_i N + 1) + nk_2 (1 - l_i - l_f) N + (1 - l_i - l_f) N k_1}{\lambda_2 ((l_i N + 1)n + (1 - l_i - l_f) N k_3)(1 + (1 - l_f) N)};
\]

\[
  l_1 = \frac{nk_1}{\lambda_2 ((l_i N + 1)n + (1 - l_i - l_f) N k_1)}; \quad l_2 = \frac{n (k_2 - 1)(l_i N + 1) - (1 - l_i - l_f) N k_1}{\lambda_2 ((l_i N + 1)n + (1 - l_i - l_f) N k_3)(1 + (1 - l_f) N)}.
\]

**Market Maker’s Pricing Rule:** We then consider the market maker’s pricing rule. The market maker takes the informed and slow traders’ trading strategies as given, and assumes that the aggregate trading volume follows
\[ w_2 = I_iN x_i + \frac{(1 - I_i - I_f)N \sum_{i=1}^{n} x_i^3}{n} + z_2. \]

Substituting the expression of the demand functions into the aggregate trading volume, we have

\[ w_2 = \frac{I_iNn + (1 - I_i - I_f)Nk_1}{\lambda_2((I_iN + 1)n + (1 - I_i - I_f)Nk_1)} V + (I_iNh_2 + (1 - I_i - I_f)Nl_2)p_1 + z_2. \]

In the late period, the market maker sees the aggregate trading volumes in both early and late periods. Applying the projection theorem, we have

\[
\lambda_2 = \frac{\text{Cov}(V, w_1)\text{Var}(w_0) - \text{Cov}(w_1, w_0)\text{Cov}(V, w_0)}{\text{Var}(w_1)\text{Var}(w_0) - \text{Cov}(w_1, w_0)^2} \\
= \left( \frac{I_iNn + (1 - I_i - I_f)Nk_1}{\lambda_2((I_iN + 1)n + (1 - I_i - I_f)Nk_1)} \right)^2 \sigma^2 + \left( \frac{I_iN}{n} + 1 \right) \sigma^2 \left( \frac{I_iNn + (1 - I_i - I_f)Nk_1}{\lambda_2((I_iN + 1)n + (1 - I_i - I_f)Nk_1)} \right) \sigma^2.
\]

Solving the above functions, we can have the equilibrium conditions for the late period.

**Equilibrium Conditions for the Late Period:** In the equilibrium, the price impact and the informed and slow informed traders’ trading intensity in the late period follow

\[
\lambda_2 = \frac{\sqrt{I_iN(n - 1)I_fN + n^2} + (1 - I_i - I_f)NN^2((n - 1)I_fN + n^2)}{(I_iN + 1)((n - 1)I_fN + n^2) + (1 - I_i - I_f)NN}\frac{\sigma}{\sigma_2};
\]  
(A-2)

\[
\beta_i = \left( \frac{I_iN}{I_fN + n} + \frac{(1 - I_i - I_f)NN^2}{(I_fN + n)((n - 1)I_fN + n^2)} \right)^{-1/2} \frac{\sigma_2}{\sigma};
\]  
(A-3)

\[
\beta_S = \frac{n^2}{(n - 1)I_fN + n^2} \beta_i; \quad \gamma_S = \frac{n^2 - n}{(n - 1)I_fN + n^2} \beta_i.
\]  
(A-4)

Equations (A-1) to (A-4) describe the equilibrium.

**A2. Proof of Theorem 2**

**Financial market equilibrium:** The procedure to prove Theorem 2 is similar to Theorem 1 for the late period. Consider the trading strategy for the informed traders, they trade strategically (considering the price impact). Hence, they maximize their expected profits based on their information set,
\[
\max_x E \left[ x_i \left( V - \lambda \left( x_i + (I_i N - 1) x_i + \frac{(1 - I_i) N \sum_{i=1}^{n} x_i^j}{n} + z \right) \right) \right],
\]

given the slow informed traders’ trading strategy follows \( x_i(v_i) = \beta_s v_i \). From the first-order condition, the informed trader’s trading intensity follows the following response function

\[
\beta_i = \frac{1}{\lambda(I_i N + 1)} - \frac{(1 - I_i)N}{n(I_i N + 1)} \beta_s.
\]

Each of the slow traders in speculator group \( i \) maximizes the expected profits. Similar to the informed trader, we can calculate the first order condition, substitute the informed traders’ demand function into it, and obtain the following response function

\[
\beta_s = \frac{n}{\lambda((1 - I)N + n)} - \frac{nIN}{(1 - I)N + n} \beta_i.
\]

These two equations jointly determine the equilibrium. With the two equations and two parameters, the linear system uniquely determines the market equilibrium.

We then consider the market maker pricing rule. The market maker takes the informed and slow informed traders’ trading strategies as given, and assumes that the aggregate trading volume follows

\[
w_i = I_i N x_i + \frac{(1 - I_i) N \sum_{i=1}^{n} x_i^j}{n} + z_i = \frac{(1 - I_i) N + n I_i N}{\lambda_i((1 - I_i) N + n + n I_i N)} V + z_i.
\]

Applying the projection theorem, we have

\[
\lambda_i = \frac{\text{Cov}(V, w_i)}{\text{Var}(w_i)} = \left( \frac{(1 - I_i) N + n I_i N}{\lambda_i((1 - I_i) N + n + n I_i N)} \right)^2 \frac{\sigma^2 + \sigma_z^2}{\sigma_z} = \frac{(1 - I_i) N + n I_i N}{\lambda_i((1 - I_i) N + n + n I_i N)} \frac{\sigma}{\sigma_z}.
\]

Solving the above functions, we have the equilibrium conditions,

\[
\beta_i = \beta_s = \sqrt{\frac{n \sigma_z}{\sigma}}; \quad \lambda_i = \sqrt{\frac{n((1 - I_i) N + n I_i N)}{(1 - I_i) N + n + n I_i N}} \frac{\sigma}{\sigma_z}.
\]

\[\text{Information Market Equilibrium:} \] By calculating the informed and slow informed traders’ revenues, we have
\[ E^f[x_i(V - p)] = \frac{n^2}{\lambda_1 ((1 - l_f)N + n + nl_n) \sigma^2}; \quad E^s[x_i(V - p)] = \frac{n}{\lambda_1 ((1 - l_f)N + n + nl_n) \sigma^2}. \]

In the equilibrium, a trader chooses to become the informed only when his expected payoff from the trading is sufficient to cover the cost of the information, comparing to a slow trader. When a trader chooses to produce information, then the value of information must be equal to its cost; that is, the trader is indifferent between producing information and being a slow trader. Formally, we have

\[ C_I = E^f[x_i(V - p)] - E^s[x_i(V - p)]. \]

Simplifying the above conditions, we have

\[ ((1 - l_f)N + n + nl_n)^2 ((1 - l_f)N + nl_n) = \frac{n(n - 1)^2}{C_I^2} \sigma^2 \sigma_x^2. \]  \hspace{1cm} (A-6)

**A3. Proof of Theorem 3**

**The Optimization Problem in the Late Period:** We use backward introduction to solve the equilibrium as in the standard literature for the reason that the rational fast traders trade twice. According to (35), the fast traders in the late period behaviour exactly like the slow traders. Therefore, the procedure to derive the equilibrium is similar to Theorem 1. The only difference is that the total fraction of the fast and slow traders is now \(1 - l_f\). Again, instead of directly using (6), (7) and (35), we assume the trading strategies for the slow and informed traders \(x^s_i(v_i, p_t) = x_s(v_i, p_t) = l_1 v_i + l_2 p_1\) and \(x_i(V, p_t) = h_1 V + h_2 p_1\) respectively. Under these assumptions, we have \(h_1 = -h_2 = \beta, l_1 = \beta_s\) and \(l_2 = \gamma - \beta_s\). Based on the above discussion on traders’ trading behaviour, we only need to set \(l_f = 0\) and then have

\[ h_1 = \frac{n}{\lambda_2 ((l_f N + 1)n + (1 - l_f)N k_1)}; \quad h_2 = -\frac{n(l_f N + 1) + nk_2 (1 - l_f)N + (1 - l_f)N k_1}{\lambda_2 ((l_f N + 1)n + (1 - l_f)N k_1)(1 + N)}; \]
\[ l_1 = \frac{nk_1}{\lambda_2 ((l_f N + 1)n + (1 - l_f)N k_1)}; \quad l_2 = -\frac{n(k_2 - 1)(l_f N + 1) - (1 - l_f)N k_1}{\lambda_2 ((l_f N + 1)n + (1 - l_f)N k_1)(1 + N)}. \]  \hspace{1cm} (A-7)

Therefore, the aggregate trading volume in the late period becomes

\[ w_2 = \frac{l_1 N n + (1 - l_f)N l_1 \lambda_2}{\lambda_2 n(l_f N + 1)} V - \frac{v N - (1 - l_f)N l_2 \lambda_2}{\lambda_2 n(l_f N + 1)} p_1 + z_2. \]
The Optimization Problem in the Early Period: We now solve the trading decision for the fast traders in the early period. Based on Definition 3, the fast traders are sophisticated and strategic. Hence, when trading in the early period, they will take their trading strategies in the late period into consideration,

\[ x_1^{F,*}(v_i) = \arg\max \ E[x_1^F (V - p_1) + E[x_2^{F,*}(V - p_2)|v_i, p_1]|v_i]. \]

Substituting the equilibrium in the late period into the above optimization problem, we obtain

\[ \max_x E[x_1(V - p_1) + x_2^{F,*}E[(V - p_2)|v_i, p_1]|v_i] = \max_x E[x_1(V - p_1) + \lambda_2(l_1v_1 + l_2p_1)^2|v_i] \]

\[ = \max_x E[x_1(V - p_1) + \lambda_2 l_1^2 V^2 + \lambda_2 l_2^2 p_1^2 + 2\lambda_2 l_1 l_2 V p_1|v_i]. \]

From the first order condition, we obtain

\[ \beta_F = \frac{(1 + 2\lambda_2 l_1 l_2)}{\lambda_1 l_F n + n - 2\lambda_2 \lambda^2 l_F^2 n}. \]

Learning and Market Maker Pricing Rule: Similar to Theorem 1, the slow and fast traders (who now also trade in the late period) only have partial information; hence, they infer the fundamental information from the equilibrium price in the early period. From the projection theorem, the fast and slow traders have expectation \( E(V|v_i, p_1) = k_1v_1 + k_2p_1 \) about the fundamental value \( V \). The difference is that, in this situation, we do not have analytical solution for coefficients \( k_1 \) and \( k_2 \).

The price impact \( \lambda_1 \) and \( \lambda_2 \) in the early and late periods are jointly determined and do not have closed form solution. By using the definition of normal distribution,

\[ k_1 = \frac{1}{n} \left( \frac{\lambda_1 l_F n \beta_F}{\sigma^2} \right)^2 + \frac{1}{\sigma^2} \frac{\lambda_1^2 \sigma^2}{n}; \quad k_2 = \frac{n - 1}{n^2} \frac{\lambda_1 l_F n \beta_F}{\sigma^2} \left( \frac{\lambda_1 l_F n \beta_F}{\sigma^2} \right)^2 + \frac{1}{\sigma^2} \frac{\lambda_1^2 \sigma^2}{n}. \] (A-8)

By applying the projection theorem, the market maker price rules satisfy

\[ \lambda_1 = \frac{l_F n \beta_F}{\left( \frac{l_F n \beta_F}{\sigma^2} \right)^2 + \sigma^2}; \quad \lambda_2 = \frac{l_F n + (1 - l_F) N l_1 \lambda_2}{\lambda_2 n (l_F N + 1)} \cdot \left( \frac{l_F n + (1 - l_F) N l_1 \lambda_2}{\lambda_2 n (l_F N + 1)} \right)^2 + \frac{1}{\sigma^2} \frac{\lambda_1^2 \sigma^2}{n}. \] (A-9)

Although we cannot obtain the closed-form solution, the above equations (A-7), (A-8) and (A-9) provide the conditions to conduct the equilibrium numerically.
A4. Homogenous Information Structure

We now discuss the information diffusion structure. The most distinguish characteristic of our model is that traders receive partial and heterogeneous information. In order to illustrate the impacts, we consider a situation where $I_p/N$ fast traders receive the homogeneous and partial information $v_i$. Different from the main model, this has no impact on the intra-temporal competitions. We only focus on the first period to differentiate the influence of different information structure.

In this case, the equilibrium is same as Kyle (1985) with multiple informed trader; thus, we omit the proofs here. Under the main model (heterogeneous information scenario) and extended model (homogeneous information scenario), we have the closed-form results. Comparing the market quality and trader’s revenue under heterogeneous and homogeneous information scenarios yields the following remarks, which play a central role in the novel implication of our information structure.

**Remark 1**: Faster information diffusion intensifies the intra-temporal competition among the fast traders under the heterogeneous information structure.

**Remark 2**: Fast traders, as a group, have the full information about the fundamental value under the heterogeneous information structure.

Under the heterogeneous information structure, with faster information diffusion, the information becomes more transparent, making the fast traders more informative. However, this also leads to a situation in which more speculators share the same information. Therefore, with faster information diffusion, the fast traders are divided into fewer groups; while in each group, the number of the speculators increases. Hence, faster information diffusion process reshapes the intra-temporal competition. More fast traders in each group intensify not only the competition within the group but also the competition among different groups, leading to hyper intra-temporal competition, resulting in some different properties comparing to the normal information structure.

We first examine the expected revenue. In the following analysis, we use superscript $h$ to represent the homogenous situation. Based on the above discussion, we anticipate that, without the competition, the profit of the fast trader would increase with faster diffusion but decrease with the
intensified intra-temporal competition. The following analysis provides the evidence on this mechanism. The revenues in these two different scenarios are, respectively,

\[ R_F = \frac{1}{I_FN + n\sqrt{I_FN}} \sigma \alpha; \]

\[ R_F^h = \frac{1}{I_FN + n\sqrt{I_FN}n} \sigma \alpha. \]

The comparison shows that, with faster information diffusion, the change in the revenue goes in two opposite directions. Faster information diffusion decreases the fast traders’ revenue through the intensified competition in the heterogeneous information situation, but increases the fast traders’ revenue by bringing more information in the homogeneous information situation. This shows that it is the competition between different groups of the fast traders that reduces their profit when the speed of the information diffusion increases. When all the fast traders are homogeneous, the faster information transmission improves their information advantage and hence increases their profit. This analysis illustrates our first remark.

We then examine the price efficiency. Note that

\[ \text{VAR}(V|\omega_1) = \frac{n}{I_FN + n} \sigma^2 < \text{VAR}(V|\omega_1)^h = \frac{I_FN(n-1) + n}{I_FNn + n} \sigma^2. \]

This implies that the price efficiency under the homogenous information situation would be worse than the heterogeneous information situation. This reflects the second important characteristic of our information structure, which is fast traders, as a group, have full information under the heterogeneous information situation. Although the in-group competition becomes more intensive under the homogenous information situation, all the fast traders are competing for the same amount but partial information. The market maker is well informed about this partial information, which is, therefore, less informative comparing to the heterogeneous information situation.

**Appendix B**

In this appendix, we provide the proofs for the main propositions and corollaries for the exogenous equilibrium.
B1. Proof of Proposition 1

We first prove the properties about the informed traders’ trading intensity. We then derive the analytical best response function for the slow informed traders’ trading intensity (similar to (13)), and examine the properties about the slow informed traders.

**The Informed Traders’ Trading Intensity:** From (14), we first look at the direct effect of the informed traders’ trading intensity.

\[
\Phi_{I,Direct}(\Phi_F, \Phi_S) = \frac{I_1N}{2(I_1N + 1)} \frac{4\Phi_F^2 \sigma^2 + 4\sigma_F^2 + (\Phi_S \sigma + \sqrt{(\Phi_S^2 + 4I_1N\Phi_F^2)\sigma^2 + 4I_1N\sigma^2})^2}{\Phi_S \sigma^2 + \sqrt{(\Phi_S^2 + 4I_1N\Phi_F^2)\sigma^2 + 4I_1N\sigma^2\sigma_F^2}}.
\]  

(B-1)

Calculating the derivatives of (B-1) with respect to the slow informed traders’ trading intensity \( \Phi_S \), we have,

\[
\frac{\partial \Phi_{I,Direct}(\Phi_F, \Phi_S)}{\partial \Phi_S} = \left( \Phi_S \sigma + \sqrt{\Phi_S^2 \sigma^2 + 4I_1N(\Phi_F^2 \sigma^2 + \sigma_F^2)} \right)^2 \frac{2(\Phi_F^2 \sigma^2 + \sigma_F^2 - 4I_1N(\Phi_F^2 \sigma^2 + \sigma_F^2))}{2(\Phi_S \sigma + \sqrt{\Phi_S^2 \sigma^2 + 4I_1N(\Phi_F^2 \sigma^2 + \sigma_F^2)})} \]

\[
> 0.
\]  

(B-2)

Therefore, an increase in \( \Phi_S \) strengthens the positive and direct effect. Also, it is easy to show that an increase in \( \Phi_S \) also strengthens the negative and indirect effect. This implies that the slope of the best response function is jointly determined by these two effects. On the overall effect, we calculate the derivatives of (14) with respect to the slow informed traders’ trading intensity \( \Phi_S \),

\[
\frac{\partial \Phi_I}{\partial \Phi_S} = \frac{2I_1N(\Phi_F^2 \sigma^2 + \sigma_F^2)\sigma^2 + 2\Phi_S \sigma \sqrt{\Phi_S^2 \sigma^2 + 4I_1N(\Phi_F^2 \sigma^2 + \sigma_F^2)\sigma^2}}{4I_1N(\Phi_F^2 \sigma^2 + \sigma_F^2)\sigma^2 + 2\sqrt{\Phi_S^2 \sigma^2 + 4I_1N(\Phi_F^2 \sigma^2 + \sigma_F^2)\sigma^2}} \]

\[
- \frac{2I_1N(\Phi_F^2 \sigma^2 + \sigma_F^2)\sigma^2 + 2\Phi_S \sigma \sqrt{\Phi_S^2 \sigma^2 + 4I_1N(\Phi_F^2 \sigma^2 + \sigma_F^2)\sigma^2}}{4I_1N(\Phi_F^2 \sigma^2 + \sigma_F^2)\sigma^2 + 2\sqrt{\Phi_S^2 \sigma^2 + 4I_1N(\Phi_F^2 \sigma^2 + \sigma_F^2)\sigma^2}} \]

\[
< 0.
\]
We see that the negative and indirect effect dominates the trade-off. In general, the increase in the slow informed traders’ trading intensity $\phi_s$ weakens the informed traders’ trading intensity. By directly calculating the derivative of (13), we can obtain the same results about how the slow traders’ trading intensity $\phi_s$ affects the informed traders’ trading intensity $\phi_i$.

Similarly, we examine how the fast traders’ trading intensity $\phi_F$ affects the informed traders’ trading behaviour. Calculating the derivatives about equation (B-1) and by using (B-2), we have

$$\frac{\partial \Phi_{i,\text{Direct}}(\phi_F, \phi_S)}{\partial \phi_F} = 4G\phi_F \left[ 2 \left( \phi_S \sigma^2 + \sqrt{\phi_S^2 \sigma^4 + 4I_i N(\phi_F^2 \sigma^2 + \sigma_i^2) \sigma^2} \right) \sqrt{\phi_S^2 \sigma^4 + 4I_i N(\phi_F^2 \sigma^2 + \sigma_i^2) \sigma^2} ight.
$$

$$+ I_i N \left( \phi_S^2 \sigma^4 + \sqrt{\phi_S^2 \sigma^4 + 4I_i N(\phi_F^2 \sigma^2 + \sigma_i^2) \sigma^2} \right) - 4(\phi_F^2 \sigma^2 + \sigma_i^2) \right] =$$

$$= 4G\phi_F \sigma^2 (I_i N + 1) \left( \phi_S \sigma^2 + \sqrt{\phi_S^2 \sigma^4 + 4I_i N(\phi_F^2 \sigma^2 + \sigma_i^2) \sigma^2} \right)^2 > 0.$$

This leads to the asymmetry reduction effect for the fast trading. Besides, the fast traders’ trading intensity has no influence on the indirect effect due to no competition. Therefore, in general, the informed traders’ trading intensity is a complement to the fast traders’ trading intensity. Similarly, we can directly calculate the derivative of (13) to analyse how the fast traders’ trading intensity $\phi_F$ can affect the informed traders’ trading intensity $\phi_i$.

**The Slow Informed Traders’ Trading Intensity:** Before formally proving Proposition 1 for the slow traders, we first derive the trading behaviors for the slow traders. Given the fast and informed traders’ trading intensities, slow trader $k$ in group $i$ maximizes his expected profit,

$$\max_{\lambda_k} E \left[ x_k \left( V - p_1 - \lambda_2 \left( x_k + \frac{(1 - I_i - I_F)N}{n} - 1 \right) I_k^{i,j} + \frac{(1 - I_i - I_F)N}{n} \sum_{j \neq i} x_S^{i,j} + \phi_F V + \Omega_i p_1 + z_2 \right) \right] v_i, w_i.$$

From the first-order condition, we obtain that

$$\phi_S = \frac{(1 - I_i - I_F)N ((\phi_F^2 + (\phi_I + \phi_S)^2) \sigma^2 + \sigma_i^2) \sigma^2}{(\phi_I + \phi_S) \sigma^2 ( (1 - I_i - I_F)N + n) \sigma^2 + (n - 1) \phi_F^2 \sigma^2) \sigma^2}$$

(B-3)

$$- \frac{(1 - I_i - I_F)N \sigma_i^2}{(1 - I_i - I_F)N + n) \sigma_i^2 + (n - 1) \phi_F^2 \sigma^2} \phi_I = \phi_{S,\text{Direct}} - \phi_{S,\text{Indirect}}.$$

Rearranging the best response function (B-3) and calculating the quadric function, we have
\[ \phi_S = h_S(\Phi_i; \Phi_F, N, n, I_i, I_F, \sigma, \sigma_z) = -\frac{\Phi_i}{2} + \frac{\Phi_i^2}{4} \left(1 - I_i - I_F\right) N \frac{\phi_F^2 \sigma^2 + \sigma_z^2}{\left(n - 1\right) \phi_F^2 \sigma^2 + n \sigma_z^2 \sigma^2} \]  

We then examine the slow informed trader’s trading intensity. As mentioned before, we can also directly calculate the derivative of (B-4). It is easy to show that the slow informed traders’ trading intensity is a substitute to the informed traders’ trading intensity; but a complement to the fast traders’ trading intensity.

**B2. Proof of Proposition 2**

Taking a total differentiation of equations (13) and (B-4) with respect to \( Q \), we obtain

\[ \frac{d \phi_i}{d Q} = \frac{\partial h_i}{\partial Q} + \frac{\partial h_i}{\partial \Phi_F} \frac{d \Phi_F}{d Q} + \frac{\partial h_i}{\partial \Phi_i} \frac{d \Phi_i}{d Q}; \]

\[ \frac{d \phi_j}{d Q} = \frac{\partial h_j}{\partial Q} + \frac{\partial h_j}{\partial \Phi_i} \frac{d \Phi_i}{d Q} + \frac{\partial h_j}{\partial \Phi_F} \frac{d \Phi_F}{d Q}. \]

Substituting equation (B-6) into (B-5), we have

\[ \frac{d \phi_i}{d Q} = \frac{\partial h_i}{\partial Q} + \frac{\partial h_i}{\partial \Phi_F} \frac{d \Phi_F}{d Q} + \frac{\partial h_i}{\partial \Phi_i} \left( \frac{\partial h_j}{\partial \Phi_F} + \frac{\partial h_j}{\partial \Phi_i} \frac{d \Phi_i}{d Q} \right). \]

Solving the above equation, we obtain (18).

Next, we examine the sign and magnitude of parameter \( M \). When \( I_i = 0 \) or \( I_i + I_F = 1 \), there is no informed trader or slow informed trader. Thus, the multiplier of the cross-derivatives \( \partial h_i/\partial \Phi_j \) and \( \partial h_j/\partial \Phi_i \) equals to zero. When both the informed and uninformed traders are active in the market, we show that the multiplier is strictly larger than one. This multiplier depends on whether trading on the two types of speculators is a complement or substitute (the signs of the cross-derivatives \( \partial h_i/\partial \Phi_j \) and \( \partial h_j/\partial \Phi_i \)). When both the informed and slow traders are active in the market, we have from (13) and (B-4) that

\[ -\frac{1}{2} < \frac{\partial h_i}{\partial \Phi_S} = -\frac{1}{2} + \frac{\sigma \phi_S}{2 \sqrt{\phi_S^2 \sigma^2 + 4(\phi_F^2 \sigma^2 + \sigma_z^2) I_i N}} \]  

\[ -\frac{1}{2} < \frac{\partial h_S}{\partial \Phi_i} = -\frac{1}{2} + \frac{\sigma \phi_i}{\sqrt{\phi_i^2 \sigma^2 + 4(1 - I_i - I_F) N \sigma_z^2 \left(n - 1\right) \phi_F^2 \sigma^2 + n \sigma_z^2 \sigma^2}} \]  

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This means that the two response functions are decreasing with higher trading intensities. Note that they both are greater than \(-1/2\). Therefore \(M > 1\) is an amplified trading intensity multiplier, meaning that the interaction between the two trading intensity measures tends to amplify the initial effect.

**B3. Proof of Proposition 3**

We examine the properties of the trading intensity for the informed traders first and then for the slow traders.

**Informed Traders’ Trading Intensity:** As discussed in subsection 3.2.1, equation (20) is positive. We now examine the effect of changing in the fraction of fast traders on informed traders’ trading intensity. Applying (18), we have

\[
\frac{d\Phi_i}{dl_F} = M \left( \left( \frac{\partial h_i}{\partial \Phi_F} + \frac{\partial h_i}{\partial \Phi_S} \frac{\partial \Phi_F}{dl_F} \right) \frac{d\Phi_F}{dl_F} + \frac{\partial h_i}{\partial \Phi_S} \frac{\partial h_S}{\partial \Phi_F} \right); \quad (B-7)
\]

We can see from (B-7) that the direct effect can be decomposed into two parts, one through the fast traders’ trading intensity and another through the slow traders’ trading intensity. From the expression of \(h_i\) in (13) and (B-4), we can see that \(\partial h_S/\partial l_F\) is negative. Furthermore, form Proposition 1, \(\partial h_i/\partial \Phi_S\) is also negative. Thus, the direct effect through the slow traders is also positive. Besides, \(d\Phi_F/dl_F\) is positive. Therefore the sign of (B-7) is determined by the sign of

\[
\frac{\partial h_i}{\partial \Phi_F} + \frac{\partial h_i}{\partial \Phi_S} \frac{\partial h_S}{\partial \Phi_F} \quad (B-8)
\]

According to (13) and (B-4), we have,

\[
\frac{\partial h_i}{\partial \Phi_F} = \frac{2\sigma^2 l_i N \Phi_F}{\sqrt{\Phi_F^2 \sigma^2 + 4l_i N (\Phi_F^2 \sigma^2 + \sigma_S^2) \sigma^2}} > 0;
\]

\[
\frac{\partial h_S}{\partial \Phi_F} = \frac{2\Phi_F (1 - l_i - l_F) N \sigma_S^4 \sigma^2}{(n - 1) \sigma_F^2 \sigma^2 + n \sigma_S^2} \left( \frac{\Phi_F^2 \sigma^2 + \sigma_S^2}{\Phi_F^2 \sigma^2 + 4 \sigma^2} \right)^{(n-1)\sigma_F^2 + n \sigma_S^2} > 0.
\]

Therefore, term (B-8) satisfies,

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\[
\frac{\partial h_i}{\partial \Phi_F} + \frac{\partial h_i}{\partial \Phi_S} \frac{\partial h_S}{\partial \Phi_F} = \frac{2\sigma^2 I_i N T_i}{\sqrt{\Phi_S^2 \sigma^4 + 4I_i N (\Phi_F^2 \sigma^2 + \sigma_S^2) \sigma^2}} (1 + H).
\] (B-9)

The term \(H\) follows:
\[
H = \frac{\sigma^2 \Phi_S - \sqrt{\Phi_S^2 \sigma^4 + 4(\Phi_S^2 \sigma^4 + \sigma_S^2) I_i N}}{4\sigma^2 I_i N \Phi_F} \frac{2 \Phi_F (1 - l_i - l_F) N \sigma_S^2 \sigma^2}{(n-1) \Phi_S^2 \sigma^4 + n \sigma_S^2} \frac{(n-1) \Phi_S^2 \sigma^4 + 4 \sigma^2 (\Phi_S^2 \sigma^2 + \sigma_S^2) (1 - l_i - l_F) N \sigma_S}{(n-1) \Phi_F^2 \sigma^2 + n \sigma_S^2}
\]
\[
> - \frac{4 \sigma^2 \sigma_S^2 I_F N + n}{n} \frac{1}{I_i N} \frac{(1 - l_i - l_F) N}{2I_i N (n-1) \frac{I_F N}{n} + n} \frac{I_F N + n}{n} \frac{(1 - l_i - l_F) N \sigma_S^2}{(n-1) \frac{I_F N}{n} + n}
\]
\[
= - \frac{\sqrt{1 - l_i - l_F}}{2 (n-1) \frac{I_F N}{n} + n} \sqrt{(n-1) \frac{I_F N}{n} + n} > -1.
\]

Hence, equation (B-9) is positive. In general, with an increase in the fast traders’ fraction, the informed traders trade more aggressively.

**The Slow Traders’ Trading Intensity:** We then consider the slow informed trader. Similar to the informed trader, by equation (18), we can express the effect of the increase in \(l_i\) in the equilibrium levels of the slow informed traders’ trading intensity as follows:
\[
\frac{d \Phi_S}{d l_i} = M \left( \frac{\partial \Phi_S}{\partial l_i} + \frac{\partial \Phi_S}{\partial \Phi_F} \frac{\partial \Phi_F}{\partial l_i} + \frac{\partial \Phi_F}{\partial l_i} \left( \frac{\partial \Phi_i}{\partial l_i} + \frac{\partial \Phi_i}{\partial \Phi_F} \frac{\partial \Phi_F}{\partial l_i} \right) \right) = M \left( \frac{\partial \Phi_S}{\partial l_i} + \frac{\partial \Phi_S}{\partial \Phi_F} \frac{\partial \Phi_F}{\partial l_i} \right) < 0.
\]

From Proposition 1, the term \(\partial h_S/\partial \Phi_i\) is negative. Furthermore, by the expression of \(h_i\) in (13) and (B-4), we can easily see that \(\partial h_i/\partial l_i\) is positive and \(\partial h_S/\partial l_i\) is negative. These lead to the above conclusion that more informed traders decrease the slow informed traders’ trading intensity, regarding the effect of the increase in \(l_i\).

We then examine the fraction of the fast traders on the slow informed traders’ trading intensity. Applying Proposition 2 generates complicated formula. Therefore, we directly calculate the derivative to the closed-form solution about the slow informed traders’ trading intensity. It is easy to show that the increase in the size \(I_F\) of the population of the fast traders reduces the slow informed traders’ trading intensity \(\Phi_S\).

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B4. Proof of Corollary 1

We now provide an analysis about the impact of the fraction of the fast traders on the trading intensity in the late period. Based on equation (21), we define a function \( Y(i_l) \) as

\[
Y(i_l) = \frac{d\Phi^2_I}{dl_F} = N \left( i_l N + \frac{(1 - i_l - i_F)Nn}{(n - 1)l_F N + n^2} \right) + (l_F N + n) \frac{Nn((n - 1)l_F N + n^2) - (1 - i_l - i_F)Nn(n - 1)N}{((n - 1)l_F N + n^2)^2}.
\]

It is easy to show that the above equation monotonically increases with the fraction of informed traders. Therefore, we can define the threshold value \( l_l^* \) as,

\[
l_l^* = \left[ N \left( \frac{Nn}{(n - 1)l_F N + n^2} \right) + (l_F N + n) \frac{Nn(n - 1)N}{((n - 1)l_F N + n^2)^2} \right]^{-1} \left[ (l_F N + n) \frac{Nn((n - 1)l_F N + n^2) - (1 - i_l - i_F)Nn(n - 1)N}{((n - 1)l_F N + n^2)^2} \right].
\]

In the late period, the trading intensity decreases in the fast traders for \( 0 < i_l < l_l^* \), but increases in fast trader for \( l_l^* < i_l < 1 - i_F \).

B5. Proof of Proposition 4

To examine the total effect, we substitute Theorem 1 into equation (10) and obtain a closed-form solution of the informed traders’ trading intensity,

\[
\Phi_I = \frac{\frac{l_l N}{\sqrt{l_l N + n + \frac{(1 - i_l - i_F)Nn^2}{(l_F N + n)((n - 1)l_F N + n^2)}}}}{\sigma_x} \sigma.
\]

Calculating the derivative of the above equation, we have

\[
\frac{d\Phi_I}{dn} = -2 \left( \frac{l_l N}{l_F N + n} \frac{(1 - i_l - i_F)Nn^2}{(l_F N + n)((n - 1)l_F N + n^2)} \right) \left[ \frac{l_l N l_F N}{(l_F N + n)^2} \right]
\]

\[
+ \frac{(1 - i_l - i_F)Nn[(n - 2)l_F N + n(-l_F N - n^2)]}{(l_F N + n)^2((n - 1)l_F N + n^2)^2}.
\]

The sign of equation (B-10) is pinned down by the sign of

\[
l_l N l_F N((n - 1)l_F N + n^2)^2 + (1 - i_l - i_F)Nn[(n - 2)l_F N + n(-l_F N - n^2)].
\]
The first term of (B-11) is positive. Hence, when the second term of (B-11) is also positive, the informed traders trade more aggressively with faster information diffusion.

On the one hand, when the fraction of the fast traders satisfies

\[ n < I_F N < \frac{n + \sqrt{n^2 + 4n(n - 2)}}{2n - 4}, \]

The second term of (B-11) is negative. Therefore, by calculating the derivative of (B-11), we obtain

\[ \frac{d}{dI_F} \left[ I_F N \left( (n-1)I_F N + n^2 \right)^2 + (1 - I - I_F)Nn[(n-2)I_F N + n(-I_F N - n^2)] \right] > 0. \]

This means that term (B-11) increases with the informed trader fraction. Therefore, we can define a threshold value on the number of informed traders that makes (B-11) equal to zero as

\[ \frac{-(1 - I_F)Nn[(n-2)I_F N + n(-I_F N - n^2)]}{I_F N \left( (n-1)I_F N + n^2 \right)^2 - n[(n-2)I_F N + n(-I_F N - n^2)]}. \]

On the other hand, the maximum number of informed traders is \( N - I_F N \).

**Appendix C**

In this appendix, we provide the proofs for the main propositions and corollaries for the endogenous equilibrium; we also prove several key equations mentioned in the main text.

**C1. Proof of Proposition 5**

We only need to examine how the fraction of the fast traders influences the value of information. From equation (25), we have the value of information as,

\[ \Gamma_I(I_F, I_I, n) = \frac{(n-1)\sqrt{(I_F N + n)n}}{\left( I_F N + 1 \right) \left( (n-1)I_F N + n^2 \right) + (1 - I - I_F)Nn} \sqrt{I_F N + \frac{(1 - I - I_F)Nn}{(n-1)(I_F N + n^2)}} \]

Calculating the derivation for the expression about value of information, we have

\[ \frac{\partial \Gamma_I(I_F, I_I, n)}{\partial I_F} = \frac{\left( \Gamma_I(I_F, I_I, n) \right)^2}{(n-1)\sigma \sigma_z} H. \]

Therefore, the sign of \( \frac{\partial \Gamma_I(I_F, I_I, n)}{\partial I_F} \) is then pinned down by the sign of term \( H \), which follows
\begin{align*}
H &= \frac{\partial}{\partial I_F} \left[ -\left((I_iN + 1)n((n-1)I_F N + n^2) \right. \\
& \quad \left. + (1 - I_i - I_F)N n^2 \right) \right] \\
& \quad + \frac{l_iN_n}{I_F N + n} + \frac{(1 - I_i - I_F)N n^2}{(n-1)(I_F N + n^2)(I_F N + n)}.
\end{align*}

(C-1)

Simplifying term (C-1), we have

\begin{align*}
H &= -\left((I_iN + 1)(n^2 - n)N - N n^2\right) \frac{l_iN_n}{I_F N + n} + \frac{(1 - I_i - I_F)N n^2}{(n-1)(I_F N + n^2)(I_F N + n)} \\
& \quad - \left((I_iN + 1)n((n-1)I_F N + n^2) \right. \\
& \quad \left. + (1 - I_i - I_F)N n^2 \right)\frac{l_iN_n}{(I_F N + n)^2} + \frac{(1 - I_i - I_F)N n^2}{(n-1)(I_F N + n^2)^2} \\
& \quad \frac{2}{l_iN_n} \frac{l_iN_n}{I_F N + n} + \frac{(1 - I_i - I_F)N n^2}{(n-1)(I_F N + n^2)(I_F N + n)} \\
& = KG(I_i).
\end{align*}

The parameter \(K\) is always negative and function \(G\) has following expression,

\begin{align*}
G(I_i) &= 2\left((I_iN + 1)(n^2 - n)N - N n^2\right) \frac{l_iN_n((n-1)I_F N + n^2)^2}{(I_F N + n)} \\
& \quad + (1 - I_i - I_F)N n^2((n-1)I_F N + n^2)(I_F N + n) \\
& \quad + \left((I_iN + 1)n((n-1)I_F N + n^2) \right. \\
& \quad \left. + (1 - I_i - I_F)N n^2 \right)\left[-l_iN_n\left((n-1)I_F N + n^2\right)^2 \\
& \quad - N n^2\left((I_F N + n)\left((n-1)I_F N + n^2\right) \\
& \quad + (1 - I_i - I_F)\left((n-1)I_F N + n^2 + (I_F N + n)(n-1)N\right)\right].
\end{align*}

(C-2)

Calculating the second order differential for \(G\) about \(I_i\), we can show that \(G''(I_i) > 0\). Besides, substituting the zero into term (C-2), we have \(G(0) < 0\). Combining these two observations, we see that function \(G\) is a quadratic equation of \(I_i\) with a unique and positive solution \(\{I_i|G(I_i) = 0, I_i > 0\}\). Hence, we conclude that, when

\begin{align*}
0 < I_i < \{I_i|G(I_i) = 0, I_i > 0\},
\end{align*}

function \(G\) is negative; term \(H\) from (C-1) is positive. This means that, with more fraction of the fast traders, the value of information increases. Finally, the maximum fraction of the informed traders can only be \(1 - I_F\). Hence, we obtain conditions (27) and (28) in Proposition 5.
**C2. Proof of Corollary 3**

On the effect of the cost on the fast traders, according to the equilibrium conditions \( r_F(I_F, I_I, n) = C_F \) and \( r_I(I_F, I_I, n) = C_I \), we have from (24) and (25) the condition for equilibrium speed acquisition,

\[
C_F = \frac{n}{I_F N + n} \frac{\sigma z}{\sqrt{I_F N n}} - \frac{n}{I_F N + n} \psi(I_F, I_I, n).
\]

Similarly, the equilibrium information condition becomes

\[
C_I = (n - 1) \psi(I_F, I_I, n).
\]

Combining the above two equations, we have

\[
C_F = \frac{n}{I_F N + n} \left( \frac{\sigma z}{\sqrt{I_F N n}} - \frac{1}{n - 1} C_I \right). \tag{C-3}
\]

Applying the implicit function theorem to (C-3), we obtain

\[
\frac{d l_F}{d C_F} = -\left( \frac{n N}{(I_F N + n)^2} \left( \frac{\sigma z}{\sqrt{I_F N n}} - \frac{1}{n - 1} C_I + \frac{n}{I_F N + n} \frac{\sigma z}{2I_F \sqrt{I_F N n}} \right) \right)^{-1} < 0. \tag{C-4}
\]

This implies that a decrease in the cost \( C_F \) of acquiring speed always increases informed trading in the equilibrium. This is intuitive since a lower \( C_F \) implies a higher net benefit of acquiring speed. More interestingly, as discussed in the above subsection, acquiring speed exhibits a strategic complementarity to producing information. Thus, the complementarity effect characterized in Proposition 5 implies that a decrease in \( C_I \), the cost of producing information, may surprisingly increase the fast trading in equilibrium, which is demonstrated by the following result (after applying the implicit function theorem to (C-3)),

\[
\frac{d l_I}{d C_I} = -\left( \frac{n}{(n - 1)(I_F N + n)} \left( \frac{n N}{(I_F N + n)^2} \left( \frac{\sigma z}{\sqrt{I_F N n}} - \frac{1}{n - 1} C_I + \frac{n}{I_F N + n} \frac{\sigma z}{2I_F \sqrt{I_F N n}} \right) \right) \right)^{-1} < 0.
\]

On the effect of the cost on the informed traders, we apply the implicit function theorem to the equilibrium conditions \( r_I(I_F, I_I, n) = C_I \) and \( r_F(I_F, I_I, n) = C_F \), respectively, and obtain

\[
\frac{d l_I}{d C_I} = -\left( \frac{\partial r_I}{\partial l_I} \right)^{-1} \frac{\partial r_I}{\partial C_I} \frac{d l_I}{d C_I} \frac{d l_F}{d C_F} = -\left( \frac{\partial r_I}{\partial l_I} \right)^{-1} \frac{\partial r_I}{\partial l_I} \frac{d l_F}{d C_F}. \tag{C-5}
\]
The term \( \frac{dI}{dC} \) is negative since a lower information cost \( C \) implies a higher net benefit of acquiring the speed. All these results are consistent with Proposition 5 that both producing information and acquiring speed are strategic substitute. More interestingly, as indicated in Proposition 5, producing information exhibits either a strategic substitute or complement to acquiring speed. From (C-5), \( \frac{dI}{dC} \) depends on \( \frac{\partial I}{\partial I} \) (which is negative based on Proposition 5), \( \frac{dI}{dC} \) (which is negative as in (C-4)) and \( \frac{\partial I}{\partial I} \) (which is determined by whether producing information exhibits substitutability or complementarity). Thus, these complementarity and substitutability effects emphasized in the above subsection imply that a decrease in the cost of acquiring speed may increase (decrease) the equilibrium market fraction of the informed traders (to producing information). Specially, Proposition 5 shows that, when (27) is satisfied, a decrease in \( C \) decreases the fraction of the informed traders. Therefore an increase in the fast trading reduces trader’s incentive to produce information, so a decrease in \( C \), which directly increases the fast trading, indirectly reduces the informed trading. Similarly, when (28) holds, a decrease in \( C \) increases the fraction of the informed traders.

C3. Proof of Equations (29) and (33)

Equation (29) examines how information diffusion influences the fraction of the fast informed trader. Applying the implicit function theorem to (C-3) delivers,

\[
\frac{dI_F}{dn} = \frac{I_F N}{I_F N + n} \left( \frac{\sigma \sigma \zeta}{\sqrt{I_F N n}} - \frac{1}{n - 1} C_i \right) + n \left( \frac{-\frac{\sigma \sigma \zeta}{2n \sqrt{I_F N n}} + \frac{C_i}{(n - 1)^2}}{\frac{\sigma \sigma \zeta}{2I_F \sqrt{I_F N n}}} \right) > 0. \tag{C-6}
\]

Equation (C-6) actually confirms our analysis in Section 5.

We now prove equation (33). Substituting (C-6) into equation (31), we have,

\[
\frac{dI_F}{dn} = \frac{1}{2n} \sqrt{\frac{n}{(I_F N + n)}} \left( \frac{n}{I_F N + n} \left( \frac{\sigma \sigma \zeta}{\sqrt{I_F N n}} - \frac{1}{n - 1} C_i \right) \right) + n \left( \frac{\sigma \sigma \zeta}{2I_F \sqrt{I_F N n}} \right).
\]

The sigh of equation (33) is then pinned down by

\[
-\frac{\sigma \sigma \zeta}{\sqrt{I_F N n}} + \frac{n}{(n - 1)^2} C_i. \tag{C-7}
\]
In the equilibrium,

\[ C_F = \frac{n}{I_F N + n} \left( \frac{\sigma z}{\sqrt{I_F N n}} - \frac{1}{n - 1} C_i \right). \]

Thus, equation (C-7) can be represented as,

\[ - \frac{\sigma z}{\sqrt{I_F N n}} + \frac{n}{(n - 1)^2} C_i = - \frac{I_F N + n}{n} C_F + \frac{1}{(n - 1)^2} C_i. \]

When both the informed and fast traders are active in the market, we show based on the numerical analysis that the speed cost should be larger than the information cost. Thus, the term (C-7) is negative.
A. Decomposition of trading intensity with respect to faster information diffusion (without trading speed hierarchies)

<table>
<thead>
<tr>
<th>Faster information diffusion</th>
<th>Late period aggregate trading intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Informed trading</td>
</tr>
<tr>
<td>Fraction</td>
<td>(1): - - - -</td>
</tr>
<tr>
<td>Trading sensitivity</td>
<td>(2): +</td>
</tr>
<tr>
<td>Total effect</td>
<td>(1)+(2): - - -</td>
</tr>
</tbody>
</table>
B. Decomposition of trading intensity with respect to faster information diffusion (with trading speed hierarchies)

<table>
<thead>
<tr>
<th>Faster information diffusion</th>
<th>Fraction</th>
<th>Informed trading</th>
<th>Market quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fast information diffusion</td>
<td>Fast trading</td>
<td>Trading sensitivity</td>
<td>Slow trading</td>
</tr>
<tr>
<td>Weakening effect</td>
<td>Trading sensitivity</td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>Late period aggregate trading intensity</th>
<th>Informed trading</th>
<th>Slow trading</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fraction</td>
<td>(a): - - -</td>
<td>(c): +</td>
</tr>
<tr>
<td>Trading sensitivity</td>
<td>(b): + + + (++)</td>
<td>(d): +</td>
</tr>
<tr>
<td>Total effect</td>
<td>(a)+(b): ? [- / +]</td>
<td>(c)+(d): + +</td>
</tr>
</tbody>
</table>
Figure 2: The timeline in Section 2

Event | Information acquisition | 1st trade | 2nd trade | Pay-off
--- | --- | --- | --- | ---
Time |  |  |  |  

$t = -1$
$t = 0$
$t = 1$
$t = 2$

Group $i$ fast trader

Information structure and fraction

Group $i$ informed trader

Group $i$ slow informed trader
Figure 3: The effect of faster information diffusion on information production

The equilibrium fraction of the informed traders with respect to the speed of information diffusion with the information production cost $C_i = 0.1$ (the left panel) and $0.2$ (the right panel), the speed acquisition cost $C_F = 6$, the number of speculators $N = 100$, the volatility of the fundamental value $\sigma = 10$, and the volatility of the order flow of the liquidity traders $\sigma_z = 10$. The blue solid line represents the equilibrium fraction of informed traders; while the red dashed line represents the minimum fraction of informed trader, based on condition (27) when information production is a substitute to information acquisition.
Figure 4: The effect of faster information diffusion on price efficiency

The equilibrium fraction of the informed traders and price efficiency with respect to the speed of information diffusion with the information production cost $C_I = 0.1$ (the left panel) and 1 (the right panel), the speed acquisition cost $C_F = 6$. The other parameters are the same as in Figure 3. The blue solid line represents the equilibrium fraction of the informed traders; while the blue dashed line represents the minimum fraction of the informed trader based on condition (27) when the information production is a substitute to the information acquisition. The red dotted line represents the condition variance, measuring the price efficiency.
Figure 5: How fast trading re-shapes the baseline trade-off in the late period

The equilibrium changing of trading intensities with respect to the speed of information diffusion with the information production cost $C_i = 0.1$ (the left panel) and 1 (the right panel), the speed acquisition cost $C_F = 6$. The other parameters are the same as in Figure 3. The blue and red lines represent the changing of trading intensity for slow and informed, respectively. The dashed and solid lines represent the cases without and with speed heterogeneity, respectively.
The aggregate trading volumes (on the left panel) and proportional trading volumes (on the right panel) for the fast (the blue lines) and informed (the red lines) traders with respect to the information diffusion. The solid and dotted lines correspond to the information production cost of $C_I = 0.1$ and $C_I = 1$, respectively. The other parameters are the same as in Figure 3.
Figure 7: Trading and return patterns

The correlation coefficient between the trades in early and late periods (the left pane) and the covariance between fast trader’s trade and return in late period (the right panel) with respect to the information diffusion. The blue and red lines correspond to information production cost of $C_i = 0.1$ and $C_i = 1$, respectively. The other parameters are the same as in Figure 3.
Figure 8: The effect of faster information diffusion on price efficiency when fast traders trade in both periods

The equilibrium fraction of the informed traders (the blue lines) and price efficiency (the red lines) with respect to the speed of information diffusion with the information production cost $C_I = 0.1$ (the left panel) and 1 (the right panel), the speed acquisition cost $C_F = 6$. The other parameters are the same as in Figure 3.
Figure 9: Trading speed of the fast traders when trading in both periods

The trading speed of the fast traders with respect to the speed of information diffusion. The other parameters are the same as in Figure 3. The blue solid and red dotted lines correspond to the information production cost of $C_i = 0.1$ and $C_i = 1$, respectively.
### Table A1: Main model variables

<table>
<thead>
<tr>
<th>Variables</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V$</td>
<td>Asset liquidation value at the end of trading period</td>
</tr>
<tr>
<td>$\sigma^2$</td>
<td>Prior variance of the asset value</td>
</tr>
<tr>
<td>$v_i$</td>
<td>sub-innovations decomposed from the fundamental value</td>
</tr>
<tr>
<td>$n$</td>
<td>groups of sub-innovation (Information diffusion speed)</td>
</tr>
<tr>
<td>$\sigma^2_z$</td>
<td>variance of the noise trading in periods 1 and 2</td>
</tr>
<tr>
<td>$N$</td>
<td>Number of the speculators</td>
</tr>
<tr>
<td>$C_F$</td>
<td>cost of being fast and partial informed trader</td>
</tr>
<tr>
<td>$C_I$</td>
<td>cost of being slow and fully informed trader</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variables</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_F$</td>
<td>Fraction of the fast traders</td>
</tr>
<tr>
<td>$I_I$</td>
<td>Fraction of the informed traders</td>
</tr>
<tr>
<td>$x_F(v_i)$</td>
<td>Orders placed by the fast trader</td>
</tr>
<tr>
<td>$x_I(V,p_1)$</td>
<td>Orders placed by the informed trader</td>
</tr>
<tr>
<td>$x_S(v_i,p_1)$</td>
<td>Orders placed by the slow trader</td>
</tr>
<tr>
<td>$p_1,p_2$</td>
<td>Asset prices in periods 1 and 2</td>
</tr>
<tr>
<td>$w_1, w_2$</td>
<td>Aggregate order flows in periods 1 and 2</td>
</tr>
<tr>
<td>$\phi_I$</td>
<td>Trading intensity of the informed traders</td>
</tr>
<tr>
<td>$\phi_F$</td>
<td>Trading intensity of the fast traders</td>
</tr>
<tr>
<td>$\phi_S$</td>
<td>Trading intensity of the slow traders</td>
</tr>
<tr>
<td>$\phi_L$</td>
<td>Trading intensity of the late period</td>
</tr>
<tr>
<td>$\gamma_F$</td>
<td>Value of the speed</td>
</tr>
<tr>
<td>$\gamma_I$</td>
<td>Value of the information</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta_F$</td>
<td>$x_F(v_i) = \beta_F v_i$</td>
</tr>
<tr>
<td>$\beta_I$</td>
<td>$x_I(V, p_1) = \beta_I (V - p_1)$</td>
</tr>
<tr>
<td>$\beta_S$</td>
<td>$x_S(v_i, p_1) = \beta_S (v_i - p_1) + \gamma_S p_1$</td>
</tr>
<tr>
<td>$\lambda_1$</td>
<td>$p_1 + \lambda_1 w_2$</td>
</tr>
<tr>
<td>$\lambda_2$</td>
<td>$p_2 = p_1 + \lambda_2 w_2$</td>
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</tbody>
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