Transaction costs and the divergence between financial and real market volatilities

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Abstract

Recent advances in alternative data and artificial intelligence enable analysts and other corporate outsiders to access private information unknown to corporate insiders. Motivated by this, we propose a theoretical model revising the linkage between transaction costs and market volatility with two key updates. First, financial markets (i.e., futures markets) aggregate information from both product-producing firms and informed investors. Second, producing firms extract private information from financial market signals to guide their production decisions, thereby influencing real market (i.e., product market) prices. Our model predicts that, in financial markets, higher transaction costs slow down price discovery, reducing information-driven volatility, but also reduce market depth, raising liquidity-driven volatility. In real markets, higher financial market transaction costs discourage informed trading and weaken market feedback, leading to less efficient production decisions and greater volatility in product markets. Overall, financial market transaction costs reduce efficiency in both financial and real markets and may contribute to divergence in their volatilities. Finally, by endogenizing investors' information acquisition decisions and firms' information disclosure policies, we provide robust predictions and further insights into the information discovery process.

Keywords: Financial market volatility; Real market volatility; Feedback effect; Disclosure; Information acquisition
JEL Classification: D80, G10, G14, L10

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1 Introduction

The stability of financial markets has long been a central concern for regulators. The idea of using transaction costs to mitigate financial market volatility dates back to Keynes' (1937) proposal of a securities transaction tax. Early proponents, including Tobin (1978), Stiglitz (1989), and Summers & Summers (1989), contend that higher transaction costs discourage non-fundamental noise traders from trading, which reduces price volatility. In contrast, critics such as Edwards (1993) and Schwert & Seguin (1993) argue that higher transaction costs can hinder the price discovery process, which reduces liquidity and potentially increases price volatility.[1] Despite a rich literature, existing theoretical work has largely overlooked the market feedback effect, in which firm managers are motivated to learn from financial markets (Bennett et al., 2020) and analysts (Guo & Zhong, 2023). This effect has attracted growing attention as the wider availability of big data and advances in artificial intelligence enhance the analytical capacities of corporate outsiders (e.g., Chi et al., 2025; Jagtiani & Lemieux, 2019; Zhu, 2019).

To incorporate the market feedback effect, this article develops a theoretical model with two key updates. First, it reassesses the link between transaction costs and market volatility under conditions where financial markets can effectively aggregate diverse information, including both public information released by firm managers and private information obtained by investors from external sources (such as alternative data supported by artificial intelligence). Second, it introduces a market feedback mechanism, allowing firm managers to learn from informed investors via market price signals and adjust their de-

[1]The relationship between transaction costs and financial market volatility remains unsolved, as both theoretical (e.g. Kupiec, 1996; Song & Zhang, 2005; Lendvai et al., 2013) and empirical (e.g. Umlauf, 1993; Hau, 2006; Lensberg et al., 2015; Deng et al., 2018; Goldstein, 2015) studies provide evidence that support both perspectives.

cisions accordingly. Within this framework, the impact of transaction costs is no longer confined to financial market dynamics (e.g., Song & Zhang, 2005) but also extends to corporate decision-making, thereby affecting real economic activity.

Regarding the first update, nearly all theoretical models in the related literature on the relationships between transaction costs and volatility rely on two key assumptions: (i) informed investors trade solely based on information provided by corporate insiders, and (ii) excess financial market volatility is primarily driven by non-fundamental traders who trade based on either erroneous beliefs (Song & Zhang, 2005; Lendvai et al., 2013) or extrapolative technical trading strategies (Westerhoff & Dieci, 2006). However, an growing strand of literature finds that the information aggregation function of the financial markets enable financial markets to incorporate firm-level information that may be unknown to the managers themselves (Dye & Sridhar, 2002), which in turn influences corporate decisions (e.g., Bennett et al., 2020; Goldstein, 2023; Luo, 2005). Moreover, the latter assumption does not hold for markets where noise traders predominantly trade for exogenous hedging or liquidity needs, as modeled in Kyle (1985) and Xiong & Yang (2021).[2] Besides, the role of non-fundamental noise trade has become less relevant for financial markets over time, as price informativeness has improved (Bai et al., 2016).

We therefore extend the classic noisy rational expectations equilibrium model (see Grossman & Stiglitz, 1980; Diamond & Verrecchia, 1981) to a setting with transaction costs (e.g., Dávila & Parlatore, 2021) and two markets (e.g., Xiong & Yang, 2021; Goldstein & Yang, 2022). The first market is a futures market (a financial market), where futures contracts are settled on a specified future date, and the underlying commodity is the product

[2]Dow & Gorton (1997a) provide theoretical evidence that, even uninformed institutional investors, who do not tend to speculate, may still have incentive to trade randomly and excessively to signal their activity to clients.

of a monopolistic firm. The second is a product market (a real market), where the same commodity is traded for immediate delivery at the maturity of the futures contracts. Following the literature on the information aggregation function of financial markets, we model noise traders as hedgers who face exogenous stochastic demand or supply shocks (as in Grossman & Stiglitz, 1980; Xiong & Yang, 2021). This choice is supported by empirical evidence showing that futures markets are dominated by hedgers (Ederington & Lee, 2002), especially large hedgers (Chang et al., 1997), and that hedging needs significantly affect futures prices (Bessembinder, 1992; De Roon et al., 2000). By adopting this setting, our model (i) allows financial markets to aggregate diverse information—an essential feature for the market feedback effect described later—and (ii) differentiates the activities in futures (financial) markets from those in product (real) markets.

For the second key update, we follow the literature and include the role of the market feedback effect (see Goldstein, 2023, for a review) by allowing firm managers and informed investors to have advantages in distinct sets of information (e.g., Benhabib et al., 2019). Firm managers have perfect information about their production costs and can choose the precision of the information they disclose, which gives them an informational advantage over outsiders on product supply. Investors, on the other hand, can acquire private information about product demand from external sources but must weigh the costs of being informed against the potential trading profits (as in Grossman & Stiglitz, 1980). The assumption that informed investors have an informational advantage in aggregate product demand is supported by empirical evidence. Studies show that analysts and institutional investors have superior insights into macroeconomic conditions (Hutton et al., 2012) and product market information (Zhang, 2023), which can help managers identify investment opportunities (Guo & Zhong, 2023). When informed investors participate in

the financial markets, their private information will be incorporated into the market prices. This information aggregation function of the financial markets (e.g. Hayek, 1945; Hellwig, 1980) allows firm managers to extract insights from other market participants and adjust their production decisions accordingly (i.e., market feedback effect), even when managers, overall, have informational advantages over outsiders.

Two main results emerge from our initial analysis when both the investors' information acquisition decision and the firm's information disclosure decision are exogenous. First, changes in transaction costs can have opposite effects on different components of financial market volatility. For information-driven volatility, higher transaction costs reduce the profitability of informed trading in the futures market, thus slowing down price discovery and reducing the volatility associated with this process. We term this effect the *information effect*. For liquidity-driven volatility, our mechanism aligns with the *liquidity effect* documented in the literature (e.g. Song & Zhang, 2005). Specifically, higher transaction costs reduce the trading volume, thus reducing market depth and potentially increasing volatility from exogenous shocks. In aggregate, higher transaction costs reduce (increase) financial market volatility when transaction costs are low (high), as the information (liquidity) effect dominates. More interestingly, our theoretical predictions for the futures market are in line with the empirical findings of Green et al. (2000), who find that higher transaction costs reduce fundamental volatility (captured by information-driven volatility in our model) but increase excess volatility (captured by liquidity-driven volatility) using a century of London Stock Exchange data, although our assumption of minimized non-fundamental herding behavior may not hold when uncertainty is high (Cipriani & Guarino, 2014).

Our second main result highlights the link between financial market transaction costs

and real market volatility due to the market feedback effect. The logic behind this result is straightforward and intuitive. Higher transaction costs discourage informed investors from trading on private information about aggregate product demand, which slows down the price discovery process. Consequently, firm managers extract less information from the financial markets, which leads to less efficient production decisions (i.e., a mismatch between the realized product supply and demand). This inefficiency, in turn, increases the volatility of the spot price of the underlying commodity on the maturity date of the future contract. In summary, when transaction costs are low and the financial market is well-informed, increasing the transaction costs reduces the volatility in the futures market (i.e., the financial markets) but increases the volatility in the product market (i.e., the real market).

Finally, we extend the model to endogenize the costly decision for the investors to acquire information and the costly decision of firms to disclose information. Our two main results remain robust after extending the model. In addition, the extended model provides further insights into the information discovery process. For investors, higher transaction costs can either encourage or discourage information acquisition. On the one hand, higher transaction costs increase trading execution expenses, thus reducing the profitability of informed trading and dis-incentivizing investors from acquiring information. On the other hand, higher transaction costs reduce the informativeness of the futures prices, thus increasing the profitability of informed trading and strengthening investors' incentives to acquire information. Overall, an increase in transaction costs increases (reduces) the proportion of informed investors when transaction costs are low (high). For producing firms, higher transaction costs deter them from releasing more precise public signals. Specifically, when transaction costs are low, firms have a stronger incentive to release pre-

cise information about production costs, which encourages informed investors to trade on their private signals regarding product demand. However, as transaction costs rise, this feedback effect diminishes, thus reducing the motivation of the firm to disclose public signals.

Our study lies at the intersection of two major strands of the literature. First, it contributes to a long-standing debate on whether increasing financial market frictions can stabilize financial markets (Umlauf, 1993; Goldstein & Kavajecz, 2004; Deng et al., 2018). Unlike traditional models, which assume that corporate insiders are the sole information providers, we allow investors to acquire private information unknown to insiders (firm managers) from external sources. This assumption reflects the enhanced analytical capacities of corporate outsiders resulting from the wider availability of big data and advances in artificial intelligence (e.g., Chi et al., 2025; Jagtiani & Lemieux, 2019; Zhu, 2019). To enable financial markets to effectively aggregate both public information released by firm managers and private information acquired from external sources, we adopt a setting in which noise traders predominantly engage in hedging or liquidity trading (Grossman & Stiglitz, 1980; Xiong & Yang, 2021). By applying this framework and decomposing financial market volatility into information-driven (fundamental) and liquidity-driven (excess) components, our model predicts opposite effects of transaction costs on the two components, resulting a U-shaped overall effect on total financial market volatility. Interestingly, although our model assumptions are informed by recent developments in alternative data and artificial intelligence, the model predictions align with empirical evidence from London Stock Exchange data between 1870 and 1986 (Green et al., 2000), suggesting broader implications.

Second, this study is also related to the impact of financial market signals on corporate

decisions (e.g., Dow & Gorton, 1997b; Mathers et al., 2017; Goldstein, 2023). By incorporating the market feedback effect into the analysis of transaction costs, our theoretical model predicts that higher transaction costs can cause a divergence between financial and real market volatilities. This extension contribute to the literature by linking transaction costs not only to financial stability but also to the stability of real markets, which highlights the potential unintended side effects of employing transaction costs as a market-stabilizing mechanism.

2 Model

Our model is a noisy rational expectations equilibrium model set in an environment with two markets (e.g., Xiong & Yang, 2021; Goldstein & Yang, 2022). The first is a futures market (a financial market), which aggregates information (signals) from different market participants. The underlying asset of futures contracts is produced by a monopoly firm. The second is a product market (a real market) for the immediate settlement of the underlying asset. Notably, investors' trading incurs quadratic transaction costs (e.g., Dávila & Parlatore, 2021) in the futures market.

The economy has five dates: $t = 0$, 0.5, 1, 1.5, and 2. At $t = 0$, the monopolistic firm selects a specific disclosure policy, determining the precision of the production cost information it will release as a public signal later. After observing the firm's disclosure policy, at $t = 0.5$, each rational investor decides whether to acquire a private signal about the product demand. At $t = 1$, the firm releases a public signal in accordance with its predetermined disclosure policy, and informed investors receive their private signals. The futures market, where the firm's product serves as the underlying commodity, then opens. Ratio-

nal investors trade based on public and private signals, which allows the futures price to incorporate both types of information. At $t = 1.5$, the firm extracts the investors' private signals from the futures price, and adjusts its production decision (i.e., the financial market feedback effect). Finally, at $t = 2$, the futures contract matures, and the product market opens, which determines the payoff of the futures contracts (i.e., the product price).

2.1 Consumer

There is a representative consumer who purchases and consumes a commodity, such as copper. Assume that the consumer surplus is $C(\varepsilon, Q) = U(\varepsilon, Q) - PQ$, where $U(\varepsilon, Q) = \varepsilon Q - \frac{1}{2}Q^2$ is the consumer's intrinsic utility function, Q is the quantity of product consumed, P is the product price, and $\varepsilon \sim N(\bar{\varepsilon}, \tau_{\varepsilon}^{-1})$ is a preference shock and its realization is privately observed by the consumer. The consumer is a price taker and chooses a quantity of the product Q to maximize his/her consumer surplus. Therefore, his/her demand for the product is $Q = \varepsilon - P$. Note that the product demand is increasing in the preference shock ε.

2.2 Firm

The commodity is produced by a monopolistic firm. The marginal cost of production is $a \sim N(\bar{a}, \tau_a^{-1})$ and its realization is privately observed by the firm. Therefore, the firm's profit is $\Pi = PQ - aQ$. Note that the inverse demand function is $P = \varepsilon - Q$. Hence, the firm's profit can also be expressed as $\Pi = (\varepsilon - a)Q - Q^2$.

2.3 Financial market and investors

A risky asset, specifically a futures contract whose underlying asset is the firm's product, and a risk-free asset are traded in a financial market. The payoff of each futures contract at maturity $(t = 2)$ is denoted by P, while its (endogenous) price before maturity is p. The return on the risk-free asset is exogenously given and normalized to 0. The use of a *futures* contract instead of a stock as the risky asset aligns with the assumption that noise traders are primarily hedgers (as in Xiong & Yang, 2021).

The financial market consists of a continuum of rational investors who derive expected utility only from their terminal wealth and have constant absolute risk aversion (CARA) utility functions. Specifically, for investor i, her utility is given by $u(W_i) = -\exp(-\gamma W_i)$, where $\gamma > 0$ represents a common risk-aversion coefficient. The investor's terminal wealth at $t = 2$ can be expressed as:

$$W_i = (W_{0i} - m_i p) + m_i P - \frac{c}{2}(m_i)^2, \tag{1}$$

where W_{0i} is the investor's initial wealth at $t = 0$, m_i is his/her holding of the futures contract, $-\frac{c}{2}(m_i)^2$ is his/her transaction cost, and $c \geq 0$ is the cost parameter. We assume the quadratic form of transaction costs for tractability. Finally, noise traders, representing random transient demand arising from hedging and/or liquidity needs, collectively demand n units of futures contracts, where $n \sim N(0, \tau_n^{-1})$.

2.4 Information disclosure and acquisition

At $t = 0$, the firm commits to a particular disclosure policy. Then, at $t = 1$, it releases a public signal regarding its production cost, $s = a + \eta$, where $\eta \sim N(0, \tau_\eta^{-1})$, based on its

prespecified disclosure policy. Specifically, if the firm commits at $t = 0$ to withholding all information, then $\tau_\eta = 0$. In contrast, if the firm commits to fully disclosing the information, then $\tau_\eta = +\infty$. A value of $\tau_\eta \in (0, +\infty)$ implies a partial disclosure policy. Notably, disclosure incurs a cost of $-\frac{k}{2}(\tau_\eta)^2$, where $k > 0$ is the disclosure cost parameter.

All of the rational investors can observe the firm's disclosure policy τ_η at $t = 0$. After doing so, each investor decides at $t = 0.5$ whether to acquire a private signal about the consumer preference shock, $x_i = \varepsilon + e_i$, $e_i \sim N(0, \tau_x^{-1})$, by paying a cost of $b > 0$. We refer to an investor who chooses to acquire the costly private information as an "informed investor". At $t = 1$, all of the investors observe the public signal s disclosed by the firm, and informed investors receive their private signals. We denote the proportion of informed investors by $\mu \in [0, 1]$.

Our assumption that firms commit to a disclosure policy is widely maintained in the literature on firm disclosure, including Gal-Or (1985), Darrough (1993), and Xiong & Yang (2021). In practice, a firm's commitment to a disclosure policy can be observed through its decisions on whether to become publicly listed, its choice of a host market, and its selection of auditing firms. All of these decisions must be made in advance and can potentially influence the precision and quality of the financial disclosures.

2.5 Financial market equilibrium

In this subsection, we define the financial market equilibrium (at $t = 1$) in which the firm's information disclosure policy τ_η and the proportion of informed investors μ are given.

The firm's problem. At $t = 1.5$, the firm chooses the quantity of product to maximize its expected profit conditional on the production cost a, public signal s, and price of the

futures contract p:

$$\max_{Q} E[(\varepsilon - a)Q - Q^2|a, s, p]. \tag{2}$$

Note that the firm can partially infer the private signals obtained by the investors from the futures price. Solving problem (2), we know that the firm's production decision is $Q = \frac{1}{2}E[\varepsilon|a, s, p] - \frac{1}{2}a$, and the product price (and thus the futures payoff) at $t = 2$ is

$$P = \varepsilon + \frac{1}{2}a - \frac{1}{2}E[\varepsilon|a, s, p]. \tag{3}$$

The investors' problems. When trading in the financial market at $t = 1$, each investor chooses his/her holding of the futures contract to maximize his/her expected utility conditional on his/her information set,

$$\max_{m_i} E[u(W_i)|\mathcal{F}_i], \text{ subject to the budget constraint Eq. (1).} \tag{4}$$

For an informed investor, the information set is $\mathcal{F}_i = \mathcal{F}_i^{IN} = \{x_i, s, p\}$. For an uninformed investor, the information set is $\mathcal{F}_i = \mathcal{F}^{UN} = \{s, p\}$. Solving problem (4), we can derive an investor's optimal holding of the futures contract:

$$m_i = \frac{E[P|\mathcal{F}_i] - p}{c + \gamma Var[P|\mathcal{F}_i]}. \tag{5}$$

Note that the absolute value of asset holding tends to decrease with the transaction cost parameter c. Intuitively, high transaction costs reduce the trading activity of rational investors.

Definition 1 (Financial market equilibrium)**.** *Given the firm's information disclosure policy τ_η and the proportion of informed investors μ, a financial market equilibrium consists of the optimal*

holdings of the futures contract by the investors $\{m_i\}$*, the futures price* p*, the firm's production decision* Q*, and the spot price of the product* $(commodity)$ P*, such that* (i) *the holding of the futures contract of each investor solves problem* (4)*, and* (ii) *the financial market clears, i.e.,*

$$\mu \int_0^1 m_i^{IN} di + (1-\mu) m^{UN} + n = 0, \tag{6}$$

where m_i^{IN} (m^{UN}) *is the holding of the futures contract by an informed* $(uninformed)$ *investor,* (iii) *the firm's production decision solves problem* (2)*, and* (iv) *the product market clears.*

3 Analysis of the financial market equilibrium

This section solves for the financial market equilibrium under an exogenously determined proportion of informed investors μ (which will be endogenized in Section 4) and an exogenously determined firm disclosure policy τ_η (which will be endogenized in Section 5).

3.1 Equilibrium characterization

We use the "conjecture and verify" and "backward induction" approaches, which are commonly used in studies on rational expectations equilibrium (e.g., Farboodi & Veldkamp, 2020; Benhabib et al., 2019), to solve the model. Conjecture that the equilibrium futures price takes the form of:

$$p = \beta_0 + \beta_1 \varepsilon + \beta_2 s + \beta_3 n, \tag{7}$$

where β_0, β_1, β_2, and β_3 are endogenous deterministic price coefficients. The firm and investors can thus transform the asset price into a signal of the consumer preference shock,

$$\tilde{p} = \frac{p - \beta_0 - \beta_2 s}{\beta_1} = \varepsilon + \frac{\beta_3}{\beta_1} n. \tag{8}$$

The precision of this signal is $\tau_p = (Var[\frac{\beta_3}{\beta_1} n])^{-1} = (\frac{\beta_1}{\beta_3})^2 \tau_n$. Since the demand of noise traders is exogenous, the magnitude of noise trading τ_n^{-1} will not be affected by price signals or transaction costs. Therefore, we define the futures price informativeness as β_1/β_3. With this price signal p, the public signal s, and the firm's private information about its production cost a, we can calculate the conditional expectation in the expression for the product price in Eq. (3).

The conditional expectations and variances in the expression for an investor's optimal asset holding Eq. (5) can also be calculated with the price signal $\tilde{p}$, the public signal s, and (if the investor is informed) the private signal about the product demand x_i. Substituting the investors' optimal asset holding into the market clearing condition Eq. (6) and rearranging terms, we can derive the implicit price function,

$$p = \frac{\omega_{IN}}{\omega_{IN} + \omega_{UN}} \int_0^1 E[P|\mathcal{F}_i^{IN}]di + \frac{\omega_{UN}}{\omega_{IN} + \omega_{UN}} E[P|\mathcal{F}^{UN}] + \frac{n}{\omega_{IN} + \omega_{UN}}, \tag{9}$$

where

$$\omega_{IN} = \frac{\mu}{c + \gamma Var[P|\mathcal{F}_i^{IN}]} \text{ and } \omega_{UN} = \frac{1 - \mu}{c + \gamma Var[P|\mathcal{F}^{UN}]}. \tag{10}$$

Eq. (9) indicates that the equilibrium futures price is determined by the weighted average of informed and uninformed investors' expectations about the asset payoff (i.e., the product price in the future) and noise traders' demand for the asset. Further calculations

show that the right-side of Eq. (9) is also linear in the preference shock ε, the public signal s, and the noise trading n.

Comparing the implicit price function Eq. (9) and the conjectured price function Eq. (7), and matching coefficients, we can derive a system of four equations with $(\beta_0, \beta_1, \beta_2, \beta_3)$ as unknowns. Solving the system of equations yields the equilibrium price function. The following proposition characterizes the financial market equilibrium.

Proposition 1 (Equilibrium characterization)**.** *Assume that the firm's disclosure policy τ_η and the proportion of informed investors μ are given. Then, there exists a unique financial market equilibrium in which the equilibrium futures price can be expressed as Eq.* (7)*, where the expressions for the price coefficients $(\beta_0, \beta_1, \beta_2, \beta_3)$ are provided in Appendix A. Notably, the equilibrium futures price informativeness β_1/β_3 is determined by the following equation,*

$$\frac{\beta_1}{\beta_3} = \frac{\omega_{IN}\tau_x}{\tau_\varepsilon + \tau_x + \tau_p}. \tag{11}$$

Moreover, price informativeness decreases with transaction costs, i.e., $\frac{\partial(\beta_1/\beta_3)}{\partial c} < 0$.

Proof. See Appendix A. □

3.2 Transaction costs and financial market

3.2.1 Futures price informativeness

The equilibrium futures price informativeness β_1/β_3 and liquidity $1/\beta_3$ as functions of the financial market transaction cost parameter c are plotted in Figure 1. Proposition 1 and the left panel of Figure 1 show that the informativeness of the futures price decreases with transaction costs. This result is intuitive and consistent with that of previous studies

(e.g.,Fu et al., 2016; Green et al., 2000; Kupiec, 1996): An increase in transaction costs reduces the trading of informed investors and thus the amount of information that they inject into the futures price.

3.2.2 Liquidity

As is standard in the literature, we define illiquidity of the financial market as the price impact of noise traders, β_3 (e.g., Kyle, 1985; Han & Yang, 2013; Farboodi & Veldkamp, 2020). When $\mu = 1$ (i.e., all of the rational investors are informed) and $\tau_a \to +\infty$ (i.e., the firm's production cost is deterministic and publicly known), illiquidity can be expressed as [3]

$$\beta_3 = \frac{(\beta_1/\beta_3)\tau_n + \gamma}{\tau_\varepsilon + \tau_x + (\beta_1/\beta_3)^2\tau_n} - \frac{1}{2}\frac{(\beta_1/\beta_3)\tau_n}{\tau_\varepsilon + (\beta_1/\beta_3)^2\tau_n} + c. \tag{12}$$

Eq. (12) shows that the transaction cost parameter c has a direct negative impact on the asset's liquidity $1/\beta_3$. The intuition is that higher transaction costs reduce the profitability of trading, discouraging rational investors from trading, which in turn reduces liquidity.

In addition to the direct effect, transaction costs can also affect liquidity through price informativeness. As shown in Eq. (12), the impact of price informativeness β_1/β_3 on the illiquidity measure β_3 is mixed. On one hand, higher price informativeness reduces the risk perceived by rational investors, thus encouraging speculative activity and increasing liquidity. On the other hand, higher price informativeness worsens the adverse selection problem, which discourages investors from trading and reduces liquidity (e.g., Han & Yang, 2013). Overall, the direct negative impact of transaction costs on liquidity tends to dominate, which leads to a decline in liquidity as transaction costs increase (see right

[3] Assuming that $\mu = 1$ and $\tau_a \to +\infty$ is for simplicity. Our interpretations are still valid when $\mu \in (0, 1)$ and $\tau_a \in (0, +\infty)$.

panel of Figure 1).

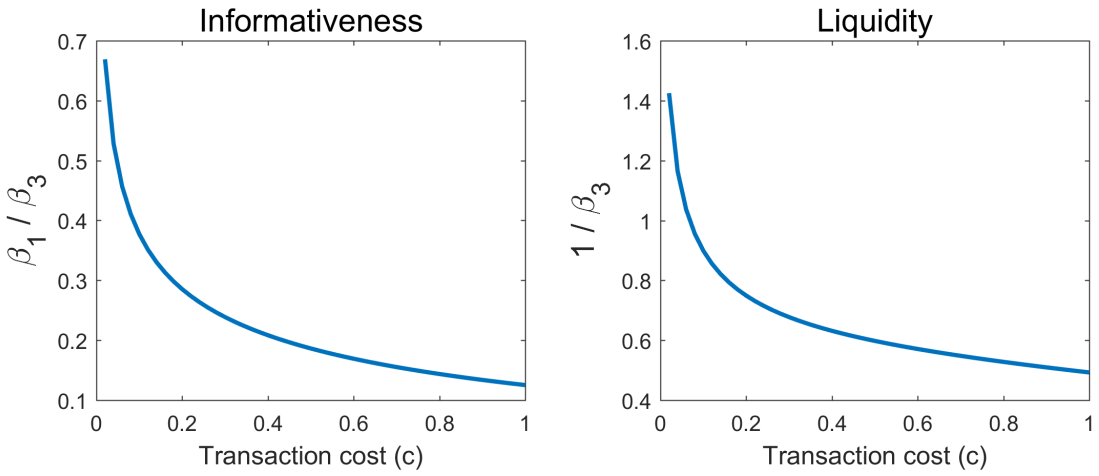


Figure 1: Impact of transaction costs on price informativeness and liquidity.
This figure plots the equilibrium futures price informativeness β_1/β_3 and liquidity $1/\beta_3$ as functions of the financial market transaction cost parameter c. The parameter values are: $\tau_\varepsilon = 3$, $\tau_a = 1$, $\tau_x = 1$, $\tau_n = 100$, $\gamma = 0.01$, $\bar{a} = 1$, $\bar{\varepsilon} = 2$, $\mu = 0.7$, and $\tau_\eta = 1$.

3.2.3 Futures price volatility

The volatility of the futures price, $\sqrt{Var[p]}$, measures the stability of the financial market. Following Ozsoylev & Walden (2011), futures price volatility can be decomposed into "information-driven volatility" and "liquidity-driven volatility", i.e.,

$$Var[p] = \underbrace{\beta_1^2 Var[\varepsilon] + \beta_2^2 Var[s]}_{\text{Information driven}} + \underbrace{\beta_3^2 Var[n]}_{\text{Liquidity driven}} . \tag{13}$$

As the transaction cost parameter c decreases liquidity (i.e., increases illiquidity measure β_3), it also increases liquidity-driven price volatility. Conversely, as transaction costs discourage trading among informed investors, they also reduce information-driven price volatility. The opposite effects of transaction costs on information-driven and liquidity-

driven volatilities align with the empirical results of Green et al. (2000).

Proposition 2 (Transaction costs and information-driven price volatility)**.** *When $\mu = 1$ and $\tau_a \to +\infty$, the price coefficient β_1 can be expressed as*

$$\beta_1 = \frac{1}{2}\frac{\tau_p^2 + (\tau_\varepsilon + \tau_x)\tau_p + 2\tau_x\tau_\varepsilon}{\tau_p^2 + (2\tau_\varepsilon + \tau_x)\tau_p + \tau_\varepsilon(\tau_\varepsilon + \tau_x)}. \tag{14}$$

Moreover, if $\tau_\varepsilon > (1+\sqrt{2})\tau_x$, then $\frac{\partial \beta_1}{\partial c} < 0$, and information-driven price volatility decreases with transaction costs, i.e., $\frac{\partial Var[\beta_1 \varepsilon]}{\partial c} < 0$.

Proof. See Appendix A. □

When the magnitude of noise trading (i.e., $Var[n]$) is relatively small and transaction costs are low, information-driven volatility dominates, thus resulting in a negative relationship between transaction costs and futures price volatility. In other words, financial transaction costs may stabilize financial markets by reducing speculative trading (see right panel of Figure 2, when $\mu < 1$ and $\tau_a < \infty$). When transaction costs are fairly high, informed traders are refrained from trading due to reduced profitability, and liquidity-driven volatility dominates, thus resulting in a positive relationship between transaction costs and futures price volatility. Figure 2 plots different types of financial market volatilities as functions of financial market transaction cost parameter c.

3.3 Financial market transaction costs and real product market

Proposition 3 (Transaction costs and the firm's profit)**.** *The unconditional expectation of the firm's profit $E[\Pi] = E[PQ - aQ]$ can be expressed as*

$$E[\Pi] = \frac{(\tau_\varepsilon^{-1} + \bar{\varepsilon}^2)\tau_p^2 + (1 + 2\tau_\varepsilon\bar{\varepsilon}^2)\tau_p + (\tau_\varepsilon\bar{\varepsilon})^2}{4(\tau_\varepsilon + \tau_p)^2} + \frac{\tau_a^{-1} + \bar{a}^2 - 2\bar{a}\bar{\varepsilon}}{4}. \tag{15}$$

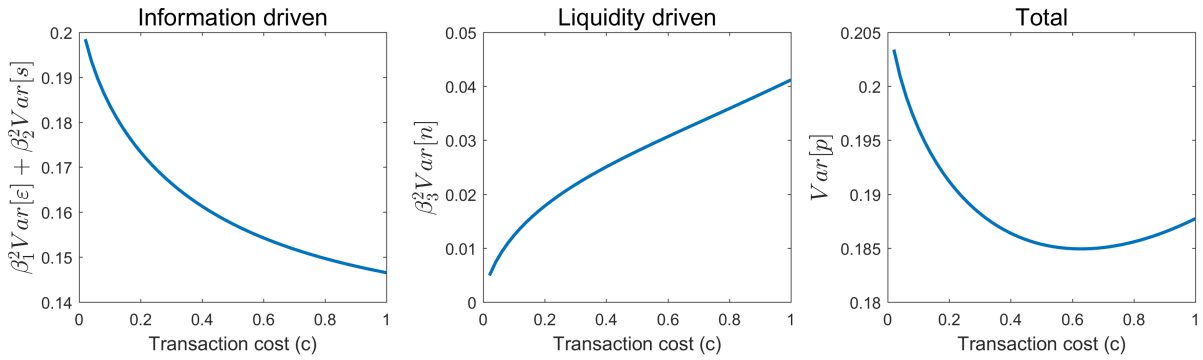


Figure 2: Impact of transaction costs on different types of financial market volatilities. This figure plots information-driven volatility ($\beta_1^2 Var[\varepsilon] + \beta_2^2 Var[s]$), liquidity-driven volatility ($\beta_3^2 Var[n]$), and total price volatility ($Var[p]$) as functions of financial market transaction cost parameter (c). The parameter values are: $\tau_\varepsilon = 3$, $\tau_a = 1$, $\tau_x = 1$, $\tau_n = 100$, $\gamma = 0.01$, $\bar{a} = 1$, $\bar{\varepsilon} = 2$, $\mu = 0.7$, and $\tau_\eta = 1$.

Notably, given the firm's disclosure policy τ_η and the proportion of informed investors μ, the expected firm profit declines with transaction costs, i.e., $\frac{\partial E[\Pi]}{\partial c} < 0$.

Proof. See Appendix A. □

Figure 3 plots the expected firm profit and expected consumer surplus as functions of transaction costs in the financial markets. Proposition 3 and the left panel of Figure 3 show that the expected firm profit decreases with transaction costs. This indicates the negative externality of financial transaction costs to the firm. As financial transaction costs increase, less information about the consumer preference shock can be inferred from the futures price. Consequently, the firm has less ability to predict product demand, which leads to less efficient production decisions. Consequently, its profit declines.

Proposition 4 (Transaction costs and consumer surplus)**.** *The unconditional expectation of consumer surplus can be expressed as $E[C] = E[U - PQ] = \frac{1}{2}E[\Pi]$, where $\Pi = PQ - aQ$ is the firm's profit. Given the firm's disclosure policy τ_η and the proportion of informed investors μ, the expected consumer surplus decreases with financial transaction costs, i.e., $\frac{\partial E[C]}{\partial c} < 0$.*

Proof. See Appendix A. □

Proposition 4 shows that the expected consumer surplus is proportional to expected firm profit. Since expected firm profit decreases with transaction costs (see Proposition 3), the expected consumer surplus also decreases with transaction costs (see also the right panel of Figure 3). Propositions 3 and 4 suggest that financial transaction costs have negative impacts on both the producer and consumer in the product market.

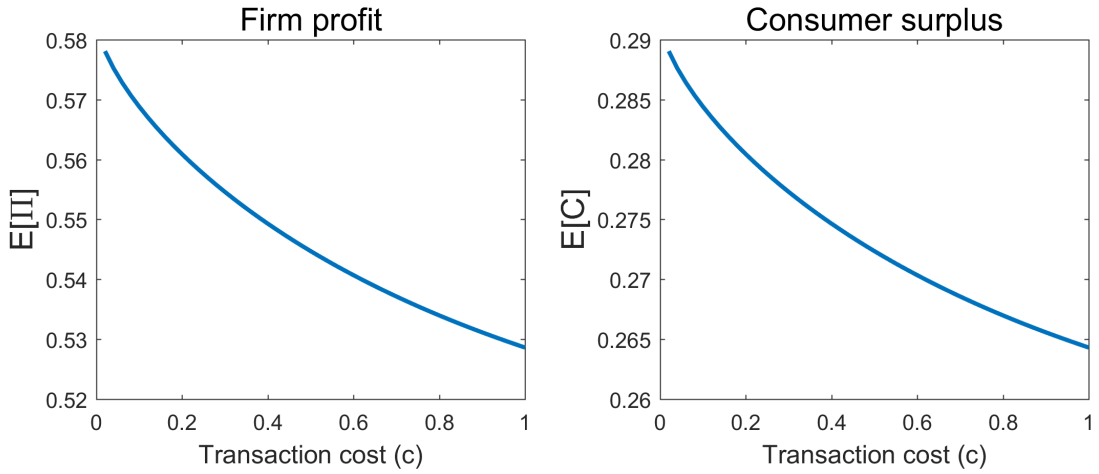


Figure 3: Impact of transaction costs on firm profit and consumer surplus.
This figure plots expected firm profit $E[\Pi]$ and expected consumer surplus $E[C]$ as functions of transaction costs in the financial market c. The parameter values are: $\tau_\varepsilon = 3$, $\tau_a = 1$, $\tau_x = 1$, $\tau_n = 100$, $\gamma = 0.01$, $\bar{a} = 1$, $\bar{\varepsilon} = 2$, $\mu = 0.7$, and $\tau_\eta = 1$.

Proposition 5 (Transaction costs and product market stability)**.** *The unconditional variance of the product price $Var[P]$ can be expressed as*

$$Var[P] = \frac{\tau_\varepsilon^{-1}\tau_p^2 + 5\tau_p + 4\tau_\varepsilon}{4(\tau_\varepsilon + \tau_p)^2} + \frac{1}{4}\tau_a^{-1}. \tag{16}$$

Notably, given the firm's information disclosure policy τ_η and the proportion of informed investors μ, the product price variance increases with transaction costs, i.e., $\frac{\partial Var[P]}{\partial c} > 0$.

Proof. See Appendix A. □

Figure 4 plots the product price volatility and futures price volatility as functions of the financial market transaction costs. Proposition 5 and Figure 4 indicate that increases in financial market transaction costs tend to destabilize the product market. Recall that the product price can be expressed as $P = \varepsilon - Q$. Therefore, the variance of the product price can be decomposed as $Var[P] = Var[\varepsilon] + Var[Q] - 2Cov[\varepsilon, Q]$. It can be observed that the variance of the product price is negatively affected by the covariance between product demand shock and product supply by the firm. This implies that if the firm could better adjust its product supply in response to changes in product demand due to consumer preference shocks, the product market would be more stable. However, an increase in financial transaction costs reduces futures price informativeness, thus compromising the firm's ability to infer information about product demand. As a result, the firm's production decision becomes less responsive to consumer demand (indicated by a lower $Cov[\varepsilon, Q]$), thus destabilizing the product market.

4 Transaction costs and information acquisition

In this section, we endogenize investors' information acquisition decisions to conduct robustness checks on our main theoretical predictions in Section 3 and further investigate the impact of financial transaction costs on investors' information acquisition decisions.

First we solve for the equilibrium proportion of informed investors. Assume that, initially, at $t = 0$, each rational investor has the same amount of wealth W_0. At $t = 0.5$, if the investor i chooses to acquire a private signal x_i, s/he pays an information cost b, which reduces his/her wealth to $W_{0i} = W_0 - b$, and becomes informed at $t = 1$. In contrast, if

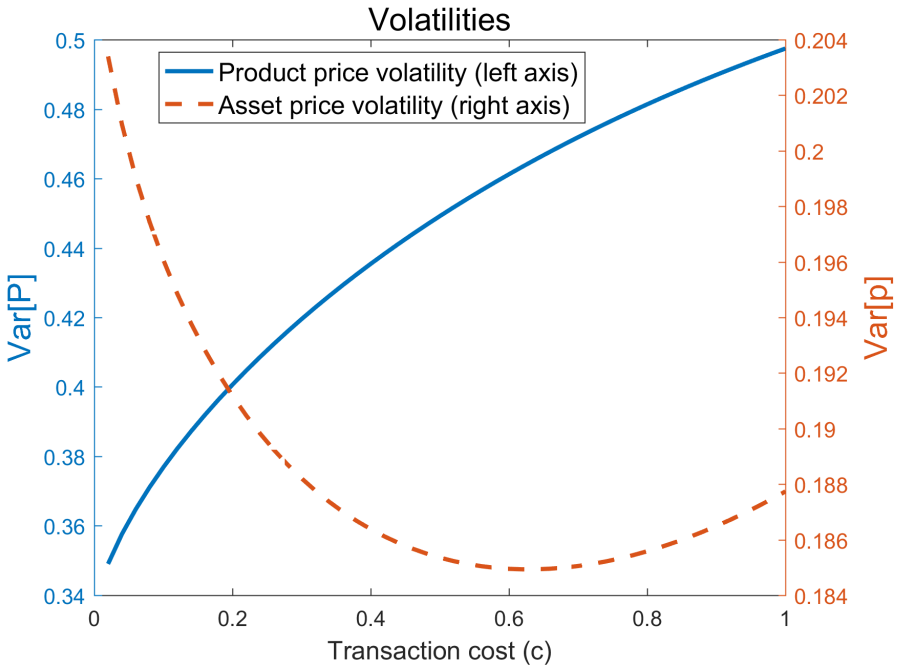


Figure 4: Impact of transaction costs on financial and real market volatilities.
This figure plots the product price volatility $Var[P]$ and futures price volatility $Var[p]$ as functions of the financial market transaction cost parameter c. The parameter values are: $\tau_\varepsilon = 3$, $\tau_a = 1$, $\tau_x = 1$, $\tau_n = 100$, $\gamma = 0.01$, $\bar{a} = 1$, $\bar{\varepsilon} = 2$, $\mu = 0.7$, and $\tau_\eta = 1$.

s/he remains uninformed, his/her wealth remains unchanged, i.e., $W_{0i} = W_0$. In the spirit of Grossman & Stiglitz (1980), in equilibrium, an investor should be indifferent between being informed and remaining uninformed. Otherwise, the proportion of informed investors will increase or decrease. Mathematically, the equilibrium proportion of informed investors is determined by:

$$E[E[u(W_i)|\mathcal{F}_i^{IN}]]|_\mu - E[E[u(W_i)|\mathcal{F}_i^{UN}]]|_\mu = 0, \tag{17}$$

where $E[E[u(W_i)|\mathcal{F}_i]]|_\mu$ is the ex ante utility of the investor i given that the proportion of informed investors is μ. Based on Eq. (17), we have the following proposition that characterizes the equilibrium proportion of informed investors.

Proposition 6 (Proportion of informed investors)**.** *Assume that the firm's information disclosure policy τ_η is given. An investor's perceived variance of the futures payoff $Var[P|\mathcal{F}_i]$ is a function of the proportion of informed investors μ. Define*

$$\Delta(\mu) = \sqrt{\frac{c + \gamma Var[P|\mathcal{F}_i^{UN}]}{c + \gamma Var[P|\mathcal{F}_i^{IN}]}} - e^{\gamma b}. \tag{18}$$

If $\Delta(0) > 0$ and $\Delta(1) < 0$, then the equilibrium proportion of informed investors is determined by $\Delta(\mu) = 0$.

Proof. See Appendix A. □

Solving Equations $\Delta(\mu) = 0$ and (11) simultaneously (taking the firm's disclosure policy τ_η as given), the equilibrium proportion of informed investors and futures price informativeness can thus be derived. We first study the impacts of transaction costs on the futures price and real economy when the investors' information choice is endogenous.

We show that the qualitative results are the same as those in Section 3.

4.1 Impacts of transaction costs with endogenous information

Proposition 7 (The impact of transaction costs on futures price informativeness when information acquisition is endogenous)**.** *Assume that* (i) *the firm's information disclosure policy* τ_η *is exogenously given, and* (ii) $\Delta(0) > 0$ *and* $\Delta(1) < 0$*. Then the futures price informativeness decreases with transaction costs, i.e.,* $\frac{\partial(\beta_1/\beta_3)}{\partial c} < 0$*. Note that the equilibrium proportion of informed investors* μ *and futures price informativeness* β_1/β_3 *are determined by* $\Delta(\mu) = 0$ *and Eq.* (11)*.*

Proof. See Appendix A. □

Proposition 7 shows that when the proportion of informed investors is endogenous, the futures price informativeness still decreases with transaction costs, as in the exogenous information scenario. Since transaction costs affect the real economy only through futures price informativeness, the impact of transaction costs on the product market remains the same as that in the setting of exogenous information acquisition decisions. Proposition 8 and Figure 5 show the results.

Proposition 8 (The impacts of transaction costs on the product market when information acquisition is endogenous)**.** *If the firm's information disclosure policy* τ_η *is exogenously given, and the equilibrium proportion of informed investors* μ *and futures price informativeness* β_1/β_3 *are determined by* $\Delta(\mu) = 0$ *and Eq.* (11)*, then higher financial transaction costs decrease the expected firm profit and consumer surplus while increasing the product price volatility, i.e.,* $\frac{\partial E[\Pi]}{\partial c} < 0$*,* $\frac{\partial E[C]}{\partial c} < 0$*, and* $\frac{\partial Var[P]}{\partial c} > 0$*, where* $\Pi = PQ - aQ$ *and* $C = U(\varepsilon, Q) - PQ$*.*

Proof. See Appendix A. □

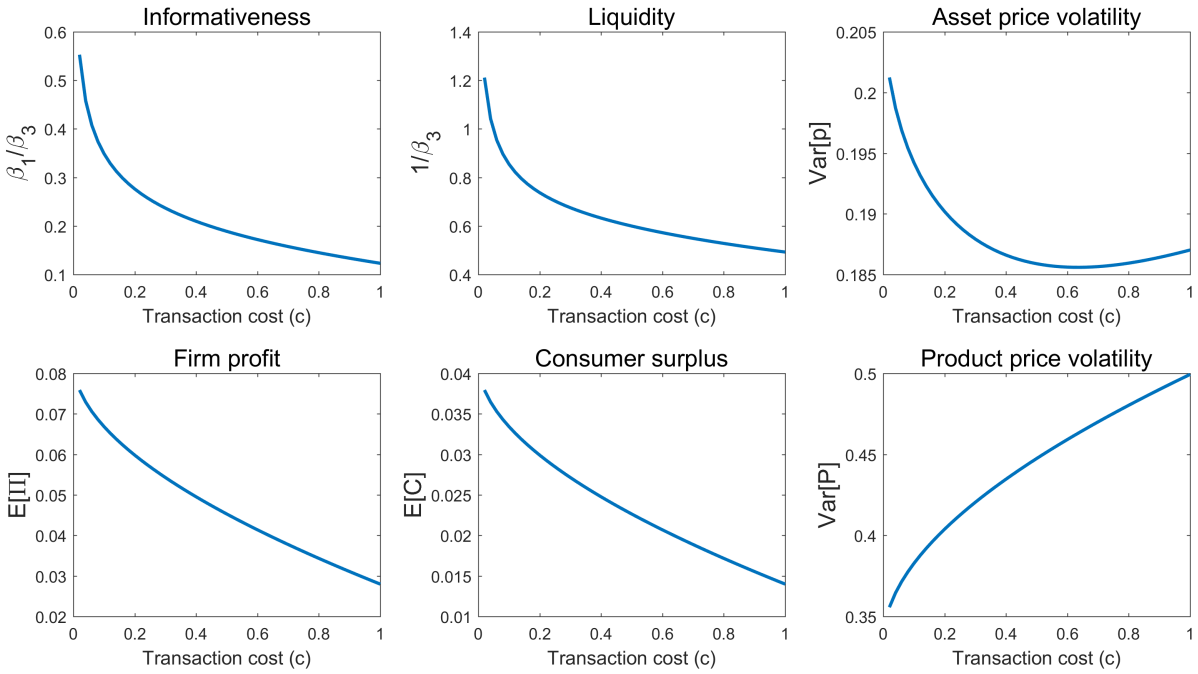


Figure 5: Market equilibrium under endogenous information acquisition decisions. This figure plots the equilibrium futures price informativeness β_1/β_3, liquidity $1/\beta_3$, futures price volatility $Var[p]$, expected firm profit $E[\Pi]$, expected consumer surplus $E[C]$, and product price volatility $Var[P]$ as functions of the financial market transaction cost parameter c. The parameter values are: $\tau_\varepsilon = 3$, $\tau_a = 1$, $\tau_x = 1$, $\tau_n = 100$, $\gamma = 0.01$, $\bar{a} = 1$, $\bar{\varepsilon} = 2$, $b = 0.02$, and $\tau_\eta = 1$.

4.2 Transaction costs and information acquisition decisions

In this subsection, we further explore the impact of transaction costs on investors' information acquisition decisions.

Proposition 9 (The impacts of transaction costs and price signal precision on the benefit of being informed)**.** *The net benefit for an investor to be informed Δ is defined in Eq.* (18)*. Notably, Δ can be expressed as a function of the transaction cost parameter c and the price signal precision τ_p, i.e., $\Delta = \Delta(c, \tau_p)$. The benefit of being informed decreases with the price signal precision, i.e., $\frac{\partial \Delta}{\partial \tau_p} < 0$, and also decreases with transaction costs, i.e., $\frac{\partial \Delta}{\partial c} < 0$.*

Proof. See Appendix A. □

Proposition 9 shows that the benefit of being informed decreases with the price signal precision. Intuitively, when an investor can extract other investors' private signals more precisely from the futures price, s/he has less incentive to acquire the costly private signal him/herself. In other words, information acquisition in the financial market exhibits "strategic substitutability", consistent with the findings of previous studies (e.g., Grossman & Stiglitz, 1980). Proposition 9 also demonstrates that higher transaction costs decrease investors' incentives to become informed. The intuition behind this is that informed traders incur transaction costs when trading on their private signals. Higher transaction costs directly reduce the benefits of becoming informed, thereby discouraging investors from acquiring private information.

Recall that transaction cost parameter c reduces futures price informativeness β_1/β_3 and, consequently, lowers the price signal precision $\tau_p = (\frac{\beta_1}{\beta_3})^2 \tau_n$ (see Proposition 1). Therefore, in addition to the direct negative impact on the benefit of being informed, transaction costs can also increase the net benefit of being informed by reducing the price signal

precision. Mathematically, given the proportion of informed investors μ, the derivative of the benefit of being informed $\Delta = \Delta(c, \tau_p(c))$ with respect to the transaction cost parameter c can be decomposed as

$$\frac{d\Delta}{dc} = \underbrace{\frac{\partial \Delta}{\partial c}}_{\text{Trading loss effect } (<0)} + \underbrace{\frac{\partial \Delta}{\partial \tau_p}\frac{d\tau_p}{dc}}_{\text{Strategic substitutability } (>0)}. \tag{19}$$

Therefore, whether transaction costs ultimately decrease or increase investors' incentives to be informed depends on the dominant effect. Consequently, in equilibrium, the proportion of informed investors is non-monotonic in the transaction cost parameter c (as shown in Figure 6).

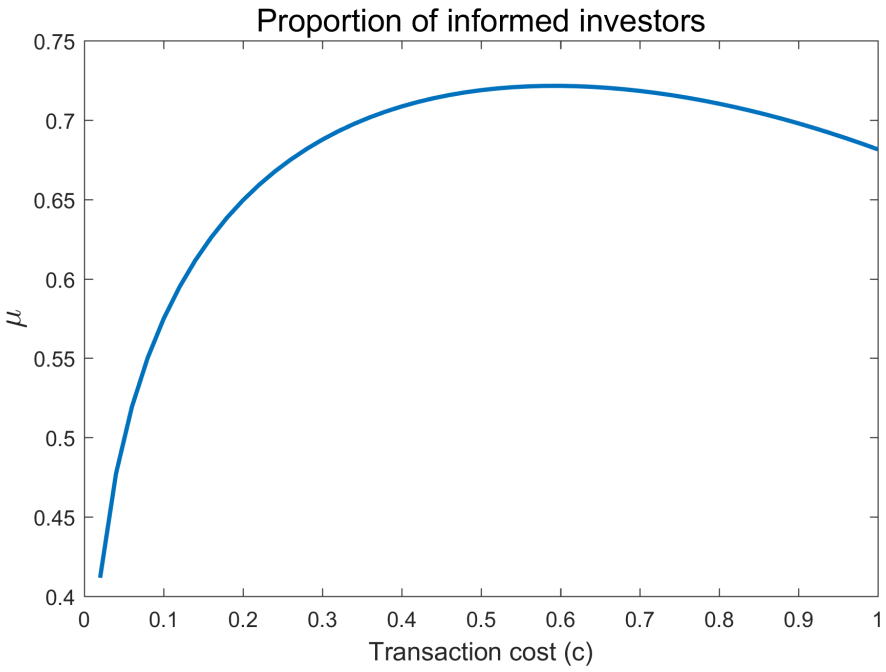


Figure 6: Impact of transaction costs on investors' information acquisition decisions.
This figure plots the equilibrium proportion of informed investors μ as a function of the financial transaction cost parameter c. The parameter values are: $\tau_\varepsilon = 3$, $\tau_a = 1$, $\tau_x = 1$, $\tau_n = 100$, $\gamma = 0.01$, $\bar{a} = 1$, $\bar{\varepsilon} = 2$, $b = 0.02$, and $\tau_\eta = 1$.

5 Transaction costs and information disclosure policy

In this section, we further extend our model by endogenizing the firm's information disclosure policy τ_η. We assume that, before investors make their information acquisition decisions, the firm first selects and announces its disclosure policy (i.e., the precision of the public signal it will disclose later), which maximizes its unconditional expected profit net of the cost of disclosure,

$$\max_{\tau_\eta} E[\Pi] - \frac{k}{2}\tau_\eta^2, \tag{20}$$

where $k > 0$ is the information disclosure cost parameter, and $\Pi = PQ - aQ$ is the firm's profit.

5.1 Information disclosure policy and firm's profit

Before we solve problem (20) and investigate the impact of transaction costs on the firm's disclosure policy, we first show that the firm has incentive to disclose. If investors know that the public signal is precise (based on the firm's pre-specified information disclosure policy), they will perceive a lower risk regarding the payoff of the futures contract and trade more aggressively based on their private signals about the consumer preference shock. This, in turn, makes the futures price more informative about the product demand. As a result, the firm can better infer product demand from the futures price and make more efficient production decisions, thus increasing its profit. The following proposition formalizes this idea.

Proposition 10 (Disclosure policy, price informativeness, and firm profit)**.** *Assume that* $\Delta(0) > 0$ *and* $\Delta(1) < 0$*, where* $\Delta(\cdot)$ *is defined by Eq.* (18)*, so that the equilibrium proportion of*

informed investors always satisfies $\mu \in (0, 1)$. *Then the futures price informativeness increases with the firm's information disclosure policy* (*i.e., the precision of the released public signal*), $\frac{\partial(\beta_1/\beta_3)}{\partial \tau_\eta} > 0$. *Notably, the expected firm profit also increases with the information disclosure policy,* $\frac{\partial E[\Pi]}{\partial \tau_\eta} > 0$.

Proof. See Appendix A. □

Proposition 10 shows that the firm's ex-ante expected profit increases with the disclosure precision, which indicates that the firm is incentivized to disclose information about its production cost. Moreover, in the numerical examples, we find that the expected firm profit is concave in its information disclosure policy (see left panel of Figure 7), which indicates that problem (20) may have a unique solution (see right panel of Figure 7).

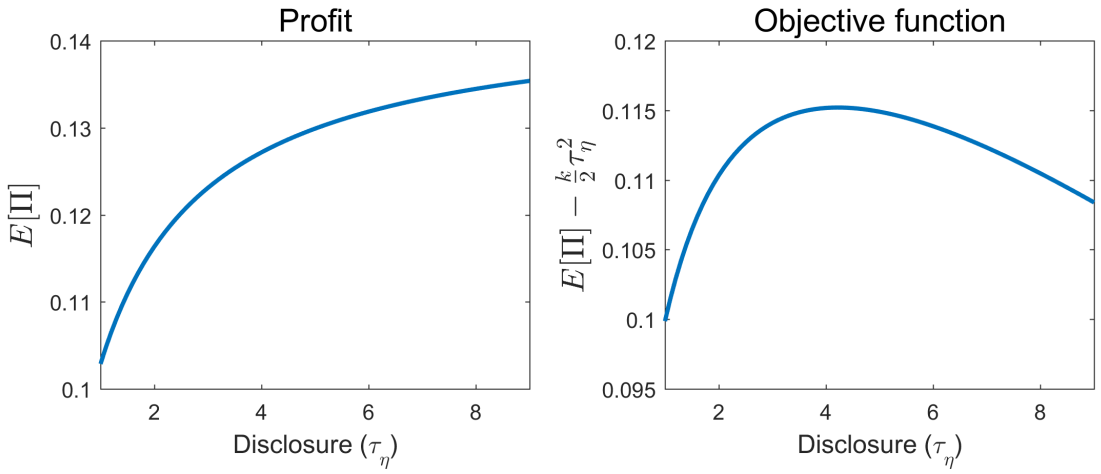


Figure 7: Impact of information disclosure policy.
This figure plots the expected firm profit $E[\Pi]$ and the firm's objective function $E[\Pi] - \frac{k}{2}(\tau_\eta)^2$ as functions of the public signal precision τ_η. The parameter values are: $\tau_\varepsilon = 1$, $\tau_a = 1$, $\tau_x = 10$, $\tau_n = 1$, $\gamma = 2$, $\bar{a} = 1$, $\bar{\varepsilon} = 2$, $b = 0.2$, and $k = 0.006$.

5.2 Transaction costs and disclosure

The complexity of the expression for the expected firm profit $E[\Pi]$ as a function of disclosure policy τ_η prevents us from analytically characterizing the equilibrium disclosure. Instead, we solve Problem (20) numerically. Figure 8 plots the optimal level of disclosure τ_η as a function of the transaction cost parameter c. Figure 9 plots the equilibrium market variables as functions of the transaction cost parameter c.

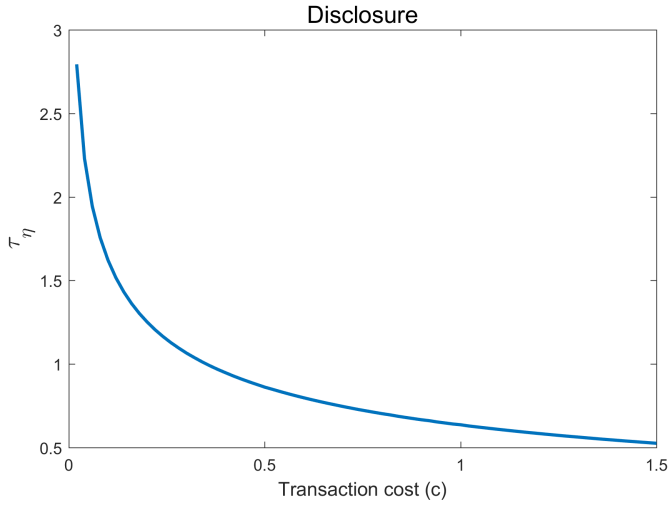


Figure 8: The impact of transaction costs on information disclosure policy.
This figure plots the optimal level of information disclosure policy τ_η as a function of the financial market transaction cost parameter c, when the information acquisition is endogenous. The parameter values are: $\tau_\varepsilon = 1$, $\tau_a = 1$, $\tau_x = 1$, $\tau_n = 55$, $\gamma = 0.01$, $\bar{a} = 1$, $\bar{\varepsilon} = 2$, $b = 0.05$, and $c = 1.5$, $k = 0.0001$.

Figure 8 shows that the firm's commitment to precise disclosure (disclosure policy) decreases as the financial market transaction costs increase. The reason for this result is based on Proposition 10 where the firm is motivated to commit to provide a more precise public signal to attract informed trading, which enables the firm to infer investors' private signals on customer demand shocks. However, higher transaction costs reduce the profitability of

informed trading, making informed investors less responsive to the firm's disclosure policy. As a result, the firm's marginal benefits of disclosure (i.e., releasing a precise public signal to attract informed trading and strengthen the market feedback effect) decreases. Consequently, the firm has less incentive to pay for disclosing a more precise public signal. This result implies that financial market transaction costs may negatively affect firm transparency. Finally, Figure 9 plots the equilibrium futures price informativeness, liquidity, futures price volatility, expected firm profit, expected consumer surplus, and product price volatility as functions of the financial market transaction cost parameter when both the information acquisition and disclosure are endogenous. The figure shows that when the firm's information disclosure decision is endogenous, the impact of transaction costs on both the financial and real market volatilities is consistent with our baseline theoretical results discussed in Section 3.

6 Conclusion

Corporate outsiders may access private information unknown to corporate insiders (Dye & Sridhar, 2002; Goldstein, 2023; Luo, 2005), particularly as their analytical capacities have been strengthened by recent developments in alternative data and artificial intelligence (Chi et al., 2025; Jagtiani & Lemieux, 2019; Zhu, 2019). To reflect this trend, we revisit the impact of transaction costs on both financial and real market volatilities through two model updates. First, financial markets can aggregate both public information released by product-producing firms (insiders) and private information unknown to insiders but acquired by informed investors from external sources. Second, producing firms can extract private information from financial market signals to guide their produc-

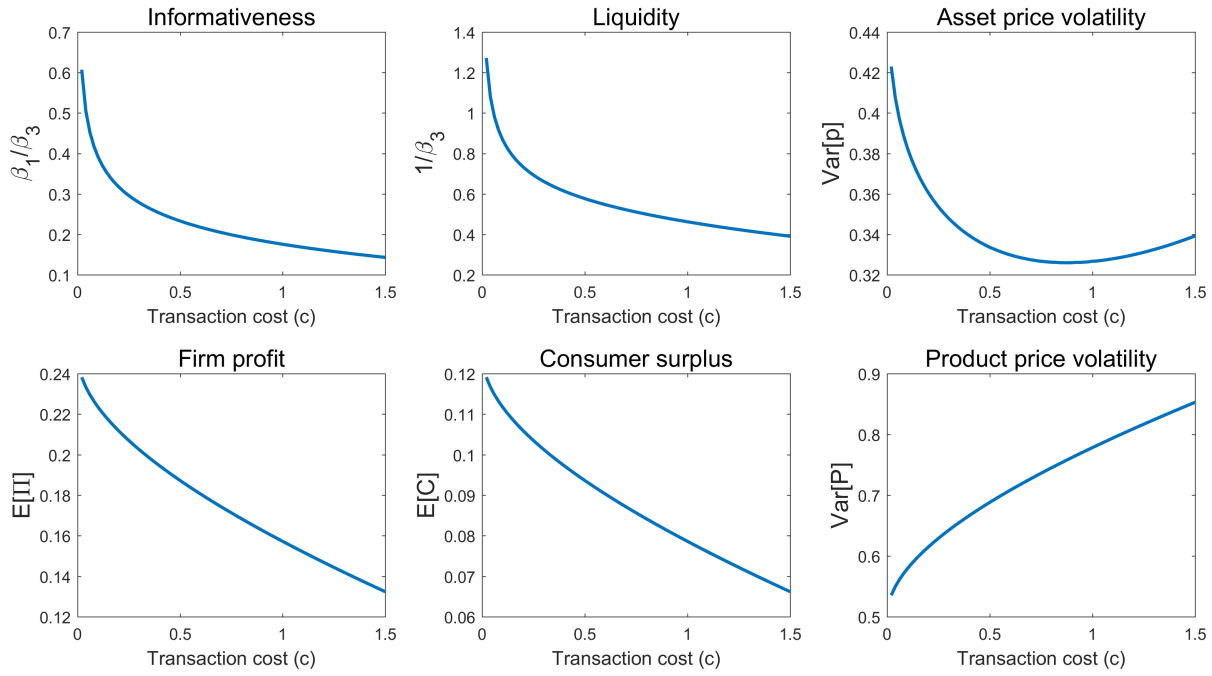


Figure 9: Market equilibrium under endogenous disclosure policy.
This figure plots the equilibrium futures price informativeness β_1/β_3, liquidity $1/\beta_3$, futures price volatility $Var[p]$, expected firm profit $E[\Pi]$, expected consumer surplus $E[C]$, and product price volatility $Var[P]$ as functions of the financial market transaction cost parameter c, when both the information acquisition and disclosure are endogenous. The parameter values are: $\tau_\varepsilon = 1$, $\tau_a = 1$, $\tau_x = 1$, $\tau_n = 55$, $\gamma = 0.01$, $\bar{a} = 1$, $\bar{\varepsilon} = 2$, $b = 0.05$, and $c = 1.5$, $k = 0.0001$.

tion decisions.

The theoretical model predicts that, in futures markets (i.e., financial markets), higher transaction costs reduce information-driven market volatility by slowing price discovery (the information effect), but increase liquidity-driven market volatility by reducing market liquidity (the liquidity effect). When transaction costs are low (high), the information effect (liquidity effect) dominates. In product markets (i.e., real markets), higher financial market transaction costs monotonically increase product price volatility by limiting managerial learning from the financial market, thereby exacerbating mismatches between realized commodity demand and supply. Additionally, we examine scenarios where investors' information acquisition decisions and the firm's information disclosure policy are endogenous, which provides robust predictions and offers further insights into the information discovery process.

A Proofs

A.1 Proof of Proposition 1

Proof. Using Bayes' rule, an informed investor's conditional expectation of the futures payoff is:

$$\begin{aligned} E[P|\mathcal{F}_i^{IN}] &= E[\varepsilon|x_i,\tilde{p}] - \frac{1}{2}E[\varepsilon|\tilde{p}] + \frac{1}{2}E[a|s] \\ &= \frac{\tau_\varepsilon\bar{\varepsilon}+\tau_x x_i+\tau_p\tilde{p}}{\tau_\varepsilon+\tau_x+\tau_p} - \frac{1}{2}\frac{\tau_\varepsilon\bar{\varepsilon}+\tau_p\tilde{p}}{\tau_\varepsilon+\tau_p} + \frac{1}{2}\frac{\tau_a\bar{a}+\tau_\eta s}{\tau_a+\tau_\eta}. \end{aligned} \tag{21}$$

His/her conditional variance of the futures payoff is:

$$Var[P|\mathcal{F}_i^{IN}] = Var[\varepsilon|\mathcal{F}_i^{IN}] + \frac{1}{4}Var[a|\mathcal{F}_i^{IN}] = \frac{1}{\tau_\varepsilon+\tau_x+\tau_p} + \frac{1}{4(\tau_a+\tau_\eta)}. \tag{22}$$

Similarly, an uninformed investor's conditional expectation of the asset's payoff is:

$$E[P|\mathcal{F}^{UN}] = \frac{1}{2}E[\varepsilon|\tilde{p}] + \frac{1}{2}E[a|s] = \frac{1}{2}\frac{\tau_\varepsilon\bar{\varepsilon} + \tau_p\tilde{p}}{\tau_\varepsilon + \tau_p} + \frac{1}{2}\frac{\tau_a\bar{a} + \tau_\eta s}{\tau_a + \tau_\eta}, \tag{23}$$

and his/her conditional variance of the asset payoff is:

$$Var[P|\mathcal{F}^{UN}] = Var[\varepsilon|\mathcal{F}^{UN}] + \frac{1}{4}Var[a|\mathcal{F}^{UN}] = \frac{1}{\tau_\varepsilon + \tau_p} + \frac{1}{4(\tau_a + \tau_\eta)}. \tag{24}$$

By the law of large numbers, we have $\int_0^1 x_i di = \varepsilon + \int_0^1 e_i di = \varepsilon$. Therefore, we get:

$$\int_0^1 E[P|\mathcal{F}_i^{IN}]di = \frac{\tau_\varepsilon\bar{\varepsilon} + \tau_x\varepsilon + \tau_p\tilde{p}}{\tau_\varepsilon + \tau_x + \tau_p} - \frac{1}{2}\frac{\tau_\varepsilon\bar{\varepsilon} + \tau_p\tilde{p}}{\tau_\varepsilon + \tau_p} + \frac{1}{2}\frac{\tau_a\bar{a} + \tau_\eta s}{\tau_a + \tau_\eta}. \tag{25}$$

Substituting the expressions for $\int_0^1 E[P|\mathcal{F}_i^{IN}]di$ and $E[P|\mathcal{F}^{UN}]$ into the implied price function, Eq. (9), and rearranging terms, we get:

$$\begin{aligned}
p = &\left\{\frac{\omega_{IN}}{\omega_{IN}+\omega_{UN}}\left[\frac{\tau_x+\tau_p}{\tau_\varepsilon+\tau_x+\tau_p} - \frac{1}{2}\frac{\tau_p}{\tau_\varepsilon+\tau_p}\right] + \frac{\omega_{UN}}{\omega_{IN}+\omega_{UN}}\left[\frac{1}{2}\frac{\tau_p}{\tau_\varepsilon+\tau_p}\right]\right\}\varepsilon \\
&+ \left\{\frac{\omega_{IN}}{\omega_{IN}+\omega_{UN}}\left[\frac{1}{2}\frac{\tau_\eta}{\tau_a+\tau_\eta}\right] + \frac{\omega_{UN}}{\omega_{IN}+\omega_{UN}}\left[\frac{1}{2}\frac{\tau_\eta}{\tau_a+\tau_\eta}\right]\right\}s \\
&+ \left\{\frac{\omega_{IN}}{\omega_{IN}+\omega_{UN}}\left[\frac{\tau_p(\frac{\beta_1}{\beta_3})}{\tau_\varepsilon+\tau_x+\tau_p} - \frac{1}{2}\frac{\tau_p(\frac{\beta_1}{\beta_3})}{\tau_\varepsilon+\tau_p}\right] + \frac{\omega_{UN}}{\omega_{IN}+\omega_{UN}}\left[\frac{1}{2}\frac{\tau_p(\frac{\beta_1}{\beta_3})}{\tau_\varepsilon+\tau_p}\right] + \frac{1}{\omega_{IN}+\omega_{UN}}\right\}n \\
&+ \left\{\frac{\omega_{IN}}{\omega_{IN}+\omega_{UN}}\left[\frac{\tau_\varepsilon\bar{\varepsilon}}{\tau_\varepsilon+\tau_x+\tau_p} - \frac{1}{2}\frac{\tau_\varepsilon\bar{\varepsilon}}{\tau_\varepsilon+\tau_p} + \frac{1}{2}\frac{\tau_a\bar{a}}{\tau_a+\tau_\eta}\right] + \frac{\omega_{UN}}{\omega_{IN}+\omega_{UN}}\left[\frac{1}{2}\frac{\tau_\varepsilon\bar{\varepsilon}}{\tau_\varepsilon+\tau_p} + \frac{1}{2}\frac{\tau_a\bar{a}}{\tau_a+\tau_\eta}\right]\right\}.
\end{aligned} \tag{26}$$

Comparing the above expression with the conjectured price function $p = \beta_0 + \beta_1\varepsilon + \beta_2 s + \beta_3 n$, we know that:

$$\frac{\beta_1}{\beta_3} = \frac{\frac{\omega_{IN}}{\omega_{IN}+\omega_{UN}}\left[\frac{\tau_x+\tau_p}{\tau_\varepsilon+\tau_x+\tau_p} - \frac{1}{2}\frac{\tau_p}{\tau_\varepsilon+\tau_p}\right] + \frac{\omega_{UN}}{\omega_{IN}+\omega_{UN}}\left[\frac{1}{2}\frac{\tau_p}{\tau_\varepsilon+\tau_p}\right]}{\frac{\omega_{IN}}{\omega_{IN}+\omega_{UN}}\left[\frac{\tau_p(\beta_1/\beta_3)}{\tau_\varepsilon+\tau_x+\tau_p} - \frac{1}{2}\frac{\tau_p(\beta_1/\beta_3)}{\tau_\varepsilon+\tau_p}\right] + \frac{\omega_{UN}}{\omega_{IN}+\omega_{UN}}\left[\frac{1}{2}\frac{\tau_p(\beta_1/\beta_3)}{\tau_\varepsilon+\tau_p}\right] + \frac{1}{\omega_{IN}+\omega_{UN}}}. \tag{27}$$

Multiplying both sides by the denominator of the right-side of the above equation, and rearranging terms, we can derive Eq. (11).

Denote $\xi \equiv \frac{\beta_1}{\beta_3}$. Then Eq. (11) can be expressed as $\xi = g(\xi, c)$, where:

$$g(\xi, c) = \frac{\mu\tau_x}{c(\tau_\varepsilon + \tau_x + \xi^2\tau_n) + \gamma(1 + \frac{\tau_\varepsilon+\tau_x+\xi^2\tau_n}{\tau_a+\tau_\eta})}. \tag{28}$$

Given c, the equilibrium price informativeness is determined by $\xi = g(\xi, c)$. Notice that $g(0, c) > 0$ and $\lim_{\xi\to+\infty} g(\xi, c) = 0$. Moreover, we can see that $\frac{\partial g(\xi,c)}{\partial \xi} < 0$. Define $h(\xi, c) \equiv \xi - g(\xi, c)$. It follows immediately from the properties of g that $h(0, c) < 0$, $\lim_{\xi\to+\infty} h(\xi, c) = +\infty$, and $\frac{\partial h(\xi,c)}{\partial \xi} > 0$. Therefore, by the intermediate value theorem, we know that there exists a unique $\xi \in (0, +\infty)$ such that $h(\xi, c) = 0$. In other words, the equilibrium is unique.

By inspection, we know that $\frac{\partial g(\xi,c)}{\partial c} < 0$, so $\frac{\partial h(\xi,c)}{\partial c} > 0$. Denote the equilibrium price informativeness as a function of c, i.e., $\xi = \xi(c)$, so we get $h(\xi(c), c) = 0$. Taking derivatives with respect to c on both sides, we have $h_\xi(\xi(c), c)\xi'(c) + h_c(\xi(c), c) = 0$, where $h_\xi(\xi, c)$ is the partial derivative of $h(\xi, c)$ with respect to its first argument, $h_c(\xi, c)$ is the partial derivative of $h(\xi, c)$ with respect to its second argument, and $\xi'(c)$ is the derivative of $\xi(c)$ with respect to c. Therefore, we have $\xi'(c) = -\frac{h_c(\xi(c),c)}{h_\xi(\xi(c),c)}$. Since $h_\xi > 0$ and $h_c > 0$, we know that $\xi'(c) < 0$, which completes the proof. □

A.2 Proof of Proposition 2

Proof. When $\mu = 1$ and $\tau_a \to +\infty$, the derivative of β_1 with respect to τ_p is:

$$\frac{\partial\beta_1}{\partial\tau_p} = \frac{\frac{\tau_\varepsilon}{2}\tau_p^2 + \tau_\varepsilon(\tau_\varepsilon - \tau_x)\tau_p + \tau_\varepsilon(\frac{1}{2}\tau_\varepsilon^2 - \frac{1}{2}\tau_x^2 - \tau_\varepsilon\tau_x)}{[\tau_p^2 + (2\tau_\varepsilon + \tau_x)\tau_p + \tau_\varepsilon(\tau_\varepsilon + \tau_x)]^2}. \tag{29}$$

Therefore, we have $\text{sgn}(\frac{\partial \beta_1}{\partial \tau_p}) = \text{sgn}[g(\tau_p)]$, where $g(\tau_p) = \frac{\tau_\varepsilon}{2}\tau_p^2 + \tau_\varepsilon(\tau_\varepsilon - \tau_x)\tau_p + \tau_\varepsilon(\frac{1}{2}\tau_\varepsilon^2 - \frac{1}{2}\tau_x^2 - \tau_\varepsilon\tau_x)$. Since $[\tau_\varepsilon(\tau_\varepsilon - \tau_x)]^2 - 4[\frac{\tau_\varepsilon}{2}][\tau_\varepsilon(\frac{1}{2}\tau_\varepsilon^2 - \frac{1}{2}\tau_x^2 - \tau_\varepsilon\tau_x)] = 2\tau_\varepsilon^2\tau_x^2 > 0$, we know that $g(\tau_p) = 0$ has two real roots. The larger solution to this equation is:

$$\bar{\tau}_p = \frac{-\tau_\varepsilon(\tau_\varepsilon - \tau_x) + \sqrt{2\tau_\varepsilon^2\tau_x^2}}{\tau_\varepsilon} = (1+\sqrt{2})\tau_x - \tau_\varepsilon. \tag{30}$$

Observe that if $\bar{\tau}_p < 0$, then $g(\tau_p) > g(\bar{\tau}_p) = 0$, $\forall \tau_p \geq 0$. Recall that $\text{sgn}(\frac{\partial \beta_1}{\partial \tau_p}) = \text{sgn}[g(\tau_p)]$, and that $\tau_p = (\beta_1/\beta_3)^2\tau_n \geq 0$ in equilibrium. Therefore, a sufficient condition for $\frac{\partial \beta_1}{\partial \tau_p} > 0$ is $\bar{\tau}_p < 0$. Recall from Proposition 1 that $\frac{\partial \tau_p}{\partial c} < 0$. Therefore, if $(1+\sqrt{2})\tau_x < \tau_\varepsilon$, we have $\bar{\tau}_p < 0$, so $\frac{\partial \beta_1}{\partial c} = \frac{\partial \beta_1}{\partial \tau_p}\frac{\partial \tau_p}{\partial c} < 0$. Since $Var[\beta_1\varepsilon] = \beta_1^2\tau_\varepsilon^{-1}$, we immediately get $\frac{\partial Var[\beta_1\varepsilon]}{\partial c} < 0$. □

A.3 Proof of Proposition 3

Proof. Substituting the firm's optimal output decision $Q = \frac{1}{2}E[\varepsilon|s,p] - \frac{1}{2}a$ into the objective function, Eq. (2), we get:

$$\begin{aligned} E[\Pi|a,s,p] &= (E[\varepsilon|s,p] - a)\left(\frac{1}{2}E[\varepsilon|s,p] - \frac{1}{2}a\right) - \left(\frac{1}{2}E[\varepsilon|s,p] - \frac{1}{2}a\right)^2 \\ &= \left(\frac{1}{2}E[\varepsilon|p] - \frac{1}{2}a\right)\left(E[\varepsilon|p] - a - \frac{1}{2}E[\varepsilon|p] + \frac{1}{2}a\right) \\ &= \frac{1}{4}\left\{(E[\varepsilon|p])^2 + a^2 - 2aE[\varepsilon|p]\right\}. \end{aligned} \tag{31}$$

We can calculate that:

$$(E[\varepsilon|p])^2 = \left(\frac{\tau_\varepsilon\bar{\varepsilon} + \tau_p\tilde{p}}{\tau_\varepsilon + \tau_p}\right)^2 = \frac{(\tau_\varepsilon\bar{\varepsilon})^2 + (\tau_p\tilde{p})^2 + 2\tau_\varepsilon\bar{\varepsilon}\tau_p\tilde{p}}{(\tau_\varepsilon + \tau_p)^2}. \tag{32}$$

Therefore, we have:

$$E\left[(E[\varepsilon|p])^2\right] = \frac{(\tau_\varepsilon\bar{\varepsilon})^2 + \tau_p^2(\tau_\varepsilon^{-1} + \tau_p^{-1} + \bar{\varepsilon}^2) + 2\tau_\varepsilon\bar{\varepsilon}^2\tau_p}{(\tau_\varepsilon + \tau_p)^2}, \tag{33}$$

using the fact that $E[\tilde{p}^2] = Var[\tilde{p}] + (E[\tilde{p}])^2 = \tau_\varepsilon^{-1} + \tau_p^{-1} + \bar{\varepsilon}^2$. By the above expressions and the law of iterated expectations, the firm's ex ante expected profit can be expressed as:

$$\begin{aligned} E[\Pi] &= E[E[\Pi|a,s,p]] \\ &= \frac{1}{4}\left\{E\left[(E[\varepsilon|p])^2\right] + E\left[a^2\right] - 2E\left[aE[\varepsilon|p]\right]\right\} \\ &= \frac{1}{4}\left\{\frac{(\tau_\varepsilon\bar{\varepsilon})^2 + \tau_p^2(\tau_\varepsilon^{-1} + \tau_p^{-1} + \bar{\varepsilon}^2) + 2\tau_\varepsilon\bar{\varepsilon}^2\tau_p}{(\tau_\varepsilon + \tau_p)^2} + \tau_a^{-1} + \bar{a}^2 - 2\bar{a}\bar{\varepsilon}\right\}. \end{aligned} \tag{34}$$

The derivative of $E[\Pi]$ with respect to τ_p, $\frac{\partial E[\Pi]}{\partial \tau_p}$, is:

$$\frac{[2(\tau_\varepsilon^{-1} + \bar{\varepsilon}^2)\tau_p + 1 + 2\tau_\varepsilon\bar{\varepsilon}^2](\tau_\varepsilon + \tau_p)^2 - 2[(\tau_\varepsilon^{-1} + \bar{\varepsilon}^2)\tau_p^2 + (1 + 2\tau_\varepsilon\bar{\varepsilon}^2)\tau_p + (\tau_\varepsilon\bar{\varepsilon})^2](\tau_\varepsilon + \tau_p)}{4(\tau_\varepsilon + \tau_p)^2}, \tag{35}$$

which is equal to $[2(\tau_\varepsilon + \tau_p)]^{-2} > 0$. Recall that we have $\frac{\partial \tau_p}{\partial c} < 0$ by Proposition 1. Therefore, by the chain rule, we get $\frac{\partial E[\Pi]}{\partial c} = \frac{\partial E[\Pi]}{\partial \tau_p}\frac{\partial \tau_p}{\partial c} < 0$. □

A.4 Proof of Proposition 4

Proof. Substituting the equilibrium product price $P = \varepsilon - Q$ into the expression for consumer surplus $C = \varepsilon Q - \frac{1}{2}Q^2 - PQ$, we get $C = \frac{1}{2}Q^2$. Recall that the equilibrium product quantity can be expressed as $Q = \frac{1}{2}(E[\varepsilon|p] - a)$. Therefore,

$$E[C] = \frac{1}{8}\left\{E\left[(E[\varepsilon|p])^2\right] + E\left[a^2\right] - 2E[aE[\varepsilon|p]]\right\} = \frac{1}{2}E[\Pi]. \tag{36}$$

where the last equality uses Eq. (31). By Proposition 3, we have $\frac{\partial E[C]}{\partial c} = \frac{1}{2}\frac{\partial E[\Pi]}{\partial c} < 0$. □

A.5 Proof of Proposition 5

Proof. Substituting the expression for $E[\varepsilon|a, s, p]$ into the expression for the equilibrium product price $P = \varepsilon + \frac{1}{2}a - \frac{1}{2}E[\varepsilon|a, s, p]$, we get:

$$P = \left[1 - \frac{\tau_p}{2(\tau_\varepsilon + \tau_p)}\right]\varepsilon + \frac{1}{2}a - \frac{\tau_p(\beta_3/\beta_1)}{2(\tau_\varepsilon + \tau_p)}n - \frac{\tau_\varepsilon \bar{\varepsilon}}{2(\tau_\varepsilon + \tau_p)}. \tag{37}$$

Recall that $\beta_1/\beta_3 = \sqrt{\tau_p/\tau_n}$. The unconditional variance of P is thus

$$Var[P] = \left[1 - \frac{\tau_p}{2(\tau_\varepsilon + \tau_p)}\right]^2 \tau_\varepsilon^{-1} + \frac{1}{4}\tau_a^{-1} + \frac{\tau_p\tau_n}{4(\tau_\varepsilon + \tau_p)^2}\tau_n^{-1}, \tag{38}$$

which yields Eq. (16). Direct calculation can show that

$$\frac{\partial Var[P]}{\partial \tau_p} = -\frac{3}{4(\tau_\varepsilon + \tau_p)^2} < 0. \tag{39}$$

By Proposition 1, we have $\frac{\partial \tau_p}{\partial c} < 0$. Therefore, by the chain rule, we get $\frac{\partial Var[P]}{\partial c} = \frac{\partial Var[P]}{\partial \tau_p}\frac{\partial \tau_p}{\partial c} > 0$. □

A.6 Proof of Proposition 6

Proof. Substituting the expression for an investor's optimal holding of the futures contract into her budget constraint, we get:

$$W_i = W_{0i} + \frac{E[P - p|\mathcal{F}_i]}{c + \gamma Var[P|\mathcal{F}_i]}(P - p) - \frac{c}{2}\left(\frac{E[P - p|\mathcal{F}_i]}{c + \gamma Var[P|\mathcal{F}_i]}\right)^2. \tag{40}$$

Using the law of iterated expectations, the moment generating function for normal random variables, and the above equation, the investor's ex ante expected utility can be expressed as:

$$\begin{aligned} E\left[-e^{-\gamma W_i}\right] &= E\left(E\left[-E^{-\gamma W_i}|\mathcal{F}_i\right]\right) \\ &= -e^{-\gamma W_{0i}+\frac{\gamma c}{2}\left(\frac{E[P-p|\mathcal{F}_i]}{c+\gamma Var[P|\mathcal{F}_i]}\right)^2} E\left[e^{-\gamma\frac{E[P-p|\mathcal{F}_i]}{c+\gamma Var[P|\mathcal{F}_i]}(P-p)}|\mathcal{F}_i\right] \\ &= -e^{-\gamma W_{0i}-\gamma(V_i^c)^{-1}X_i^2}, \end{aligned} \tag{41}$$

where $X_i = E[P-p|\mathcal{F}_i]$ and

$$\begin{aligned} V_i^c &= \left[\frac{-c}{2}\left(\frac{1}{c+\gamma Var[P|\mathcal{F}_i]}\right)^2 + \frac{1}{c+\gamma Var[P|\mathcal{F}_i]} - \frac{\gamma}{2}\frac{Var[P|\mathcal{F}_i]}{(c+\gamma Var[P|\mathcal{F}_i])^2}\right]^{-1} \\ &= (c+\gamma V_i)^2\left[\frac{-c}{2}+c+\gamma V_i - \frac{\gamma}{2}V_i\right]^{-1} \\ &= 2\left(c+\gamma V_i\right), \end{aligned} \tag{42}$$

where $V_i \equiv Var[P|\mathcal{F}_i]$. Let $V^o \equiv Var[X_i]$ and $V = Var[P-p]$. Notice that $V = V_o + V_i$, and that $\frac{X_i^2}{V^o}$ is non-central chi-squared distributed. Rearranging terms and using the moment generating function for non-central chi-squared random variables, we get:

$$U_i \equiv E\left[-e^{-\gamma W_i}\right] = -e^{-\gamma W_{0i}}\sqrt{\frac{V_i^c}{V_i^c+2\gamma V^o}}e^{\frac{-\gamma}{V_i^c+2\gamma V^o}(E[P-p])^2}. \tag{43}$$

We can calculate that

$$V_i^c + 2\gamma V^o = 2c + 2\gamma(V_i+V^o) = 2(c+\gamma V). \tag{44}$$

By Equations (43) and (44), we know that if the investor chooses to be informed, then her ex ante expected utility can be expressed as

$$U^{IN} = -e^{-\gamma W_0} e^{-\gamma b} e^{-\frac{\gamma}{2(c+\gamma V)}(E[P-p])^2} \sqrt{\frac{V_{IN}^c}{2(c+\gamma V)}}, \tag{45}$$

where $V_{IN}^c = 2\left(c + \gamma Var[P|\mathcal{F}_i^{IN}]\right)$. Similarly, if the investor chooses to be uninformed, then her ex ante expected utility can be expressed as:

$$U^{UN} = -e^{-\gamma W_0} e^{-\frac{\gamma}{2(c+\gamma V)}(E[P-p])^2} \sqrt{\frac{V_{UN}^c}{2(c+\gamma V)}}, \tag{46}$$

where $V_{UN}^c = 2\left(c + \gamma Var[P|\mathcal{F}_i^{UN}]\right)$. Notice that U^{IN} and U^{UN} are functions of the proportion of informed investors μ. If $U^{IN}|_{\mu=1} - U^{UN}|_{\mu=1} < 0$ and $U^{IN}|_{\mu=0} - U^{UN}|_{\mu=0} > 0$, then the equilibrium μ is determined by $U^{IN}/U^{UN} = 1$, which yields Eq. (18). □

A.7 Proof of Proposition 7

Proof. From Eq. (18) and the equilibrium condition $\Delta = 0$, we can find that the equilibrium price signal precision τ_p is determined by:

$$\gamma f(\tau_p) + \left(e^{2\gamma b} - 1\right) c = B, \tag{47}$$

where the function $f(\tau_p)$ and the constant B are respectively

$$f(\tau_p) = e^{2\gamma b} \frac{1}{\tau_\varepsilon + \tau_x + \tau_p} - \frac{1}{\tau_\varepsilon + \tau_p}, \text{ and } B = -\left(e^{2\gamma b} - 1\right) \frac{\gamma}{4(\tau_a + \tau_\eta)}. \tag{48}$$

For Eq. (47) to have a solution, we must have $f(\tau_p) < 0$, which results in

$$\tau_p < \frac{\tau_x - \left(e^{2\gamma b} - 1\right)\tau_\varepsilon}{e^{2\gamma b} - 1} = g\left(e^{2\gamma b} - 1\right), \tag{49}$$

where $g(A) = \frac{\tau_x - A\tau_\varepsilon}{A}$. Notice that the derivative of g is $g'(A) = -\frac{\tau_x}{A^2} < 0$.

One can calculate that

$$f'(\tau_p) = \frac{(\tau_\varepsilon + \tau_x + \tau_p)^2 - e^{2\gamma b}(\tau_\varepsilon + \tau_p)^2}{(\tau_\varepsilon + \tau_x + \tau_p)^2(\tau_\varepsilon + \tau_p)^2}. \tag{50}$$

Therefore, the following equivalence relation holds,

$$f'(\tau_p) > 0 \iff \tau_p < g\left(e^{\gamma b} - 1\right). \tag{51}$$

Since $e^{\gamma b} < e^{2\gamma b}$, and $g'(\cdot) < 0$, from the Inequality (49), we have:

$$\tau_p < g(e^{2\gamma b} - 1) < g(e^{\gamma b} - 1). \tag{52}$$

Therefore, $f'(\tau_p) > 0$.

Now suppose that c increases. For Eq. (47) to hold, $f(\tau_p)$ must decrease. Therefore, τ_p must decrease because $f'(\tau_p) > 0$. Recall that $\tau_p = (\frac{\beta_1}{\beta_3})^2\tau_n$. Consequently, $\frac{\beta_1}{\beta_3} = \sqrt{\frac{\tau_p}{\tau_n}}$ must decrease. In other words, $\frac{\partial(\beta_1/\beta_3)}{\partial c} < 0$, which completes the proof. □

A.8 Proof of Proposition 8

Proof. The proof is the same as those of Propositions 3, 4, and 5. □

A.9 Proof of Proposition 9

Proof. Consider an investor i. Denote $V_{UN} \equiv Var[P|\mathcal{F}_i^{UN}]$ and $V_{IN} \equiv Var[P|\mathcal{F}_i^{IN}]$. Define

$$\pi(c, \tau_p) \equiv \frac{c + \gamma V_{UN}}{c + \gamma V_{IN}}, \tag{53}$$

so $\Delta(c, \tau_p) = \sqrt{\pi(c, \tau_p)} - \exp(\gamma b)$. Notice that $V_{UN} > V_{IN}$. Therefore, we have

$$\frac{\partial \pi}{\partial c} = \frac{c + \gamma V_{IN} - (c + \gamma V_{UN})}{(c + \gamma V_{IN})^2} = \frac{\gamma(V^{IN} - V^{UN})}{(c + \gamma V_{IN})^2} < 0. \tag{54}$$

It immediately follows that $\frac{\partial \Delta}{\partial c} < 0$. The derivative of $\pi(c, \tau_p)$ with respect to τ_p is

$$\frac{\partial \pi}{\partial \tau_p} = \frac{\frac{-\gamma}{(\tau_\varepsilon + \tau_p)^2}\left[c + \gamma\left(\frac{1}{\tau_x + \tau_\varepsilon + \tau_p} + \frac{1}{4(\tau_a + \tau_\eta)}\right)\right] + \frac{\gamma}{(\tau_\varepsilon + \tau_x + \tau_p)^2}\left[c + \gamma\left(\frac{1}{\tau_\varepsilon + \tau_p} + \frac{1}{4(\tau_a + \tau_\eta)}\right)\right]}{(c + \gamma V_{IN})^2}, \tag{55}$$

in which the numerator can be simplified as:

$$\frac{-\gamma^2 \tau_x}{(\tau_x + \tau_\varepsilon + \tau_p)^2(\tau_\varepsilon + \tau_p)^2} < 0. \tag{56}$$

Therefore, $\frac{\partial \pi}{\partial \tau_p} < 0$ and thus $\frac{\partial \Delta}{\partial \tau_p} < 0$. □

A.10 Proof of Proposition 10

Proof. Recall that the equilibrium price signal precision τ_p is determined by $\gamma f(\tau_p) + (e^{2\gamma b} - 1)c = B(\tau_\eta)$, where f, B are defined in Eq. (48). By inspection, we know that $B'(\tau_\eta) > 0$. Recall that $f'(\tau_p) > 0$. Therefore, if τ_η increases, then τ_p must also increase for the equation $\gamma f(\tau_p) + (e^{2\gamma b} - 1)c = B(\tau_\eta)$ to hold. In other words, $\frac{\partial \tau_p}{\partial \tau_\eta} > 0$. Moreover, since

$\tau_p = (\frac{\beta_1}{\beta_3})^2 \tau_n$, we immediately get $\frac{\partial(\beta_1/\beta_3)}{\partial \tau_\eta} > 0$. Recall that the expression for the expected firm profit $E[\Pi]$ as a function of τ_p is given in Eq. (15). Direct calculations show that $\frac{\partial E[\Pi]}{\partial \tau_\eta} = [4(\tau_\varepsilon + \tau_p)^2]^{-1} > 0$. By the chain rule, we get $\frac{\partial E[\Pi]}{\partial \tau_\eta} = \frac{\partial E[\Pi]}{\partial \tau_p} \frac{\partial \tau_p}{\partial \tau_\eta} > 0$. □

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