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Information disclosure and price discovery ☆

Ya Tang

Peking University, Beijing 100871, PR China

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ABSTRACT

In this paper, I present a parsimonious, theoretical model to examine the influence of disclosure on market efficiency and on the cost of capital in the presence of endogenous information acquisition. Because disclosure "crowds out" private-information production, disclosure can either improve or harm market efficiency and the cost of capital, depending on whether investors' private-information production is sensitive to disclosure. This non-monotonic disclosure-cost-of-capital relation helps reconcile the existing mixed empirical evidence and has implications for the disclosure policies of firms.

1. Introduction

The accuracy with which asset prices reflect fundamental value is a critical indicator of well-functioning capital markets (e.g., Hayek, 1945; Fama, 1970; Peress, 2010; Ozsoylev and Walden, 2011). The process by which prices incorporate fundamental information is termed "price discovery" in the literature, and its effectiveness is called "market efficiency," "price efficiency," or "informational efficiency." Regulators and academics often see improving price discovery as an important goal. For example, O'Hara (1997, p. 270) writes: "How well and how quickly a market aggregates and impounds information into the price must surely be a fundamental goal of market design."

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E-mail address: yatang429@gmail.com

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The idea that public information disclosure improves price efficiency is compelling and intuitive to regulators. For instance, the conceptual framework of the Financial Accounting Standards Board (FASB) states that "(i)nformation about a reporting entity's financial performance helps users to understand the return that the entity has produced on its economic resources. [...] Information about the variability and components of that return also is important, especially in assessing the uncertainty of future cash flows, [...] and is helpful in predicting the entity's future returns on its economic resources" (FASB, 2010). Despite its obvious importance to regulation-related discussions, the market efficiency effect of disclosure is relatively less explored in the literature.[1] In this paper, I fill this gap by proposing a parsimonious model to examine the effect of disclosure on price discovery and on other important issues, such as information production and the cost of capital.

The model is a standard rational expectations equilibrium model extended with disclosure in the context of endogenous information acquisition. In the model economy, rational traders learn about a risky asset's payoff through three sources: stock price, costly information acquisition, and the firm's disclosure. In equilibrium, information acquisition and stock prices are determined simultaneously and are affected by disclosure.

I show that with endogenous private information acquisition, disclosure has opposing effects on market efficiency and thus it can either improve or harm price discovery. The first effect is a positive direct effect—more disclosure simply injects more information into the market, making the price closer to the fundamental value and thereby improving market efficiency. Disclosure also has negative indirect effects that occur through a "crowding out effect" on private information production. Specifically, public disclosure reduces the benefit of becoming informed, which in turn decreases the equilibrium number of traders who collect private information at a cost and hence decreases the total amount of information produced in the economy. When private information production is insensitive to public disclosure, the positive effect of disclosure dominates, and more disclosure helps the process of price discovery. When private information production is sensitive to public disclosure, the negative impact of disclosure on price efficiency could be strong enough to overwhelm the positive effect. As a result, the consequence of more disclosure could be less efficient price discovery.

The non-monotonic relation between disclosure and price efficiency has an important implication for the cost of capital, which is an essential factor for corporate decision making, asset pricing, and the development of institutional infrastructure. The cost of capital is typically measured by the expected rate of return on a risky asset, which is the expected difference between the cash flow generated by the asset and its price (e.g., Easley and O'Hara, 2004; Lambert, Leuz, and Verrecchia, 2007). There is a large empirical literature that reports the association between disclosure and the cost of capital, and the evidence is mixed.[2] For example, in a recent survey, Beyer, Cohen, Lys, and Walther (2010, p. 309) write: "Overall, the empirical evidence on the relation between voluntary disclosures, financial reporting quality attributes, and cost of capital is still inconclusive. We cannot draw unambiguous conclusions whether the theory and the related empirical evidence so far supports a significant statistical and economic link between information quality and cost of capital."[3]

In my model, when disclosure increases the informativeness of the asset price, it reduces the uncertainty faced by investors, thereby lowering the required rate of return. Conversely, when disclosure decreases the informativeness of the asset price, it raises the required rate of return by increasing the uncertainty faced by investors. Thus, the non-monotonic relation between disclosure and market efficiency is readily translated into a non-monotonic relation between disclosure and the cost of capital. This helps to reconcile the mixed empirical findings on the cost-of-capital effect of disclosure documented in the literature. That is, given the non-monotonic relationship, different kinds of empirical results could be identified based on different samples or types of firms being used in the

[1] There are a few exceptions (e.g., Tong, 2007; Gao, 2008).

[2] See Appendix A for the literature on disclosure and the cost of capital.

[3] Similarly, Leuz and Wysocki (2008, p. 35) state: "Overall, the evidence on the cross-sectional relation between a firm's voluntary disclosures, accounting attributes and cost of capital is still evolving and hence it is difficult to draw definitive and unambiguous conclusions whether the empirical evidence supports current theories on the link between information quality and cost of capital."

tests, and thus it is hard for researchers to detect a definitive association between disclosure and the cost of capital.

I further show that this non-monotonic relation between disclosure and the cost of capital has implications for the disclosure policies of firms. I demonstrate that disclosure is unique in the sense that parameters governing private information do not generate non-monotonic implications for market efficiency and the cost of capital. Finally, the results are robust to some variations in acquisition-cost structures or in information structures.

A large number of authors, for example Easley and O'Hara (2004), Hughes, Liu, and Liu (2007), among others, study the cost of capital and disclosure by incorporating endogenous information acquisition into a disclosure model and demonstrating a possible non-monotonic relation between disclosure and the cost of capital.[4] To the best of my knowledge, this is the first analytical study to show that corporate disclosure can either improve or harm market efficiency and the cost of capital depending on how private information acquisition is sensitive to disclosure. In addition, the findings in this paper provide new financial reporting regulation implications. That is, the non-monotonic implications of disclosure raise “red flags” for regulators; thus, in a rational, competitive market, the provision of more and better disclosure should be carefully designed and executed if regulators want to increase market quality and attempt to reduce the cost of capital by improving financial reporting standards.

I here employ the crowding out effect of disclosure on private information acquisition to capture the negative role of disclosure, which complements other studies that investigate the dark side of disclosure from other dimensions (e.g., Indjejikian, 1991; Kim and Verrecchia, 1994, 1997; Gao, 2008; Clinch and Verrecchia, 2011, Edmans, Heinle, and Huang, 2013). The crowding out effect has also been investigated (e.g.,Verrecchia, 1982; Diamond, 1985; Bushman, 1991; Lundholm, 1991), but its negative implications for market efficiency and the cost of capital have not yet been reported. In particular, without formal modeling, it is difficult to know ex ante whether these negative implications of disclosure dominate in equilibrium.

Finally, I want to emphasize the parsimony of my model, which puts together two separately studied effects: (1) that disclosure can reduce the uncertainty faced by investors and hence decrease the cost of capital (e.g., Easley and O'Hara, 2004, Hughes, Liu, and Liu, 2007, Lambert, Leuz, and Verrecchia, 2007), and (2) that free access to information might deter private information production and harm market efficiency (e.g., Paul, 1993; Han and Yang, 2013). My model is both simple and empirically relevant, but at the same time it can be used to explain the puzzling empirical relation between disclosure and the cost of capital, which has attracted a large amount of research interest in the accounting and finance literatures. Meanwhile, the simple model also leads to a new set of testable empirical predictions and important regulation implications.

The remainder of the paper is organized as follows. In Section 2, I present the model, as well as define and solve for the equilibrium. In Section 3, I examine the market efficiency and cost-of-capital consequences of information disclosure and discusses the implications. In Section 4, I explore the uniqueness of public disclosure in delivering the results and show the robustness of the results to some variations. I conclude in Section 5. All proofs are provided in Appendix B.

2. The model

2.1. Setup

I consider a one-period, noisy, rational expectations equilibrium model à la Grossman and Stiglitz (1980) and Hellwig (1980). There are two tradable assets in a competitive market: a risk-free asset and a risky asset, which can be understood as a firm's stock. The risk-free asset has a constant value of

[4] See Verrecchia (2001) for a survey. For recent studies, see Lambert, Leuz, and Verrecchia (2007, 2012), Gao (2010), Armstrong, Core, Taylor, and Verrecchia (2011), Bertomeu, Beyer, and Dye (2011), Bertomeu and Cheynel (2013), and Gao and Liang (2013), among others.

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1 and is in unlimited supply. The risky asset is traded at an endogenous price $\tilde{p}$ and has a fixed supply of $S>0$. It pays an uncertain payoff at the end of the period, denoted $\tilde{v}$, which is unknown to traders until the end of the period. I assume that $\tilde{v}$ is normally distributed with a mean of $\overline{v}>0$ and a precision (reciprocal of variance) of τ_v; that is, $\tilde{v}\sim N(\overline{v},1/\tau_v)$ with $\overline{v}>0$ and $\tau_v>0$.

There are two types of traders in the financial market. The first type is a [0,1] continuum of rational traders that have constant absolute risk aversion (CARA) utility with a risk aversion coefficient of $\gamma>0$; that is, $u(W)=-e^{-\gamma W}$, where W is their final wealth at the end of the period. The second type of traders are noise traders that provide liquidity to rational traders by supplying $\tilde{u}$ units of stock per capita to the market, where $\tilde{u}\sim N(0,1/\tau_u)$ with $\tau_u>0$. As is standard in the literature, I do not model the decision problem of noise traders. Noise trading is simply introduced as a modeling device for preventing a fully revealing price.

Rational traders have access to both private and public information. The private information is costly. Specifically, at the beginning of the period and before trading, rational traders can spend an amount $k>0$ to acquire private information. Those traders who decide to acquire private information are labeled "informed traders," while other rational traders who do not acquire private information are labeled "uninformed traders." I use $\lambda\in[0,1]$ to denote the mass of informed traders. Of course, the remaining mass $(1-\lambda)$ is equal to the size of the uninformed trader population.

Informed traders observe differential information. Specifically, an informed trader i observes a private signal, $\tilde{s}_i$, that contains information about the fundamental value $\tilde{v}$ of the risky asset in the following form:

$$\tilde{s}_i=\tilde{v}+\tilde{\varepsilon}_i \quad \text{with } \tilde{\varepsilon}_i\sim N\left(0,\frac{1}{\tau_\varepsilon}\right) \text{ and } \tau_\varepsilon>0. \tag{1}$$

The public information observed by all traders, including both informed and uninformed traders, is a public signal disclosed by the firm. This is the main departure from the standard setting of Grossman and Stiglitz (1980) and Hellwig (1980). Specifically, the firm is endowed with information $\tilde{s}_m$, given by

$$\tilde{s}_m=\tilde{v}+\tilde{\epsilon}_m \quad \text{with } \tilde{\epsilon}_m\sim N\left(0,\frac{1}{\tau_m}\right) \text{ and } \tau_m>0, \tag{2}$$

and it can decide to disclose a noisy version of $\tilde{s}_m$ in the following form:

$$\tilde{y}=\tilde{s}_m+\tilde{\delta} \quad \text{with } \tilde{\delta}\sim N\left(0,\frac{1}{\tau_\delta}\right) \text{ and } \tau_\delta\in[0,\infty]. \tag{3}$$

All of the underlying random variables $(\tilde{v},\tilde{\epsilon}_m,\tilde{\delta},\{\tilde{\varepsilon}_i\}_i,\tilde{u})$ are mutually independent.

Parameter τ_δ captures the precision of the public signal, which is determined by the firm's pre-announced disclosure policy. A higher quality of disclosure is represented by a higher value of τ_δ. In particular, in (3), I deliberately include the values of 0 and ∞ in the range of τ_δ: When $\tau_\delta=0$, the firm does not disclose any information to the market, and when $\tau_\delta=\infty$, the firm discloses all of its information $\tilde{s}_m$ without error. Also, the linear property of the multivariate normal distribution implies that a higher value of τ_δ can summarize both the case of more frequent announcements and the case of more precise information released by the firm.

Combining Eqs. (2) and (3), I can rewrite the public signal $\tilde{y}$ in terms of a sum of the stock's fundamental value $\tilde{v}$ and a noise term $\tilde{\eta}$ as follows:

$$\tilde{y}=\tilde{v}+\tilde{\eta}, \tag{4}$$

where:

$$\tilde{\eta}\equiv\tilde{\epsilon}_m+\tilde{\delta} \quad \text{with } \tilde{\eta}\sim N\left(0,\frac{1}{\tau_\eta}\right) \text{ and } \tau_\eta=(\tau_m^{-1}+\tau_\delta^{-1})^{-1}\in[0,\tau_m]. \tag{5}$$

It is clear that parameter τ_η also controls the disclosure quality; that is, a high value of τ_η corresponds to a high level of disclosure. So, henceforth I will use τ_η to denote disclosure quality.

To sum up, the exogenous parameters in the model are $\gamma>0$, the risk aversion of rational traders; $\overline{v}>0$, the mean of the stock's fundamental value; $\tau_v>0$, the prior precision of the stock's fundamental value; τ_u, the precision of the noise trading; $\tau_\varepsilon>0$, the precision of traders' private signals; $\tau_m>0$, the precision of the firm's private information; $\tau_\eta \in [0, \tau_m]$, the quality of disclosure; and k, the traders' cost of acquiring their private information. The order of events is as follows. At the beginning of the period, an endogenous mass λ of rational traders decide to acquire private information at cost k, and an informed trader i will observe a signal $\widetilde{s}_i$. The firm observes its private signal $\widetilde{s}_m$ and announces a public signal $\widetilde{y}$ to all traders. The financial market opens, all rational traders trade the risky and risk-free assets, and noise traders supply $\widetilde{u}$ shares of the risky asset. Finally, at the end of the period, asset payoffs are received and all rational traders consume.

The rational expectations equilibrium of this model is composed of two sub-equilibriums: the financial market equilibrium and the information market equilibrium. In the financial market equilibrium, (1) rational traders choose investments in the assets to maximize their expected utilities, conditional on all available information, including the information contained in the price; (2) the markets clear; and (3) traders have rational expectations in the sense that their beliefs about all random variables are consistent with the true underlying distribution. In the information market equilibrium, rational traders make private information acquisition decisions to maximize their indirect utilities in the future financial market, taking the equilibrium price function and disclosure as given. In the following two subsections, I first solve the financial market equilibrium, taking as given a fixed mass λ of informed traders, and then I endogenize the mass λ^* of informed traders by solving the information market equilibrium.

2.2. Financial market equilibrium

In equilibrium, the price $\widetilde{p}$ aggregates information possessed by rational traders, and therefore traders will glean information from observing the price. The price is a function of the stock fundamental $\widetilde{v}$, the public disclosure $\widetilde{y}$, and the noise trading $\widetilde{u}$. I consider the linear rational expectations equilibrium, in which traders conjecture the following price function:

$$\widetilde{p} = a + b\widetilde{v} + c\widetilde{y} - d\widetilde{u}, \tag{6}$$

where a, b, c, and d will be endogenously determined. Given the public signal $\widetilde{y}$, the information contained in the price is equivalent to the following signal:

$$\widetilde{s}_p = \frac{\widetilde{p} - a - c\widetilde{y}}{b} = \widetilde{v} - \frac{d}{b}\widetilde{u}, \tag{7}$$

which, conditional on $\widetilde{v}$, is normally distributed with mean $\widetilde{v}$ and precision τ_p, given by:

$$\tau_p = \left(\frac{b}{d}\right)^2 \tau_u. \tag{8}$$

I now derive the demand functions of rational traders. Consider a typical informed trader i, who has an information set $\{\widetilde{p}, \widetilde{y}, \widetilde{s}_i\}$. By solving the expected utility maximization problem, the trader's demand function for the stock is $D_I(\widetilde{p}, \widetilde{y}, \widetilde{s}_i) = (\mathrm{E}(\widetilde{v}|\widetilde{p}, \widetilde{y}, \widetilde{s}_i) - \widetilde{p})/\gamma Var(\widetilde{v}|\widetilde{p}, \widetilde{y}, \widetilde{s}_i)$, where $\mathrm{E}(\widetilde{v}|\widetilde{p}, \widetilde{y}, \widetilde{s}_i)$ and $Var(\widetilde{v}|\widetilde{p}, \widetilde{y}, \widetilde{s}_i)$ represent investor i's estimates of the mean and variance of the random payoff $\widetilde{v}$ conditional on the information set. Bayes' rule implies that:

$$\mathrm{E}(\widetilde{v}|\widetilde{p}, \widetilde{y}, \widetilde{s}_i) = \frac{\tau_v \overline{v} + \tau_\eta \widetilde{y} + \tau_p \widetilde{s}_p + \tau_\varepsilon \widetilde{s}_i}{\tau_v + \tau_\eta + \tau_p + \tau_\varepsilon}, \tag{9}$$

$$Var(\widetilde{v}|\widetilde{p}, \widetilde{y}, \widetilde{s}_i) = \frac{1}{\tau_v + \tau_\eta + \tau_p + \tau_\varepsilon}. \tag{10}$$

Plugging the above expressions into the demand function $D_I(\widetilde{p}, \widetilde{y}, \widetilde{s}_i)$ yields the demand function as follows:

$$D_I(\widetilde{p}, \widetilde{y}, \widetilde{s}_i) = \frac{(\tau_v \overline{v} + \tau_\eta \widetilde{y} + \tau_p \widetilde{s}_p + \tau_\varepsilon \widetilde{s}_i) - (\tau_v + \tau_\eta + \tau_p + \tau_\varepsilon)\widetilde{p}}{\gamma}. \tag{11}$$

So, the CARA-normal setup implies that trader i's demand for stocks is linear in his or her information set (including the price).

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Similarly, an uninformed trader has an information set $\{\tilde{p}, \tilde{y}\}$, and the demand is $D_U(\tilde{p}, \tilde{y}) = (E(\tilde{v}|\tilde{p}, \tilde{y}) - \tilde{p})/\gamma Var(\tilde{v}|\tilde{p}, \tilde{y})$. Using Bayes' rule, I can compute:

$$E(\tilde{v}|\tilde{p}, \tilde{y}) = \frac{\tau_v \overline{v} + \tau_\eta \tilde{y} + \tau_p \tilde{s}_p}{\tau_v + \tau_\eta + \tau_p}, \tag{12}$$

$$Var(\tilde{v}|\tilde{p}, \tilde{y}) = \frac{1}{\tau_v + \tau_\eta + \tau_p}. \tag{13}$$

Thus, an uninformed trader's demand function for the stock is:

$$D_U(\tilde{p}, \tilde{y}) = \frac{(\tau_v \overline{v} + \tau_\eta \tilde{y} + \tau_p \tilde{s}_p) - (\tau_v \overline{v} + \tau_\eta \tilde{y} + \tau_p \tilde{s}_p)\tilde{p}}{\gamma}. \tag{14}$$

The market-clearing condition is:

$$\int_0^\lambda D_I(\tilde{p}, \tilde{y}, \tilde{s}_i)\, di + (1-\lambda) D_U(\tilde{p}, \tilde{y}) = S + \tilde{u}, \tag{15}$$

where the left-hand side is the aggregate demand from the rational traders and the right-hand side is the per-capita supply of stock perturbed by the noise trading.

Substituting the demand functions (given by Eqs. (11) and (14)) and the expressions for $\tilde{s}_p$ (given by Eq. (7)) into the market-clearing condition (Eq. (15)), solving for $\tilde{p}$, and checking the conjectured form of the price function yields Proposition 1.

Proposition 1. *There exists a unique, linear, partially revealing, rational-expectations equilibrium, with the price function*:

$$\tilde{p} = a + b\tilde{v} + c\tilde{y} - d\tilde{u},$$

where:

$$a = \frac{\tau_v \overline{v} - \gamma S}{\tau_v + \tau_\eta + \tau_p + \lambda\tau_\varepsilon}, \quad b = \frac{\tau_p + \lambda\tau_\varepsilon}{\tau_v + \tau_\eta + \tau_p + \lambda\tau_\varepsilon}, \quad c = \frac{\tau_\eta}{\tau_v + \tau_\eta + \tau_p + \lambda\tau_\varepsilon}, \quad d = \frac{(\lambda\tau_\varepsilon/\gamma)\tau_u + \gamma}{\tau_v + \tau_\eta + \tau_p + \lambda\tau_\varepsilon},$$

with $\tau_p = (\lambda\tau_\varepsilon/\gamma)^2 \tau_u$.

2.3. Information market equilibrium

I now analyze the choice made by rational traders on whether to pay the cost k and become informed. The equilibrium mass λ of informed traders is determined by comparing the ex ante utility V_I of an informed trader with the ex ante utility V_U of an uninformed trader. Using the demand functions in (11) and (14) and the property of normal distributions, I can compute:

$$V_I = -\sqrt{\frac{Var(\tilde{v} - \tilde{p}|\tilde{p}, \tilde{y}, \tilde{s}_i)}{Var(\tilde{v} - \tilde{p})}} \exp\left\{\gamma k - \frac{[E(\tilde{v} - \tilde{p})]^2}{2Var(\tilde{v} - \tilde{p})}\right\}, \tag{16}$$

$$V_U = -\sqrt{\frac{Var(\tilde{v} - \tilde{p}|\tilde{p}, \tilde{y})}{Var(\tilde{v} - \tilde{p})}} \exp\left\{-\frac{[E(\tilde{v} - \tilde{p})]^2}{2Var(\tilde{v} - \tilde{p})}\right\}. \tag{17}$$

The expected net benefit $B(\lambda; \tau_\eta)$ of the information to a potential purchaser is the difference between the certainty equivalent $CE_I \equiv -(1/\gamma)\log(-V_I)$ of an informed trader and the certainty equivalent $CE_U \equiv -(1/\gamma)\log(-V_U)$ of an uninformed trader; that is,

$$B(\lambda; \tau_\eta) \equiv CE_I - CE_U = \frac{1}{2\gamma} \log\left[\frac{Var(\tilde{v}|\tilde{p}, \tilde{y})}{Var(\tilde{v}|\tilde{p}, \tilde{y}, \tilde{s}_i)}\right] - k, \tag{18}$$

where the second equality follows from Eqs. (16) and (17). Then, using the expressions of $Var(\tilde{v}|\tilde{p},\tilde{y},\tilde{s}_i)$ and $Var(\tilde{v}|\tilde{p},\tilde{y})$ in Eqs. (10) and (13), I can further express $B(\lambda;\tau_\eta)$ as follows:

$$B(\lambda;\tau_\eta) = \frac{1}{2\gamma}\log\left[1+\frac{\tau_\varepsilon}{\tau_v+\tau_\eta+(\lambda\tau_\varepsilon/\gamma)^2\tau_u}\right]-k. \tag{19}$$

In Eqs. (18) and (19), I deliberately express B as a function of $(\lambda;\tau_\eta)$ to emphasize the fact that the net benefit of acquiring the private information is affected by the mass λ of traders who have already acquired information and by the disclosure quality τ_η.

The benefit function $B(\lambda;\tau_\eta)$ determines the equilibrium mass λ^* of informed traders. There are three possible cases. (1) If $B(0)\le 0$ (i.e., a rational trader does not benefit from becoming informed when no other traders are informed), then $\lambda^*=0$ (i.e., an equilibrium exists in the information market when no trader acquires private information). (2) If $B(1)\ge 0$, rational traders are better off by being informed when all other rational traders are also informed. It is then an information-market equilibrium when all traders are informed (i.e., $\lambda^*=1$). (3) Given an interior fraction of rational traders ($0<\lambda^*<1$), if every rational trader is indifferent to becoming informed versus remaining uninformed, or in other words,

$$B(\lambda^*;\tau_\eta)=0 \Rightarrow \frac{1}{2\gamma}\log\left[1+\frac{\tau_\varepsilon}{\tau_v+\tau_\eta+(\lambda^*\tau_\varepsilon/\gamma)^2\tau_u}\right]=k, \tag{20}$$

then that mass λ^* is an information market equilibrium. In addition, the benefit function $B(\lambda;\tau_\eta)$ is monotonically decreasing in λ, so the information market equilibrium λ^* is unique.

Eq. (19) also shows that more disclosure (a higher τ_η) will reduce the benefit $B(\lambda;\tau_\eta)$ of becoming informed, and hence it will (weakly) decrease the equilibrium mass λ^* of informed traders. I label this effect the "crowding out effect," namely, public information disclosure crowds out private information production by market participants, as long as their private information production is sensitive to disclosure (i.e., $0<\lambda^*<1$). This crowding out effect captures the negative side of disclosure and underlies the emphasized non-monotonic implications of disclosure for market efficiency and the cost of capital. I formally summarize this result in Proposition 2.

Proposition 2 (*Crowding-out effect*). *Suppose that* $0<\lambda^*<1$. *Disclosure reduces the equilibrium mass of informed traders; that is,* $d\lambda^*/d\tau_\eta<0$.

3. Disclosure, market efficiency, and the cost of capital

3.1. Market efficiency and the cost of capital

Market efficiency and the cost of capital are two key concepts in finance, and they have attracted much attention in the literature. Market efficiency reflects how well financial markets discover asset values. An informationally efficient market is desirable because better price discovery in financial markets may eventually translate into better resource allocations. The cost of capital is a critical variable determining firms' investment decisions, and it can be broadly related to stockholders' final wealth level.

I follow the literature (e.g., Bloomfield and O'Hara, 1999; Gao, 2008) in measuring market efficiency M as the reciprocal of the mean squared error (MSE) between the stock's fundamental value $\tilde{v}$ and its price $\tilde{p}$, as follows:

$$M \equiv \frac{1}{MSE} = \frac{1}{\mathrm{E}\left[(\tilde{v}-\tilde{p})^2\right]} \tag{21}$$

$$M = \frac{(\tau_v+\tau_\eta+\tau_p+\lambda\tau_\varepsilon)^2}{(\gamma S)^2+(\tau_v+\tau_\eta+\tau_p)+2\lambda\tau_\varepsilon+\gamma^2\tau_u^{-1}}, \tag{22}$$

where (22) follows from Proposition 1. The metric of $1/MSE$ reflects market efficiency in the sense that it captures the accuracy with which the stock price incorporates the fundamental information.

In other words, statistically, this metric of market efficiency underscores the goodness of the stock price as an estimator of the fundamental value. A lower value of MSE means that the stock price is closer to the fundamental value, resulting in greater market efficiency.

I also follow the literature (see, e.g., Easley and O'Hara, 2004) in defining the cost of capital (*COC*) as follows:

$$COC \equiv \mathrm{E}(\tilde{v} - \tilde{p}) = \frac{\gamma S}{\tau_v + \tau_\eta + \tau_p + \lambda \tau_\varepsilon}, \tag{23}$$

where the second equality follows from Proposition 1. That is, the cost of capital is the expected difference between the cash flow generated by the risky stock and its price, which is due to the risk taken by the traders who hold the stock. In particular, the denominator $(\tau_v + \tau_\eta + \tau_p + \lambda \tau_\varepsilon)$ in (23) is the average conditional precision of stock payoff $\tilde{v}$ across all rational traders: τ_v is the prior precision, τ_η is the precision of the public disclosure, τ_p is the precision gleaned from the price, and $(\lambda \tau_\varepsilon)$ is the precision of the total amount of private information produced by rational traders. So, $1/(\tau_v + \tau_\eta + \tau_p + \lambda \tau_\varepsilon)$ measures the average risk regarding the stock payoff, and hence when multiplied by the risk aversion γ and stock supply S it determines the cost of capital.

3.2. The non-monotonic implications of disclosure

In Eqs. (22) and (23), disclosure quality τ_η affects market efficiency M and the cost of capital *COC* in three ways. First, there is a direct effect, as captured by the term τ_η in the expressions of M and *COC*. This effect states that public disclosure directly expands the information sets of all traders and reduces the risk faced by them in trading the risky asset. This tends to improve market efficiency and lower the cost of capital.

The other two effects are indirect: the crowding out effect posited in Proposition 2, as captured by the term $\lambda \tau_\varepsilon$ in Eqs. (22) and (23); and the effect on the informational content in the price, as captured by the term τ_p in Eqs. (22) and (23). That is, disclosure may crowd out the production of private information, thereby harming market efficiency and raising the cost of capital (by raising the risk faced by rational traders). In addition, the reduction in private information will further reduce the information contained in the price because in the end it is through the trading of informed traders that brings private information into the price. Thus, these two indirect effects tend to harm market efficiency and increase the cost of capital.

The overall effect of disclosure on market efficiency and the cost of capital is determined by the trade-off among these three effects. When private information is insensitive to disclosure (i.e., when $\lambda^* = 0$ or 1), the two indirect effects are mute and only the first effect is at work. Therefore, in this case, public disclosure will improve market efficiency and reduce the cost of capital because its only consequence is to inject more information into the price system.

In contrast, when private information production is sensitive to public disclosure (i.e., when $0 < \lambda^* < 1$), all three effects are at work. In particular, the information-market equilibrium is determined by Eq. (20), which implies that:

$$\tau_v + \tau_\eta + \tau_p = \frac{\tau_\varepsilon}{e^{2\gamma k} - 1}. \tag{24}$$

That is, because rational traders trade off the benefits and the costs of acquiring private information, the information market adjusts in such a way that, in equilibrium, the total precision $\tau_v + \tau_\eta + \tau_p$ gleaned from the free public information (i.e., the disclosure and the price) always equates the precision τ_ε of the costly private information, adjusted by a cost related factor of $1/(e^{2\gamma k} - 1)$.

Importantly, this fact implies that the direct effect of disclosure and the indirect effect associated with price information exactly cancel each other out, thereby causing the disclosure implications to be determined by the crowding out effect. To see this, inserting (24) into (22) and (23) yields:

$$M = \frac{\left(\frac{\tau_\varepsilon}{e^{2\gamma k} - 1} + \lambda^* \tau_\varepsilon\right)^2}{(\gamma S)^2 + \frac{\tau_\varepsilon}{e^{2\gamma k} - 1} + 2\lambda^* \tau_\varepsilon + \gamma^2 \tau_u^{-1}} \quad \text{and} \quad COC = \frac{\gamma S}{\frac{\tau_\varepsilon}{e^{2\gamma k} - 1} + \lambda^* \tau_\varepsilon} \quad \text{for } 0 < \lambda^* < 1. \tag{25}$$

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Thus, when $0<\lambda^*<1$, disclosure quality λ^* affects M and COC only through its effect on λ^*. Direct computation shows that $dM/d\lambda^*>0$ and $dCOC/d\lambda^*<0$ in (25). Given Proposition 2, $d\lambda^*/d\tau_\eta<0$ for $0<\lambda^*<1$, and thus when $0<\lambda^*<1$ disclosure harms market efficiency and raises the cost of capital because of the crowding out effect.

The contrasting implications of disclosure in the two cases ($\lambda^*\in\{0,1\}$ vs. $\lambda^*\in(0,1)$) give rise to the possibility of non-monotonic relations between disclosure and market efficiency and between disclosure and the cost of capital. It turns out whether this non-monotonicity arises depends crucially on the size of the information acquisition cost k. Specifically, recall that the benefit $B(\lambda;\tau_\eta)$ of acquiring information in (20) decreases with both λ and τ_η. So, if:

$$B(0;0)\le 0 \Leftrightarrow k\ge \frac{1}{2\gamma}\log\left(1+\frac{\tau_\varepsilon}{\tau_v}\right), \tag{26}$$

then $B(\lambda;\tau_\eta)\le 0$ for all $\lambda\in[0,1]$ at any disclosure level τ_η, thus $\lambda^*=0$. As a result, private-information acquisition is insensitive to public disclosure, and disclosure only has the direct effect of improving market efficiency and decreasing the cost of capital. In contrast, if condition (26) is violated (i.e., if $k<(1/2\gamma)\log(1+\tau_\varepsilon/\tau_v)$), then at some disclosure levels private-information acquisition is sensitive to disclosure, while at other disclosure levels it becomes insensitive to disclosure. This causes market efficiency and the cost of capital to vary non-monotonically with disclosure.

The fact that the implications of the non-monotonicity of disclosure exist only for relatively low information acquisition costs helps in the testing of my theory because the literature contains various information acquisition cost measures. For example, one measure used in Duchin, Matsusaka, and Ozbas (2010, p. 202) is the analyst forecast error, which is “the absolute difference between the mean analyst earnings forecast prior to a quarterly earnings announcement and the actual earnings, normalized by the firm's total book assets and averaged across four quarters in a given year.” A larger forecast error indicates a greater difficulty of becoming informed and thus a higher cost k of acquiring information.

Summarizing the above discussions leads to Proposition 3.

Proposition 3 (*Non-monotonicity of disclosure implications*).

(a) *If $k\ge(1/2\gamma)\log(1+\tau_\varepsilon/\tau_v)$, then COC monotonically decreases with τ_η, M monotonically increases with τ_η, and no traders acquire information (i.e., $\lambda^*=0$).*

(b) *If $k<(1/2\gamma)\log(1+\tau_\varepsilon/\tau_v)$, both COC and M non-monotonically change with τ_η. Specifically:*

(1) *If $(1/2\gamma)\log[1+\tau_\varepsilon/(\tau_v+(\tau_\varepsilon/\gamma)^2\tau_u)]<k<(1/2\gamma)\log(1+\tau_\varepsilon/\tau_v)$, then, for $\tau_\eta<\tau_\varepsilon/(e^{2\gamma k}-1)-\tau_v$, COC increases with τ_η, M decreases with τ_η, and there is an interior fraction $\lambda^*\in(0,1)$ of traders acquiring information; but for $\tau_\eta\ge\tau_\varepsilon/(e^{2\gamma k}-1)-\tau_v$, COC decreases with τ_η, M increases with τ_η, and no traders acquire information (i.e., $\lambda^*=0$).*

(2) *If $k\le(1/2\gamma)\log[1+\tau_\varepsilon/(\tau_v+(\tau_\varepsilon/\gamma)^2\tau_u)]$, then, first, for $\tau_\eta\le\tau_\varepsilon/(e^{2\gamma k}-1)-\tau_v-(\tau_\varepsilon/\gamma)^2\tau_u$, COC decreases with τ_η, M increases with τ_η, and all traders acquire information (i.e., $\lambda^*=1$); second, for $\tau_\varepsilon/(e^{2\gamma k}-1)-\tau_v-(\tau_\varepsilon/\gamma)^2\tau_u<\tau_\eta<\tau_\varepsilon/(e^{2\gamma k}-1)-\tau_v$, COC starts to increase with τ_η, M starts to decrease with τ_η, and there is an interior fraction $\lambda^*\in(0,1)$ of traders acquiring information; and third, for $\tau_\eta\ge\tau_\varepsilon/(e^{2\gamma k}-1)-\tau_v$,COC starts to decrease again with τ_η, M starts to increase again with τ_η, and no traders acquire information (i.e., $\lambda^*=0$).*

3.3. *An application: optimal disclosure policies of firms*

Because the cost of capital represents the cost that companies have to bear when they raise funds, it may be in their best interest to minimize the cost of capital by choosing an optimal level of disclosure. The model presented in this paper provides a parsimonious framework of analyzing this issue. Specifically, as shown in Eq. (5), the precision τ_m of the firm's private signal $\tilde{s}_m$ specifies an upper bound for the firm's possible disclosure level. So, for a fixed level of τ_m, the firm can choose $\tau_\eta\in[0,\tau_m]$

to minimize the resulting equilibrium *COC*. As a corollary of Proposition 3, I show the following formal results.

Corollary 1 (*Optimal disclosure policy*). *Let τ_η^* denote the disclosure level that minimizes the cost of capital.*

(a) *If $k \geq (1/2\gamma)\log(1+\tau_\varepsilon/\tau_v)$, then the firm discloses all of its private information to minimize its cost of capital (i.e., $\tau_\eta^* = \tau_m$).*

(b) *If $k < (1/2\gamma)\log(1+\tau_\varepsilon/\tau_v)$, then the firm may withhold some of its private information to minimize its cost of capital. Specifically*:

$$(1)\quad \text{If } \frac{1}{2\gamma}\log\left[1+\frac{\tau_\varepsilon}{\tau_v+\left(\frac{\tau_\varepsilon}{\gamma}\right)^2\tau_u}\right] < k < \frac{1}{2\gamma}\log\left(1+\frac{\tau_\varepsilon}{\tau_v}\right), \text{ then}$$

$$\tau_\eta^* = \begin{cases} 0 & \text{for } \tau_m \in \left[0, \dfrac{\tau_\varepsilon}{e^{2\gamma k}-1}+\gamma\sqrt{\dfrac{\dfrac{\tau_\varepsilon}{e^{2\gamma k}-1}-\tau_v}{\tau_u}}-\tau_v\right]; \\ \tau_m & \text{otherwise} \end{cases}$$

$$(2)\quad \text{If } k \leq \frac{1}{2\gamma}\log\left[1+\frac{\tau_\varepsilon}{\tau_v+\left(\frac{\tau_\varepsilon}{\gamma}\right)^2\tau_u}\right], \text{ then}$$

$$\tau_\eta^* = \begin{cases} \dfrac{\tau_\varepsilon}{e^{2\gamma k}-1}-\tau_v-\left(\dfrac{\tau_\varepsilon}{\gamma}\right)^2\tau_u & \text{for } \tau_m \in \left[\dfrac{\tau_\varepsilon}{e^{2\gamma k}-1}-\tau_v-\left(\dfrac{\tau_\varepsilon}{\gamma}\right)^2\tau_u, \dfrac{\tau_\varepsilon}{e^{2\gamma k}-1}+\tau_\varepsilon-\tau_v\right]. \\ \tau_m & \text{otherwise} \end{cases}$$

In (a), *COC* decreases with disclosure τ_η, and thus firms would like to disclose all of the information they have; those firms are characterized by relatively high information acquisition cost k. In contrast, in (b), *COC* non-monotonically changes with disclosure τ_η, and some firms—in particular, those firms with low precision τ_m of private signals—tend to withhold some of their private information.

So, I suggest in Corollary 1 that those firms with higher information acquisition cost k and/or with more precise private information τ_m are more likely to disclose all of their private information. This is broadly consistent with Chen, DeFond, and Park (2002), who find that voluntary disclosures are more likely among firms with larger forecast errors and among firms in high technology industries. That is, according to Duchin, Matsusaka, and Ozbas (2010), those firms with larger forecast errors are expected to have a higher information acquisition cost k, and so according to Corollary 1 those firms are less likely to withhold private information. Also, it is arguable that the firms in high-technology industries might have better information about their own fundamental values, which therefore corresponds to a higher τ_m. Again, according to Corollary 1 those high-tech firms are less likely to withhold their private information.

3.4. A calibration exercise

In this subsection, I conduct a calibration exercise to examine how disclosure affects market efficiency and the cost of capital for reasonable parameter values. In this exercise, I take one period as a year and choose parameter values as shown in Table 1. Of course, as mentioned by Easley and O'Hara (2004), the specific values attached to the model parameters are surely debatable, and the quantitative results presented here should be interpreted with some caution.

Specifically, the ex ante precision τ_v of the stock payoff is set at 25, which gives an annual volatility of approximately 20%. I also set the precision τ_ε of rational traders' private signals at 25, which implies that rational traders know half of the uncertainty of the stock payoff (i.e., their signal-to-noise ratio

Table 1
Parameter values.

Parameters	Values
Information parameters	
Ex ante stock payoff precision (τ_ν)	25
Private signal precision (τ_ε)	25
Precision of noise trading (τ_u)	10
Preference and technology parameters	
Risk aversion parameter (γ)	10
Information-acquisition cost (k)	0.012
Ex ante expected stock payoff ($\overline{v}$)	1
Per capita stock supply (S)	1

Note: This table presents parameter values that are used to compute the equilibrium outcomes in the calibration exercise.

τ_ε/τ_v is 1). Both the expected payoff of the risky asset and the per-capita supply of the stock are normalized at 1, so that $\overline{v}=S=1$. The precision of the noise trading is set at 10 (i.e., $\tau_u=10$), which corresponds to an annual volatility of liquidity supply equal to about 30% of total supply. The preference parameter is set at $\gamma=10$.

Under these parameter values, the two threshold values of the information acquisition cost parameter k in Proposition 3 are: $(1/2\gamma)\log(1+\tau_\varepsilon/\tau_v)=0.0347$ and $(1/2\gamma)\log[1+\tau_\varepsilon/(\tau_v+(\tau_\varepsilon/\gamma)^2\tau_u)]=0.0126$. Thus, as long as $k<0.0347$, both market efficiency M and the cost of capital COC will non-monotonically change with the disclosure level τ_η. Specifically, if $0.0126<k<0.0347$, M first decreases and then increases with τ_η, while COC first increases and then decreases with τ_η. If $k<0.0126$, M first increases with τ_η, then decreases with τ_η, and finally increases with τ_η, while COC displays an opposite pattern. In this calibration exercise, I borrow the calibration value in Veldkamp (2006, p. 583) and set k as 0.012.

To gain some intuitive interpretation of the choice of k, I conduct the following thought experiment and compare two hypothetical economies. In both economies, the disclosure level τ_η is fixed at 25 (i.e., public disclosure removes half of the uncertainty of the stock payoff given that the signal-to-noise ratio τ_η/τ_v of public disclosure is 1). In the first economy, suppose that there is no information acquisition cost, so that all rational traders acquire private information (i.e., $\lambda^*_{k=0}=1$). Then, by Eq. (16), the certainty equivalent of rational traders can be computed as $CE^*_{k=0}=0.0403$. In the second economy, the information-acquisition cost k is raised to the value 0.012 in Table 1. In this case, both the fraction of informed traders and the certainty equivalent of informed traders decrease: $\lambda^*_{k=0.012}=0.82$ and $CE^*_{k=0.012}=0.0368$. Thus, by comparing the two economies, one can conclude that the welfare loss of setting $k=0.012$ is around $8.68\%=(CE^*_{k=0}-CE^*_{k=0.012})/CE^*_{k=0}$.

Fig. 1 shows the equilibrium mass λ^* of informed traders, market efficiency M, and the cost of capital COC as functions of disclosure level τ_η in Panels (a), (b), and (c), respectively. In Panel (a), when $\tau_\eta\le 4.67$, all rational traders choose to acquire information so that $\lambda^*=1$; when $\tau_\eta\ge 67.17$, the public disclosure is so precise that traders do not find it beneficial to acquire private information (i.e., $\lambda^*=0$). In these two regions, private information production is not sensitive to the disclosure level. In contrast, when $\tau_\eta\in(4.67,67.17)$, some traders acquire private information, while others do not (i.e., $\lambda^*\in(0,1)$). In this region of τ_η, private information acquisition is sensitive to public disclosure, and the crowding out effect in Proposition 2 manifests itself as a downward sloping relation between τ_η and λ^*.

As an implication, market efficiency and the cost of capital non-monotonically change with the disclosure level. Specifically, when private information production is sensitive to disclosure in Panel (a) (i.e., when $\tau_\eta\in(4.67,67.17)$), disclosure harms market efficiency and increases the cost of capital in Panels (b) and (c). In contrast, if private information production does not vary with disclosure in Panel (a) (i.e., when $\tau_\eta\le 4.67$ or $\tau_\eta\ge 67.17$), disclosure improves market efficiency M and decreases the cost of capital COC in Panels (b) and (c). In this calibration exercise, the effect of disclosure on M and COC is substantial. For instance, when private-information production is sensitive to disclosure in Panel (a) (i.e., when $\tau_\eta\in(4.67,67.17)$), the variation in COC can be more than 2% in Panel (c).

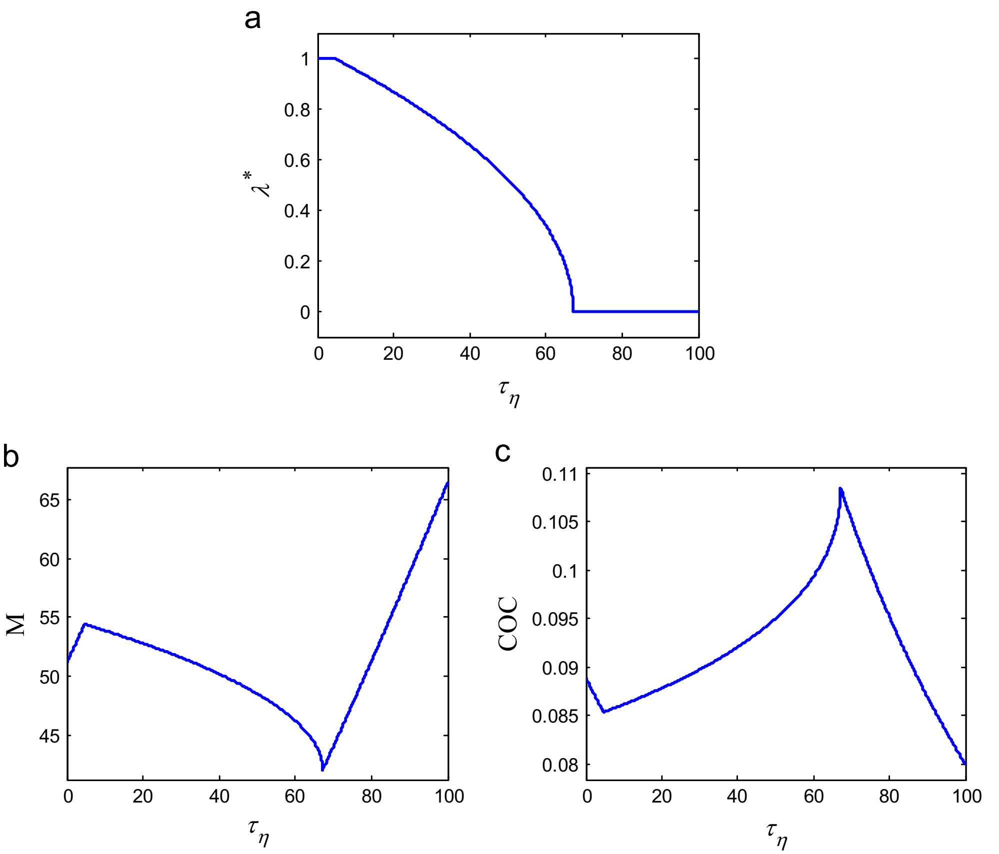

Fig. 1. Non-monotonic implications of public disclosure. *Note*: This figure shows the mass of informed traders (λ^*), market efficiency (M), and the cost of capital (COC) as a function of disclosure quality (τ_η). The parameter values are fixed at the values in Table 1. Panel (a): mass of informed traders, Panel (b): market efficiency and Panel (c): cost of capital.

The non-monotonic relationship between disclosure and the cost of capital in Panel (c) helps to reconcile the mixed empirical findings in the literature. As I mentioned in the Introduction and summarize in Appendix B, researchers have documented evidence that accounting-disclosure quality can either decrease, increase, or have no effect on the cost of capital. Because the model in this paper shows that the relationship between disclosure and the cost of capital is non-monotonic, anything can happen if researchers use different samples. For example, if researchers happen to use samples that include data points coming both from the upward-sloping branch and from the downward sloping branches in Panel (c), then the effects of disclosure may cancel out on average, making it hard to detect a robust connection between disclosure and the cost of capital.

A cleaner connection between disclosure and the cost of capital may be teased out if researchers can condition the tests on the sensitivity of private information production to public disclosure. Clearly, any such effort would need a proxy for this sensitivity, and here is a possible candidate: In practice, institutional traders are more likely to be informed traders than retail investors, and so institutional ownership can be a proxy for the fraction λ of informed traders. For each stock, then, one can run a time series regression from institutional ownership to disclosure proxies, and the obtained estimation coefficient is a possible candidate for the sensitivity of private-information production to public disclosure. I posit that for those stocks with sufficiently negative sensitivities, disclosure can raise the cost of capital.

4. Discussion and variations

In this section, I first discuss the uniqueness of public disclosure in generating non-monotonic implications for market efficiency and the cost of capital. I then show the robustness of the main results in Propositions 2 and 3 to some variations in model assumptions.

4.1. The uniqueness of disclosure implications

I compare public disclosure with private information to demonstrate the unique role of disclosure in delivering non-monotonic implications. Specifically, there are two parameters associated with private information: τ_ε, the precision of private signals; and k, the cost of acquiring private information. I show that changing τ_ε and/or k always monotonically affects market efficiency M and the cost of capital COC. This contrasts with the implications of changing the public disclosure quality τ_η in Proposition 3.

It turns out that τ_ε and k affect M and COC only through the total amount of private information produced by the whole economy, which is represented by $(\lambda^*\tau_\varepsilon)$ (recall that λ^* is the mass of informed traders and also the mass of private signals and that τ_ε is the precision of each private signal). This makes sense because the total amount of private information is the source of improving informational efficiency and reducing the uncertainty faced by traders (hence lowering the cost of capital). Formally, Eqs. (22) and (23) and $\tau_p = (\lambda^*\tau_\varepsilon/\gamma)^2\tau_u$ imply that:

$$M = \frac{\left(\tau_v + \tau_\eta + \left(\frac{\lambda^*\tau_\varepsilon}{\gamma}\right)^2 \tau_u + \lambda^*\tau_\varepsilon\right)^2}{(\gamma S)^2 + \left(\tau_v + \tau_\eta + \left(\frac{\lambda^*\tau_\varepsilon}{\gamma}\right)^2 \tau_u\right) + \gamma^2\tau_u^{-1} + 2\lambda^*\tau_\varepsilon}, \tag{27}$$

$$COC = \frac{\gamma S}{\tau_v + \tau_\eta + \left(\frac{\lambda^*\tau_\varepsilon}{\gamma}\right)^2 \tau_u + \lambda^*\tau_\varepsilon}. \tag{28}$$

Then, direct computation shows that $dM/d(\lambda^*\tau_\varepsilon) > 0$ and $dCOC/d(\lambda^*\tau_\varepsilon) < 0$.

By Proposition 3, when $k \in ((1/2\gamma)\log(1+\tau_\varepsilon/(\tau_v + (\tau_\varepsilon/\gamma)^2\tau_u + \tau_\eta)), (1/2\gamma)\log(1+\tau_\varepsilon(\tau_v+\tau_\eta)))$, λ^* takes interior values and is determined by Eq. (20). When k falls outside this range, λ^* is fixed at 0 or 1. Clearly, when $\lambda^* = 0$ or $\lambda^* = 1$, it is true that $d(\lambda^*\tau_\varepsilon)/dk = 0$ and $d(\lambda^*\tau_\varepsilon)/d\tau_\varepsilon > 0$. When $\lambda^* \in (0,1)$, Eq. (20) implies that $d(\lambda^*\tau_\varepsilon)/dk < 0$ and $d(\lambda^*\tau_\varepsilon)/d\tau_\varepsilon > 0$. Combining with $dM/d(\lambda^*\tau_\varepsilon) > 0$ and $dCOC/d(\lambda^*\tau_\varepsilon) < 0$, it must be true that $dM/dk \le 0$, $dCOC/dk \ge 0$, $dM/d\tau_\varepsilon > 0$, and $dCOC/d\tau_\varepsilon < 0$. That is, private information parameters affect market efficiency and the cost of capital in a monotonic way, which contrasts with the public disclosure implications and illustrates the uniqueness of disclosure in delivering the main results. Proposition 4 summarizes the above discussions.

Proposition 4 (*Monotonicity of private information implications*). *Increasing the information acquisition cost k (weakly) harms market efficiency and increases the cost of capital, while increasing the private-information precision τ_ε improves market efficiency, and reduces the cost of capital. That is, $dM/dk \le 0$, $dCOC/dk \ge 0$, $dM/d\tau_\varepsilon > 0$, and $dCOC/d\tau_\varepsilon < 0$.*

4.2. A model with heterogeneous information acquisition costs

So far, the model presented in Sections 2 and 3 has demonstrated the possibility that disclosure decreases market efficiency and increases the cost of capital. This possibility arises only when disclosure does not affect private information acquisition at all (i.e., only when $\lambda^* = 0$ or 1). In this section, I consider a variant of the model to show that the results still hold even when $\lambda^* \in (0,1)$, which is more likely to be empirically relevant.

Specifically, I keep intact most of the structure of the baseline model and assume that traders now have different information acquisition costs. Trader i's cost of acquiring a private signal $\tilde{s}_i$ is k_i, which is independently drawn from a uniform distribution $U[0, \overline{k}]$ with $\overline{k} > 0$. Since there is a continuum of traders, each k in $[0, \overline{k}]$ will be drawn with certainty, and the information acquisition costs will be uniformly distributed across traders. In this setting, those traders whose costs are close to 0 will always acquire information, and if $\overline{k}$ is high (precisely, if $\overline{k} > (1/2\gamma)\log[1+\tau_\varepsilon/(\tau_v+(\tau_\varepsilon/\gamma)^2\tau_u)]$), then those traders whose costs are close to $\overline{k}$ will not acquire information. As a result, the fraction of informed traders will be interior all the time; that is, $\lambda^* \in (0,1)$.

The financial market equilibrium is still characterized by Proposition 1, and so, market efficiency and the cost of capital are still given by Eqs. (22) and (23), respectively. In addition, the benefit of acquiring private information is also given by $B(\lambda;\tau_\eta,k)$ in expression (19), where I now deliberately incorporate k as an argument to emphasize the fact that different traders have different information-acquisition costs in this new setting.

In equilibrium, there exists a critical value of $k^* \in (0, \overline{k})$ such that traders whose information acquisition costs k are lower than k^* will decide to acquire information, while traders whose information acquisition costs k are greater than k^* will not. At the critical level k^* of information acquisition cost, traders are indifferent between becoming informed and staying uninformed, so that:

$$B(\lambda;\tau_\eta,k^*)=0 \Rightarrow \tau_v+\tau_\eta+\left(\frac{\lambda^*\tau_\varepsilon}{\gamma}\right)^2\tau_\mu=\frac{\tau_\varepsilon}{e^{2\gamma k^*}-1}. \tag{29}$$

The equilibrium mass λ^* of informed traders is:

$$\lambda^*=\frac{k^*}{\overline{k}}. \tag{30}$$

Combining (29) and (30) delivers:

$$\tau_v+\tau_\eta+\left(\frac{\lambda^*\tau_\varepsilon}{\gamma}\right)^2\tau_u=\frac{\tau_\varepsilon}{e^{2\gamma\overline{k}\lambda^*}-1}, \tag{31}$$

which implicitly determines the equilibrium fraction λ^* of informed traders. Using the implicit function theorem:

$$\frac{d\lambda^*}{d\tau_\eta}=-\frac{1}{\dfrac{2\lambda^*\tau_\varepsilon^2\tau_u}{\gamma^2}+\dfrac{2\gamma\overline{k}\tau_\varepsilon e^{2\gamma\overline{k}\lambda^*}}{(e^{2\gamma\overline{k}\lambda^*}-1)^2}}<0. \tag{32}$$

Therefore, the crowding out effect still arises in this economy.

By (23) and (31), the equilibrium cost of capital is:

$$COC=\frac{\gamma S}{\tau_v+\tau_\eta+\left(\dfrac{\lambda^*\tau_\varepsilon}{\gamma}\right)^2\tau_u+\lambda^*\tau_\varepsilon} \tag{33}$$

$$COC=\frac{\gamma S}{\dfrac{\tau_\varepsilon}{e^{2\gamma\overline{k}\lambda^*}-1}+\lambda^*\tau_\varepsilon}. \tag{34}$$

It is clear that disclosure τ_η still affects COC only through its effect on λ^*, which is similar to the baseline model. However, unlike Eq. (25), there are now two terms related to λ^* in (34), and these two terms affect COC in opposite directions. This in turn can generate a non-monotonic relation between disclosure and the cost of capital in this setting. I show in Appendix B that disclosure reduces the cost of capital if and only if the disclosure level τ_η is sufficiently high. The intuition is similar to the baseline model: When the disclosure level is high, there are not many traders actively searching for private information, and thus the strength of the crowding out effect is limited. As a result, the main role of disclosure is to augment each trader's information set, reducing their trading risks and lowering the equilibrium cost of capital.

Similarly, by Eqs. (22) and (31)market efficiency becomes:

$$MSE = \frac{(\gamma S)^2 + \gamma^2 \tau_\mu^{-1} + \tau_v + \tau_\eta + \left(\frac{\lambda^* \tau_\varepsilon}{\gamma}\right)^2 \tau_\mu + 2\lambda^* \tau_\varepsilon}{\left[\tau_v + \tau_\eta + \left(\frac{\lambda^* \tau_\varepsilon}{\gamma}\right)^2 \tau_\mu + \lambda^* \tau_\varepsilon\right]^2} = \frac{(\gamma S)^2 + \gamma^2 \tau_\mu^{-1} + \frac{\tau_\varepsilon}{e^{2\gamma k^*} - 1} + 2\lambda^* \tau_\varepsilon}{\left(\frac{\tau_\varepsilon}{e^{2\gamma k^*} - 1} + \lambda^* \tau_\varepsilon\right)^2}. \tag{35}$$

Again, disclosure τ_η still affects M only through its effect on λ^*. It is difficult to give a full analytical characterization of the market efficiency effect of disclosure because the sign of $dMSE/d\tau_\eta$ is determined by a fourth-order polynomial in λ^*, as given by Eq. (B.15) in Appendix B. However, I can provide a sufficient condition for the non-monotonic relation between disclosure and market efficiency. Specifically, when the size of noise trading is sufficiently large (i.e., when τ_u is small), it is likely for non-monotonicity to arise. These results are summarized in Proposition 5.

Proposition 5 (*Heterogenous information acquisition cost*). *Suppose that the information acquisition cost k follows a uniform distribution* $U[0, \overline{k}]$. *Then,* (a) *disclosure reduces the equilibrium mass λ^* of informed traders* (*i.e.,* $d\lambda^*/d\tau_\eta < 0$); (b) *disclosure reduces the cost of capital if and only if the disclosure level is sufficiently large* (*i.e., $dCOC/d\tau_\eta < 0$ if and only if $\tau_\eta < \hat{\tau}_\eta$ with $\hat{\tau}_\eta$ given by* (B.12) *in* Appendix B); (*c*) *if the size of noise trading is sufficiently large* (*i.e.,* $\tau_u \approx 0$), *then when the disclosure level τ_η is large, disclosure improves market efficiency*; *when the disclosure level τ_η is small and the private signal quality $\tau_\varepsilon/\tau_\eta$ is high, disclosure harms market efficiency*.

4.3. *A model with a common private signal*

In the baseline model presented in Sections 2 and 3, it was assumed that the firm and informed traders observe differential signals. In this subsection, I consider a variation in which there is only one common private signal that is observed by the firm and all informed traders, and I show that the results go through. Specifically, the asset payoff is changed to:

$$\tilde{v} = \tilde{\theta} + \tilde{\omega}, \tag{36}$$

where $\tilde{\theta} \sim N(0, 1/\tau_\theta)$ (with $\tau_\theta > 0$) is the private information, and $\tilde{\omega} \sim N(0, 1/\tau_\omega)$ (with $\tau_\omega > 0$) is the residual uncertainty.

The firm is endowed with information $\tilde{\theta}$, and rational traders can spend a cost k to acquire the information $\tilde{\theta}$. The public disclosure is now modeled as:

$$\tilde{y} = \tilde{\theta} + \tilde{\eta} \quad \text{where } \tilde{\eta} \sim N(0, 1/\tau_\eta) \text{ with } \tau_\eta \geq 0, \tag{37}$$

where τ_η controls the disclosure quality (i.e., a high τ_η indicates a precise disclosure). The noise trading is still $\tilde{u} \sim N(0, 1/\tau_u)$ with $\tau_u \geq 0$. The underlying random variables $\{\tilde{\theta}, \tilde{\omega}, \tilde{\eta}, \tilde{u}\}$ are mutually independent. The rest of the model structure is kept the same as the baseline model.

The price function becomes:

$$\tilde{p} = a + b\tilde{\theta} + c\tilde{y} - d\tilde{u}, \tag{38}$$

where the coefficients a, b, c, and d are endogenous. Market efficiency and the cost of capital are still defined by (21) and (23), respectively. I then can go through steps that are similar to those in Sections 2 and 3 and show that Propositions 2 and 3 continue to hold in this economy. That is, disclosure reduces the production of private information, and disclosure can non-monotonically affect market efficiency and the cost of capital. Formally, I posit Proposition 6.

Proposition 6 (*Common private signal*). *Suppose that informed traders and the firm have access to the same private signal $\tilde{\theta}$ as in* (36). *Then,* (a) *disclosure reduces the equilibrium mass λ^* of informed traders* (*i.e.,* $d\lambda^*/d\tau_\eta < 0$); (b) *when* $\max\{\tau_\omega/(e^{2\gamma k} - 1) - \tau_\theta - (\tau_\omega/\gamma)^2 \tau_u, 0\} < \tau_\eta < \max\{\tau_\omega/(e^{2\gamma k} - 1) - \tau_\theta, 0\}$, *increasing the disclosure level τ_η will decrease market efficiency M and increase the cost of capital COC*; *otherwise, increasing τ_η will increase M and decrease COC.*

5. Conclusion

In this paper, I propose a parsimonious rational expectations equilibrium model with disclosure in order to comprehensively examine the consequences of disclosure on price discovery and the cost of capital. By introducing endogenous private information production into a theoretical framework, the model generates interesting results with regard to the economic consequences of disclosure. It shows that disclosure either improves or harms market efficiency and the cost of capital, depending on whether investors' private information production is sensitive to disclosure. The implied non-monotonic relationship between disclosure and the cost of capital helps to reconcile the mixed empirical evidence on the cost of capital effect of disclosure and generates applications such as the optimal disclosure policies of firms. The non-monotonicity is robust to various model assumptions. I have also shown that the non-monotonic implications are unique to public disclosure in the sense that varying the private information parameters always monotonically changes market efficiency and the cost of capital.

Appendix A. Literature on disclosure and the cost of capital

In this Appendix, I summarize some empirical studies to illustrate the inclusiveness of the evidence on the relation between disclosure and the cost of capital. The literature on this topic is voluminous, and the summary provides only a key sampling of the related material. The summary only covers some recent studies using direct measures of the cost of capital (i.e., the estimated implied cost of capital, the internal rate of return, and the realized return). There are many studies using indirect cost of capital proxies such as proxies of priced risk (e.g., Dhaliwal, Spicer, and Vickrey, 1979; Prodhan and Harris, 1989), proxies of transaction cost or information asymmetry (e.g., Prodhan and Harris, 1989; Leuz and Verrecchia, 2000; Mohd, 2005). For more complete literature reviews of disclosure, see Core (2001), Leuz and Wysocki (2008), and Beyer, Cohen, Lys, and Walther (2010).

Articles	Key findings	Proxy of disclosure	Proxy of the cost of capital	Relation b/n disclosure and the COC
Hail (2002)	There is a negative association between the firms' voluntary disclosure and the implied cost of capital for a sample of 73 Swiss firms. The firms with the highest disclosure levels enjoy about a 1.8% to 2.4% cost advantage over the least disclosed firms	Disclosure scores based on voluntary disclosure in the annual report	The internal rate of return	Negative
Botosan and Plumlee (2002)	The cost of equity capital decreases in the annual report disclosure level but increases in the level of timely disclosures	(AIMR report based) Annual report disclosure levels; the level of timely disclosure	The internal rate of return	Mixed
Francis, LaFond, Olsson, and Schipper (2004)	The authors find that firms with favorable values of seven attributes of earnings have lower costs of capital than firms with unfavorable values. The attributes of earnings include accrual quality, persistence, predictability, smoothness, value relevance, timeliness, and conservatism	Accrual quality, persistence, predictability, smoothness, value relevance, timeliness, and conservatism	The implied cost of equity capital	Negative
Gomes, Borton, and Madureira (2007)	This paper provides evidence that adoption of Reg FD[a] caused a significant reallocation of information-producing resources, resulting in a higher cost of capital for small firms	Regulation Fair Disclosure (Reg FD)	A dummy variable investigating shifts in the cost of capital unrelated to the three Fama-French risk factors	Positive (small firms)
Duarte, Han, Harford, and Young (2008)	The authors investigate the impact of Regulation FD on firms' cost of capital and find no change in the cost of capital	Regulation Fair Disclosure (Reg FD)	Expected stock returns estimated from the Fama-French model	Mixed

	for AMEX and NYSE firms and a small increase in the cost of capital for NASDAQ firms			
Francis, Nanda, and Olsson (2008)	The authors investigate the relations among voluntary disclosure, earnings quality, and the cost of capital and find that the documented negative association between disclosure and the cost of capital is substantially reduced or completely disappears when controlling for earnings quality	Voluntary disclosure measures (management forecast and conference calls)	Expected stock returns estimated based on the value line forecasts	Mixed
Chen, Dhliwal, and Xie (2010)	The authors find that the cost of equity capital declines in the post-Reg. FD period relative to the pre-Reg. FD period, on average, for a broad cross-section of U.S. firms	Regulation Fair Disclosure (Reg FD)	Implied cost of equity capital	Negative
McInnis (2010)	The author finds no implications of earnings smoothness for average stock returns and a firm's implied cost of capital after adjusting for analysts' biases in their earnings forecasts.[b]	Earnings smoothness	Realized stock returns; estimated implied cost of capital	No relation
Bhattacharya, Ecker, Olsson, and Schipper (2012)	The authors investigate the direct and indirect paths between earnings quality and the cost of equity and find that both direct and indirect paths are mediated by information asymmetry	Accruals quality; absolute abnormal accruals; earnings variability	Expected stock returns estimated based on the Value Line forecasts	Mixed

[a] Regulation Fair Disclosure is aimed at stopping the practice of “selective disclosure,” in which companies give material information only to certain selected analysts and institutional investors prior to disclosing it publicly (“selective disclosure”).
[b] McInnis (2010) indicates that the bias in analysts forecasts may drive the apparent association between accruals quality and a firm's implied cost of capital.

Appendix B. Proofs

Proof of Proposition 1. Substituting the demand functions into the market clearing condition delivers:

$$\lambda\frac{(\tau_v\overline{v}+\tau_\eta\widetilde{y}+\tau_p\widetilde{s}_p+\tau_\varepsilon\widetilde{v})-(\tau_v+\tau_\eta+\tau_p+\tau_\varepsilon)\widetilde{p}}{\gamma}+(1-\lambda)\frac{(\tau_v\overline{v}+\tau_\eta\widetilde{y}+\tau_p\widetilde{s}_p)-(\tau_v+\tau_\eta+\tau_p)\widetilde{p}}{\gamma}=S+\widetilde{u}.$$

Inserting $\widetilde{s}_p=\widetilde{v}-(d/b)\widetilde{u}$ into the above equation and solving $\widetilde{p}$ yields:

$$\widetilde{p}=\frac{\tau_v\overline{v}-\gamma S}{\tau_v+\tau_\eta+\tau_p+\lambda\tau_\varepsilon}+\frac{\tau_p+\lambda\tau_\varepsilon}{\tau_v+\tau_\eta+\tau_p+\lambda\tau_\varepsilon}\widetilde{v}+\frac{\tau_\eta}{\tau_v+\tau_\eta+\tau_p+\lambda\tau_\varepsilon}\widetilde{y}-\frac{\tau_p\frac{d}{b}+\gamma}{\tau_v+\tau_\eta+\tau_p+\lambda\tau_\varepsilon}\widetilde{u}. \tag{B.1}$$

Comparing with the conjectured price function in (6), I have:

$$\frac{d}{b}=\frac{\tau_p\frac{d}{b}+\gamma}{\tau_p+\lambda\tau_\varepsilon}\Rightarrow\frac{b}{d}=\frac{\lambda\tau_\varepsilon}{\gamma},$$

and so, $\tau_p=(b/d)^2\tau_u=(\lambda\tau_\varepsilon/\gamma)^2\tau_u$. Again, comparing (B.1) with (6) delivers the expressions of a, b, c, and d in terms of primitive parameters. □

Proof of Proposition 3. Part (a) of the proposition has been proved in the text. I now turn to proving Part (b) when $k<(1/2\gamma)\log(1+\tau_\varepsilon/\tau_v)$.

(b1) If, in addition,

$$B(1;0)<0 \Leftrightarrow k>\frac{1}{2\gamma}\log\left[1+\frac{\tau_\varepsilon}{\tau_v+\left(\frac{\tau_\varepsilon}{\gamma}\right)^2\tau_u}\right],$$

then at $\tau_\eta=0$, it is true that $\lambda^*\in(0,1)$. Hence, *COC* first increases and *M* first decreases with τ_η until a level $\hat{\tau}_\eta^0$ such that $\lambda^*=0$, with $\hat{\tau}_\eta^0$ determined by:

$$B\left(0;\hat{\tau}_\eta^0\right)=0 \Rightarrow \hat{\tau}_\eta^0=\frac{\tau_\varepsilon}{e^{2\gamma k}-1}-\tau_v.$$

Once $\tau_\eta>\hat{\tau}_\eta^0$, *COC* starts to decrease, and *M* starts to increase with τ_η.

(b2) If $k\le(1/2\gamma)\log[1+\tau_\varepsilon/(\tau_v+(\tau_\varepsilon/\gamma)^2\tau_u)]$, then at $\tau_\eta=0$ it is true that $\lambda^*=1$. So, *COC* first decreases and *M* first increases with τ_η until a level $\hat{\tau}_\eta^1$ such that $\lambda^*=1$, with $\hat{\tau}_\eta^1$ determined by:

$$B\left(1;\hat{\tau}_\eta^1\right)=0 \Rightarrow \tau_\eta^1=\frac{\tau_\varepsilon}{e^{2\gamma k}-1}-\tau_v-\left(\frac{\tau_\varepsilon}{\gamma}\right)^2\tau_u.$$

Once $\tau_\eta>\hat{\tau}_\eta^1$, the pattern becomes the same as (b1). □

Proof of Corollary 1. (a) If $\tau_\varepsilon/(e^{2\gamma k}-1)-\tau_v\le 0$, then by Proposition 3, *COC* decreases with τ_η for all $\tau_\eta>0$. Thus, over the range of $[0,\tau_m]$, *COC* achieves its minimum at $\tau_\eta^*=\tau_m$.

(b1) If $\tau_\varepsilon/(e^{2\gamma k}-1)-\tau_v-(\tau_\varepsilon/\gamma)^2\tau_u<0<\tau_\varepsilon/(e^{2\gamma k}-1)-\tau_v$, then by Proposition 3, *COC* first increases with τ_η in the range of $[0,\tau_\varepsilon/(e^{2\gamma k}-1)-\tau_v]$ and then decreases in the range of $(\tau_\varepsilon/(e^{2\gamma k}-1)-\tau_v,\infty)$. In addition, when $\tau_\eta=0$, by (25), the cost of capital is:

$$COC_{\tau_\eta=0}=\frac{\gamma S}{\frac{\tau_\varepsilon}{e^{2\gamma k}-1}+\lambda^*_{\tau_\eta=0}\tau_\varepsilon}, \tag{B.2}$$

where $\lambda^*_{\tau_\eta=0}\in(0,1)$ is determined by:

$$\frac{1}{2\gamma}\left[1+\frac{\tau_\varepsilon}{\tau_v+\left(\frac{\lambda^*_{\tau_\eta}\tau_\varepsilon}{\gamma}\right)^2\tau_u}\right]=k. \tag{B.3}$$

Using Eqs. (B.2) and (B.3), I can compute:

$$COC_{\tau_\eta=0}=\frac{\gamma S}{\frac{\tau_\varepsilon}{e^{2\gamma k}-1}+\gamma\sqrt{\frac{\frac{\tau_\varepsilon}{e^{2\gamma k}-1}-\tau_v}{\tau_u}}}. \tag{B.4}$$

Note that in the range of $(\tau_\varepsilon/(e^{2\gamma k}-1)-\tau_v,\infty)$, it is true that $\lambda^*=0$, and thus, by (23),

$$COC=\frac{\gamma S}{\tau_v+\tau_\eta}. \tag{B.5}$$

So, as $\tau_\eta\to\infty$, *COC* will approach 0. This implies that there exists a $\tau_\eta^b\in(\tau_\varepsilon/(e^{2\gamma k}-1)-\tau_v,\infty)$ such that $COC<COC_{\tau_\eta=0}$ if $\tau_\eta>\tau_\eta^b$. By (B.4) and (B.5),

$$\tau_v+\tau_\eta^b=\frac{\tau_\varepsilon}{e^{2\gamma k}-1}+\gamma\sqrt{\frac{\frac{\tau_\varepsilon}{e^{2\gamma k}-1}-\tau_v}{\tau_u}} \Rightarrow \tau_\eta^b=\frac{\tau_\varepsilon}{e^{2\gamma k}-1}+\gamma\sqrt{\frac{\frac{\tau_\varepsilon}{e^{2\gamma k}-1}-\tau_v}{\tau_u}}-\tau_v.$$

Therefore, when $\tau_m \le \tau_\eta^b$, τ_η can take values over the range of $[0,\tau_m] \subseteq [0,\tau_\eta^b]$, and COC achieves its minimum at $\tau_\eta = 0$. Once $\tau_m > \tau_\eta^b$, τ_η can take values over the range of $[0,\tau_m] \supseteq [0,\tau_\eta^b]$, and COC achieves its minimum at $\tau_\eta = \tau_m \ge \tau_\eta^b$.

(b2) If $\tau_\varepsilon/(e^{2\gamma k}-1)-\tau_v-(\tau_\varepsilon/\gamma)^2\tau_u \ge 0$, then, by Proposition 3, COC first decreases in τ_η in the range of $[0,\tau_\varepsilon/(e^{2\gamma k}-1)-\tau_v-(\tau_\varepsilon/\gamma)^2\tau_u]$, then increases in τ_η in the range of $[\tau_\varepsilon/(e^{2\gamma k}-1)-\tau_v-(\tau_\varepsilon/\gamma)^2\tau_u,\ \tau_\varepsilon/(e^{2\gamma k}-1)-\tau_v]$, and finally starts to decrease in τ_η in the range of $(\tau_\varepsilon/(e^{2\gamma k}-1)-\tau_v,\infty)$. When $\tau_\eta = \tau_\varepsilon/(e^{2\gamma k}-1)-\tau_v-(\tau_\varepsilon/\gamma)^2\tau_u$, it is true that $\lambda^* = 1$, and by Eq. (25) the cost of capital is given by:

$$COC_{\tau_\eta = \tau_\varepsilon/(e^{2\gamma k}-1)-\tau_v-(\tau_\varepsilon/\gamma)^2\tau_u} = \frac{\gamma S}{\dfrac{\tau_\varepsilon}{e^{2\gamma k}-1}+\tau_\varepsilon}. \tag{B.6}$$

Again, when $\tau_\eta > \tau_\varepsilon/(e^{2\gamma k}-1)-\tau_v$, λ^* is equal to 0, and COC is given by (B.5), which gradually decreases to 0 as τ_η approaches ∞. So, there exists a $\tau_\eta^c \in (\tau_\varepsilon/(e^{2\gamma k}-1)-\tau_v,\infty)$, such that $COC < COC_{\tau_\eta=0}$ if $\tau_\eta > \tau_\eta^b$. By (B.5) and (B.6), $\tau_v + \tau_\eta^c = \tau_\varepsilon/(e^{2\gamma k}-1)+\tau_\varepsilon \Rightarrow \tau_\eta^b = \tau_\varepsilon/(e^{2\gamma k}-1)+\tau_\varepsilon-\tau_v$. Thus, if $\tau_m \in [\tau_\varepsilon/(e^{2\gamma k}-1)-\tau_v-(\tau_\varepsilon/\gamma)^2\tau_u,\ \tau_\varepsilon/(e^{2\gamma k}-1)+\tau_\varepsilon-\tau_v]$, $\tau_\eta = \tau_\varepsilon/(e^{2\gamma k}-1)-\tau_v-(\tau_\varepsilon/\gamma)^2\tau_u$ minimizes the cost of capital COC, and otherwise $\tau_\eta = \tau_m$ minimizes COC. □

Proof of Proposition 5. Because the text has already established part (a), I now prove parts (b) and (c).

Part (b): Direct computation shows:

$$\begin{aligned}\frac{dCOC}{d\tau_\eta} &= -\frac{\gamma S}{\left(\dfrac{\tau_\varepsilon}{e^{2\gamma\bar{k}\lambda^*}-1}+\lambda^*\tau_\varepsilon\right)^2}\left[\frac{-\tau_\varepsilon(e^{2\gamma\bar{k}\lambda^*})2\gamma\bar{k}}{(e^{2\gamma\bar{k}\lambda^*}-1)^2}+\tau_\varepsilon\right]\frac{d\lambda^*}{d\tau_\eta}\\ &= \frac{\gamma S\tau_\varepsilon\bar{k}\left[\dfrac{1}{\bar{k}}-\dfrac{2\gamma e^{2\gamma\bar{k}\lambda^*}}{(e^{2\gamma\bar{k}\lambda^*}-1)^2}\right]}{\left(\dfrac{\tau_\varepsilon}{e^{2\gamma\bar{k}\lambda^*}-1}+\lambda^*\tau_\varepsilon\right)^2\left[\dfrac{2\lambda^*\tau_\varepsilon^2\tau_u}{\gamma^2}+\dfrac{2\gamma\bar{k}\tau_\varepsilon e^{2\gamma\bar{k}\lambda^*}}{(e^{2\gamma\bar{k}\lambda^*}-1)^2}\right]},\end{aligned} \tag{B.7}$$

where the second equality follows from the expression of $d\lambda^*/d\tau_\eta$ in (32). This implies:

$$\frac{dCOC}{d\tau_\eta} > 0 \Leftrightarrow \frac{1}{\bar{k}}-\frac{2\gamma e^{2\gamma\bar{k}\lambda^*}}{(e^{2\gamma\bar{k}\lambda^*}-1)^2} > 0. \tag{B.8}$$

I can further express this condition as a quadratic function of $e^{2\gamma\bar{k}\lambda^*}$ and show:

$$\frac{1}{\bar{k}}-\frac{2\gamma e^{2\gamma\bar{k}\lambda^*}}{(e^{2\gamma\bar{k}\lambda^*}-1)^2} > 0 \Leftrightarrow \lambda^* > \hat{\lambda}, \tag{B.9}$$

where:

$$\hat{\lambda} \equiv \frac{1}{2\gamma\bar{k}}\log\left(1+\gamma\bar{k}+\sqrt{\gamma^2\bar{k}^2+2\gamma\bar{k}}\right). \tag{B.10}$$

Note that $d\lambda^*/d\tau_\eta < 0$, and thus:

$$\lambda^* > \hat{\lambda} \Leftrightarrow \tau_\eta < \hat{\tau}_\eta, \tag{B.11}$$

where $\hat{\tau}_\eta$ is set such that:

$$\tau_v + \hat{\tau}_\eta + \left(\frac{\hat{\lambda}\tau_\varepsilon}{\gamma}\right)^2\tau_u = \frac{\tau_\varepsilon}{e^{2\gamma\bar{k}\hat{\lambda}}-1}$$

$$\Rightarrow \hat{\tau}_\eta = \frac{\tau_\varepsilon}{\gamma\overline{k}+\sqrt{\gamma^2\overline{k}^2+2\gamma\overline{k}}} - \tau_v - \left(\frac{\tau_\varepsilon}{2\overline{k}\gamma^2}\log\left(1+\gamma\overline{k}+\sqrt{\gamma^2\overline{k}^2+2\gamma\overline{k}}\right)\right)^2\tau_u. \tag{B.12}$$

That is, $dCOC/d\tau_\eta > 0$ if and only if $\tau_\eta < \hat{\tau}_\eta$, with $\hat{\tau}_\eta$ given by (B.12).

Part (c): The expression for MSE is more complicated. Using Eqs. (22), (29), (31), and (32), after massive computation, I can compute:

$$\frac{dMSE}{d\tau_\eta} = \frac{2f(\lambda^*, \tau_u, \tau_\varepsilon, \tau_v, \gamma, S)}{\left[\left(\frac{\tau_\varepsilon}{\gamma}\right)^2\frac{\tau_u 2\lambda^*}{\overline{k}} + \frac{2\gamma\tau_\varepsilon e^{2\gamma k^*}}{(e^{2\gamma k^*}-1)^2}\right]\left(\tau_v+\tau_\eta+\left(\frac{\lambda^*\tau_\varepsilon}{\gamma}\right)^2\tau_u+\lambda^*\tau_\varepsilon\right)^3}, \tag{B.13}$$

where:

$$\begin{aligned} & f(\lambda^*, \tau_u, \tau_\varepsilon, \tau_v, \gamma, S) \\ & \equiv \left(\tau_\varepsilon\overline{k}^{-1}[\gamma^2(S^2+\tau_u^{-1})+\lambda^*\tau_\varepsilon] - \gamma\left\{\begin{array}{l}\left[\tau_v+\tau_\eta+\left(\frac{\lambda^*\tau_\varepsilon}{\gamma}\right)^2\tau_u+\frac{1}{\tau_\varepsilon}\left(\tau_v+\tau_\eta+\left(\frac{\lambda^*\tau_\varepsilon}{\gamma}\right)^2\tau_u\right\}^2\right] \\ \times\left[\tau_v+\tau_\eta+\left(\frac{\lambda^*\tau_\varepsilon}{\gamma}\right)^2\tau_u+2\gamma^2\left(S^2+\tau_u^{-1}\right)+3\lambda^*\tau_\varepsilon\right]\end{array}\right)\right). \end{aligned} \tag{B.14}$$

Thus, the sign of $dMSE/d\tau_\eta$ is determined by $f(\lambda^*, \tau_u, \tau_\varepsilon, \tau_v, \gamma, S)$, which is a fourth-order polynomial in λ^*. It is difficult to give an analytical expression as I did for the cost of capital, so, I examine the limiting case of $\tau_u \approx 0$, which implies that $(S^2+\tau_u^{-1}) \approx \infty$, and hence:

$$f(\lambda^*, \tau_u, \tau_\varepsilon, \tau_v, \gamma, S) \approx \left(\tau_\varepsilon\overline{k}^{-1} - 2\gamma\left[\tau_v+\tau_\eta+\frac{1}{\tau_\varepsilon}(\tau_v+\tau_\eta)^2\right]\right)\gamma^2\left(S^2+\tau_u^{-1}\right). \tag{B.15}$$

Clearly, if τ_η is very large, the expression of $f(\lambda^*, \tau_u, \tau_\varepsilon, \tau_v, \gamma, S)$ in (B.15) is negative. If τ_η is very small, then $f(\lambda^*, \tau_u, \tau_\varepsilon, \tau_v, \gamma, S) \approx \tau_v[\tau_\varepsilon/\tau_v - 2\gamma(1+\tau_v/\tau_\varepsilon)]\gamma^2(S^2+\tau_\mu^{-1})$. If, in addition, τ_ε/τ_v is large, then $f(\lambda^*, \tau_u, \tau_\varepsilon, \tau_v, \gamma, S)$ is positive. □

Proof for the Results in Section 4.3. In this section, I characterize the equilibrium in an economy in which informed traders and the firm are informed of the same private signal, and I also show Proposition 6 along the way.

Financial market equilibrium: For informed traders, their information set is $\{\widetilde{p}, \widetilde{y}, \widetilde{\theta}\}$. In the presence of $\widetilde{\theta}$, the price $\widetilde{p}$ and the public signal $\widetilde{y}$ are redundant in predicting $\widetilde{v}$, and therefore:

$$\mathrm{E}(\widetilde{v}|\widetilde{\theta}) = \widetilde{\theta}, \quad Var(\widetilde{v}|\widetilde{\theta}) = 1/\tau_\omega. \tag{B.16}$$

As a result, the demand function is:

$$DI\left(\widetilde{p}, \widetilde{y}, \widetilde{\theta}\right) = \frac{\mathrm{E}(\widetilde{v}|\widetilde{\theta}) - \widetilde{p}}{\gamma Var(\widetilde{v}|\widetilde{\theta})} = \frac{\tau_\omega(\widetilde{\theta}-\widetilde{p})}{\gamma}. \tag{B.17}$$

For uninformed traders, the information set is $\{\widetilde{p}, \widetilde{y}\}$, and the price is equivalent to the following signal in predicting $\widetilde{v}$:

$$\widetilde{s}_p = \frac{\widetilde{p}-a-c\widetilde{y}}{b} = \widetilde{\theta} - \frac{d}{b}\widetilde{u}, \tag{B.18}$$

which has a precision of:

$$\tau_p = (b/d)^2\tau_u. \tag{B.19}$$

The forecast and demand function are:

$$\mathrm{E}(\widetilde{v}|\widetilde{p},\widetilde{y}) = \frac{\tau_\eta \widetilde{y} + \tau_p \widetilde{s}_p}{\tau_\theta + \tau_\eta + \tau_p}, \quad Var(\widetilde{v}|\widetilde{p},\widetilde{y}) = \frac{1}{\tau_\theta + \tau_\eta + \tau_p} + \frac{1}{\tau_\omega}, \tag{B.20}$$

$$DU(\widetilde{p},\widetilde{y}) = \frac{\mathrm{E}(\widetilde{v}|\widetilde{p},\widetilde{y}) - \widetilde{p}}{\gamma Var(\widetilde{v}|\widetilde{p},\widetilde{y})} = \frac{(\tau_\eta \widetilde{y} + \tau_\eta \widetilde{s}_p)\tau_\omega - (\tau_\theta + \tau_\eta + \tau_p)\tau_\omega \widetilde{p}}{\gamma(\tau_\theta + \tau_\eta + \tau_p + \tau_\omega)}. \tag{B.21}$$

The market-clearing condition is $\lambda DI(\widetilde{p},\widetilde{y},\widetilde{\theta}) + (1-\lambda)DU(\widetilde{p},\widetilde{y}) = S + \widetilde{u}$. Plugging the expressions of $DI(\widetilde{p},\widetilde{y},\widetilde{\theta})$, $DU(\widetilde{p},\widetilde{y})$, and $\widetilde{s}_p$ into the market-clearing condition and solving $\widetilde{p}$ delivers:

$$\widetilde{p} = -\frac{\dfrac{\dfrac{\gamma}{\tau_\omega}S}{\tau_\theta+\tau_\eta+\tau_p+\lambda\tau_\omega}}{\tau_\theta+\tau_\eta+\tau_p+\tau_\omega} + \frac{\dfrac{\lambda + \dfrac{(1-\lambda)\tau_p}{\tau_\theta+\tau_\eta+\tau_p+\tau_\omega}}{\tau_\theta+\tau_\eta+\tau_p+\lambda\tau_\omega}}{\tau_\theta+\tau_\eta+\tau_p+\tau_\omega}\widetilde{\theta} + \frac{\dfrac{\dfrac{(1-\lambda)\tau_\eta}{\tau_\theta+\tau_\eta+\tau_p+\tau_\omega}}{\tau_\theta+\tau_\eta+\tau_p+\lambda\tau_\omega}}{\tau_\theta+\tau_\eta+\tau_p+\tau_\omega}\widetilde{y} - \frac{\dfrac{\dfrac{(1-\lambda)\frac{d}{b}\tau_p}{\tau_\theta+\tau_\eta+\tau_p+\tau_\omega} + \dfrac{\gamma}{\tau_\omega}}{\tau_\theta+\tau_\eta+\tau_p+\lambda\tau_\omega}}{\tau_\theta+\tau_\eta+\tau_p+\tau_\omega}\widetilde{u}. \tag{B.22}$$

Comparing (B.22) with (38) implies that:

$$\frac{b}{d} = \frac{\dfrac{\dfrac{\lambda + \dfrac{(1-\lambda)\tau_p}{\tau_\theta+\tau_\eta+\tau_p+\tau_\omega}}{\tau_\theta+\tau_\eta+\tau_p+\lambda\tau_\omega}}{\tau_\theta+\tau_\eta+\tau_p+\tau_\omega}}{\dfrac{\dfrac{\dfrac{(1-\lambda)\frac{d}{b}\tau_p}{\tau_\theta+\tau_\eta+\tau_p+\tau_\omega} + \dfrac{\gamma}{\tau_\omega}}{\tau_\theta+\tau_\eta+\tau_p+\lambda\tau_\omega}}{\tau_\theta+\tau_\eta+\tau_p+\tau_\omega}} \Rightarrow \frac{b}{d} = \frac{\lambda\tau_\omega}{\gamma} \Rightarrow \tau_p = \left(\frac{\lambda\tau_\omega}{\gamma}\right)^2 \tau_u, \tag{B.23}$$

$$a = -\frac{(\tau_\theta+\tau_\eta+\tau_p+\tau_\omega)\dfrac{\gamma}{\tau_\omega}}{\tau_\theta+\tau_\eta+\tau_p+\lambda\tau_\omega}, \quad b = \frac{\lambda(\tau_\theta+\tau_\eta+\tau_\omega)+\tau_p}{\tau_\theta+\tau_\eta+\tau_p+\lambda\tau_\omega},$$

$$c = \frac{(1-\lambda)\tau_\eta}{\tau_\theta+\tau_\eta+\tau_p+\lambda\tau_\omega}, \quad d = \frac{\dfrac{\lambda\tau_\omega}{\gamma}\tau_u + \dfrac{\gamma}{\tau_\omega}(\tau_\theta+\tau_\eta+\tau_\omega)}{\tau_\theta+\tau_\eta+\tau_p+\lambda\tau_\omega}.$$

The cost of capital and MSE can be computed as follows:

$$COC \equiv \mathrm{E}(\widetilde{v} - \widetilde{p}) = \frac{(\tau_\theta+\tau_\eta+\tau_p+\tau_\omega)\dfrac{\gamma}{\tau_\omega}}{\tau_\theta+\tau_\eta+\tau_p+\lambda\tau_\omega}S, \tag{B.24}$$

and

$$\begin{aligned} MSE \equiv \mathrm{E}\left[(\widetilde{v}-\widetilde{p})^2\right] &= \left\{\frac{(\tau_\theta+\tau_\eta+\tau_p+\tau_\omega)\dfrac{\gamma}{\tau_\omega}}{\tau_\theta+\tau_\eta+\tau_p+\lambda\tau_\omega}S\right\}^2 + \frac{1}{\tau_\omega} \\ &+ \frac{(1-\lambda)^2(\tau_\theta+\tau_\eta) + \left\{(1-\lambda)\dfrac{\lambda\tau_\omega}{\gamma}\tau_u + \dfrac{\gamma}{\tau_\omega}(\tau_\theta+\tau_\eta+\tau_p+\tau_\omega)\right\}^2\tau_u^{-1}}{(\tau_\theta+\tau_\eta+\tau_p+\lambda\tau_\omega)^2}. \end{aligned} \tag{B.25}$$

Direct computation shows that when λ is fixed at a constant value, increasing τ_η will decrease *COC* and *MSE*.

Information market equilibrium: Similar to the main text, the benefit of acquiring the signal $\widetilde{\theta}$ is:

$$B(\lambda;\tau_\eta) = \frac{1}{2\gamma}\log\left[\frac{Var(\widetilde{v}|\widetilde{p},\widetilde{y})}{Var(\widetilde{v}|\widetilde{\theta})}\right] - k = \frac{1}{2\gamma}\log\left[\frac{\tau_\omega}{\tau_\theta+\tau_\eta+\left(\dfrac{\lambda\tau_\omega}{\gamma}\right)^2\tau_u} + 1\right] - k. \tag{B.26}$$

So, if $\lambda^* \in (0,1)$, or, equivalently, if:

$$\frac{1}{2\gamma}\log\left[\frac{\tau_\omega}{\tau_\theta+\tau_\eta+\left(\frac{\tau_\omega}{\gamma}\right)^2\tau_u}+1\right] < k < \frac{1}{2\gamma}\log\left[\frac{\tau_\omega}{\tau_\theta+\tau_\eta}+1\right]$$

$$\Leftrightarrow \frac{\tau_\omega}{e^{2\gamma k}-1}-\tau_\theta-\left(\frac{\tau_\omega}{\gamma}\right)^2\tau_u < \tau_\eta < \frac{\tau_\omega}{e^{2\gamma k}-1}-\tau_\theta, \tag{B.27}$$

then:

$$B(\lambda^*;\tau_\eta)=0 \Rightarrow \tau_\theta+\tau_\eta+\left(\frac{\lambda^*\tau_\omega}{\gamma}\right)^2\tau_u=\frac{\tau_\omega}{e^{2\gamma k}-1}. \tag{B.28}$$

Eq. (B.28) implies that increasing τ_η decreases λ^* (i.e., $d\lambda^*/d\tau_\eta<0$), which is part (a) of Proposition 6.

When $\lambda^* \in (0,1)$, by (B.24), (B.25), and (B.28), I have:

$$COC=\frac{\frac{e^{2\gamma k}}{e^{2\gamma k}-1}\gamma S}{\frac{\tau_\omega}{e^{2\gamma k}-1}+\lambda^*\tau_\omega}, \tag{B.29}$$

and

$$MSE=\frac{1}{\tau_\omega}+\frac{\left(\frac{e^{2\gamma k}}{e^{2\gamma k}-1}\gamma S\right)^2+\left(\frac{e^{2\gamma k}}{e^{2\gamma k}-1}\gamma\right)^2\tau_u^{-1}+(1-\lambda^*)^2\frac{\tau_\omega}{e^{2\gamma k}-1}+2(1-\lambda^*)\lambda^*\frac{e^{2\gamma k}}{e^{2\gamma k}-1}\tau_\omega}{\left(\frac{\tau_\omega}{e^{2\gamma k}-1}+\lambda^*\tau_\omega\right)^2}. \tag{B.30}$$

Again, τ_η affects COC and MSE only through its effect on λ^*. Direct computation shows that $dCOC/d\lambda^*<0$ and that:

$$\frac{dMSE}{d\lambda^*}=-2\tau_\omega\left(\frac{e^{2\gamma k}}{e^{2\gamma k}-1}\right)^2\frac{\gamma^2S^2+\gamma^2\tau_u^{-1}+\lambda^*\tau_\omega}{\left(\frac{\tau_\omega}{e^{2\gamma k}-1}+\lambda^*\tau_\omega\right)^3}<0.$$

Given $d\lambda^*/d\tau_\eta<0$ when $\lambda^*\in(0,1)$, it must be true that $dCOC/d\tau_\eta>0$ and $dMSE/d\tau_\eta>0$. Note that $\lambda^*\in(0,1)$ if and only if condition (B.27) is satisfied. When condition (B.27) is not satisfied, λ^* is fixed at 0 or 1, and hence $dCOC/d\tau_\eta<0$ and $dMSE/d\tau_\eta<0$, as shown in the financial market equilibrium. This completes the proof of parts (b) and (c). □

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