Regulation FD, Analysts' Information Acquisition, and the Public Goods Problem

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Abstract

Analysts collect their own information to improve the precision of their earnings forecast. However, once the Regulation Fair Disclosure (FD) takes effect and information includes the aspect of public goods, individual analysts are expected to begin free-riding on information acquired by other analysts. This paper develops a model in which analysts decide whether or not to collect costly information, and an investor predicts earnings based on the analysts' behavior. The findings of this paper include, under Regulation FD, as the number of analysts grows, the motivation to collect information becomes weaker, and analysts depend on public information only. Further, without Regulation FD, an increase in the number of analysts has a nonnegative effect on the investor's predictive ability. Finally, under Regulation FD, the investor's predictive ability is at a low level compared to a case without the Regulation. It is noteworthy that Reg FD, which intends to improve the information environment surrounding security market participants, has these unintended consequences.

Keywords
Earnings forecast, Forecast accuracy, Regulation FD, Free-rider, Public information

(1) Introduction

Mitigation of the information asymmetry among security market participants is seen as major purpose of disclosure regulation. The Regulation Fair Disclosure (hereafter "Reg FD"), which was enacted in 2000 in the United States, prohibits firms from privately disclosing important information to select investors or analysts without simultaneously disclosing the same information to the public. As a result, enactment of Reg FD has banned so-called selective disclosure, which comprises that firms transmit material information only to particular participants. Further, a regulation with the same effect as Reg FD will be introduced in Japan in the near future. The purpose of this paper is to investigate the effect of Reg FD on analysts' information acquisition and the investor's predictive ability.

There are abundant prior researches that empirically inquire how Reg FD affected analysts and investors. Concerning analysts, enactment of Reg FD has (1) increased (or decreased) the number of analysts who follow the firm (Irani and Karamanou 2003; Mohanram and Sunder 2006; Gomes et al. 2007); (2) rendered analysts' information acquisition active (or inactive) (Mohanram and Sunder 2006; Janakiraman et al. 2007; Mensah and Yang 2008; Kross and Suk 2012; Hahn and Song 2013); and (3) improved (or worsened) the precision of analysts' forecasts(Irani and Karamanou 2003; Heflin et al. 2003; Bailey et al. 2003; Agrawal et al. 2006; Francis et al. 2006; Mohanram and Sunder 2006; Gomes et al. 2007; Srinidhi et al. 2009; Kross and Suk 2012). With respect to investors, enactment of Reg FD has (1) changed (or not changed) their information environment (Heflin et al. 2003; Francis et al. 2006; Ahmed and Schneible 2007) and (2) reduced (or expanded) information asymmetry among investors (Eleswarapu et al. 2004; Chiyachantana et al. 2004; Gomes et al. 2007; Sidhu et al. 2008; Duarte et al. 2008; Chen et al. 2010). These prior studies do not necessarily come to the same conclusion. On the contrary, some opposing results are presented.

Arya et al. (2005) investigate Reg FD analytically. Their model, which includes two analysts and a representative investor, reveals the following. First, if the firm discloses information to all players (two analysts and an investor), an information cascade will arise among them so that the investor's predictive ability will worsen. Second, if the information is offered to only one analyst (in other words, the firm issues a selective disclosure), cascade formation may be restrained and the investor is better off. Lastly, under Reg FD, the firm may decide not to disclose information intentionally in order to improve the investor's predictive ability.

The work of Arya et al. (2005) is closely related to this paper. Both studies pay attention to the nature of the influence of Reg FD on analysts and investors. They differ in the following point: Arya et al. (2005) is concerned with the information cascade caused by Reg FD, while this study focuses on a particular phenomenon, namely that Reg FD renders information a public good. Therefore, Arya et al. (2005) see analysts as rational decision-makers, but they do not consider the strategic interactions of analysts. On the other hand, this study sees analysts as strategic agents who rationally expect other agents' incentive. In particular, the study pays attention to the motivation of analysts to be free-riders in information collection. In general, most firms are covered by multiple analysts. Therefore, to gain deeper insight into analysts' decision-making, a study of their behavior in the presence of rivals is needed. As mentioned above, a model is developed to examine the influence of Reg FD on analysts' information collection and the investor's predictive ability, while taking analysts' strategies into account.

The paper is organized as follows. Section 2 presents the model and derives an equilibrium. Section 3 shows the comparative statics and discusses the case where Reg FD is not enforced. Section 4 concludes.

(2) Model

There are n analysts and a representative investor who are forecasting the firm's forthcoming earnings. The variable n is a positive integer and larger than one. The forthcoming earnings of the firm, which are denoted by θ, are the realization of a random variable $\tilde{\theta}$, where $\tilde{\theta} \sim N(0, 1/\omega)$. Note that tilde ("~") represents a random variable.

All analysts and the investor obtain public information (or signals) $\tilde{y}$ released by the firm at no charge. Assume that public information $\tilde{y}$ is represented by:

$$\tilde{y} = \tilde{\theta} + \tilde{\eta},$$

where $\tilde{\eta}$ represents the prediction error and $\tilde{\eta} \sim N(0, 1/\alpha)$. Managers' initial earnings forecast, which is made public (so-called "management forecast"), illustrates $\tilde{y}$.

Analysts can extract additional (private) information (or signals) with an effort from manager, and c_i denotes the cost of effort incurred by analyst i. Assume that signal $\tilde{x}$ is represented by:

$$\tilde{x} = \tilde{\theta} + \tilde{\varepsilon},$$

where $\tilde{\varepsilon}$ represents the prediction error and $\tilde{\varepsilon} \sim N(0, 1/\beta)$. One of the examples of $\tilde{x}$ is the manager's own prospect, which is not expressed in the management forecast. To avoid being pursued as responsible for the wrong prediction, this study assumes that the manager will not venture to release his prospect voluntarily. However, if he is interviewed by analysts, he will reveal it in a passive manner. The cost of acquiring $\tilde{x}$, which is dependent on the ability to extract information from the manager, differs among analysts. Suppose that each analyst observes his c_i, but cannot know another analyst's cost. He only knows that another analyst's cost is a random variable that is uniformly distributed in [0,1].[1] Meanwhile, the investor does not have access to a manager, and he cannot obtain $\tilde{x}$ on his own. Assume that $\tilde{\theta}$, $\tilde{\eta}$, and $\tilde{\varepsilon}$ are mutually independent.[2]

To begin with, the analysts' behavior is considered. According to the so-called projection theorem, an analyst, who has observed y and x, will expect

[1] Because there is no reason to specify the distribution of c_i a priori, it is assumed that c_i distributes uniformly on [0,1]. Alternatively, even if the distribution function of c_i is assumed to be a monotone increasing function that is continuous on [0,1], the main results (except for Corollary 1) remain unchanged. For convenience, it is assumed that c_i is a uniformly distributed random variable on [0,1].

[2] Due to the release of signals y or x, a firm may incur proprietary costs. However, the decision-making of disclosure by firms is beyond the scope of this work, since proprietary cost is not considered in this model.

that $\tilde{\theta}$ is represented by:

$$\mathrm{E}(\tilde{\theta}|y,x) = \frac{\alpha y + \beta x}{\omega + \alpha + \beta} \quad (1)$$

In this case, the variance of the prediction error is represented by $1/(\omega + \alpha + \beta)$. In contrast, when an analyst does not collect additional information, he can observe only y, and his conditional expectation is represented by:

$$\mathrm{E}(\tilde{\theta}|y) = \frac{\alpha y}{\omega + \alpha} \quad (2)$$

The variance of the prediction error is represented by $1/(\omega + \alpha)$. Assume that, after the formation of expectation, the analysts release their forecast simultaneously, but without communication among them. In this paper, it is assumed that sales of signal x to other analysts are prohibited.[3] In addition, it is assumed that each analyst reveals his expectation truthfully and without garbling.

Based on prior studies (Laster et al. 1999; Lim 2001; Morgan and Stocken 2003; Fischer and Stocken 2010; Kameda et al. 2011), the analyst's payoff function is represented.[4] When an analyst i collects signal x, his payoff is denoted as follows:

$$U_i = \Pi - (a_i - \theta)^2 - c_i \quad (3)$$

where $\Pi\ (\geq 0)$ represents a fixed reward for analysts, a_i represents estimates submitted by the analyst, and c_i is the cost of acquiring $\tilde{x}$.[5] In contrast, when an analyst i does not collect x, the payoff is denoted as follows:

$$U_i = \Pi - (a_i - \theta)^2 \quad (4)$$

As stated above, when an analyst observes $\{y, x\}$, then $a_i = \mathrm{E}(\tilde{\theta}|y,x)$. Further, when he observes $\{y\}$, then $a_i = \mathrm{E}(\tilde{\theta}|y)$. Therefore, in each case, the expected payoff is represented as follows:

$$\begin{aligned} \mathrm{E}U_i &= \mathrm{E}\left[\Pi - \left\{\mathrm{E}(\tilde{\theta}|y,x) - \theta\right\}^2 - c_i\right] \\ &= \Pi - \frac{1}{\omega + \alpha + \beta} - c_i \end{aligned} \quad (5)$$

$$\begin{aligned} \mathrm{E}U_i &= \mathrm{E}\left[\Pi - \left\{\mathrm{E}(\tilde{\theta}|y) - \theta\right\}^2\right] \\ &= \Pi - \frac{1}{\omega + \alpha} \end{aligned} \quad (6)$$

$\Pi - 1/(\omega + \alpha + \beta)$ of equation (5) can be interpreted as the reputation that an analyst gains in the capital market. The remaining amount after deducting c_i is analyst i's expected payoff. Meanwhile, $\Pi - 1/(\omega + \alpha)$ of equation (6) shows that, if the analyst does not collect signal x, his reputation declines, but the cost of information gathering is saved.

Now consider the behavior of a

[3] The assumption that sales of signal x to other analysts is prohibited is based on the following. There are various rules that require financial institutions to build information barriers.
For example, to prevent premature leakage of market-moving information, several SEC and stock exchange rules mandate that the Chinese Wall be set up as an imaginary barrier between the investment banking, corporate finance, and research departments of a brokerage house, and the sales and trading departments (Downes and Goodman 2014). As long as these information barriers exist, transactions of signal x among analysts seem impossible to carry out.

[4] These prior researches consider forecasters' incentive to minimize forecast error by incorporating the quadratic loss term into their utility function.

[5] Unlike the investor, analysts may have an interview with managers. In that case, it is assumed that information acquisition cost is incurred to constant Π. However, none of the conclusions are changed on the assumption that $\Pi = 0$.

representative investor. The investor's objective is to maximize the precision of the forecast, and the analyst's forecast can be utilized at the prediction of forthcoming earnings. Therefore, the investor's action is described as follows. When all analysts submit $\alpha y/(\omega+\alpha)$ as their forecast, the investor adopts $\alpha y/(\omega+\alpha)$ as forecast. In contrast, when an estimate that is different from $\alpha y/(\omega+\alpha)$ is submitted by at least one analyst, the investor adopts the value, for the reason outlined below. Knowledge about signal y raises the investor's expectation that $\mathrm{E}(\tilde{\theta}|y)=\alpha y/(\omega+\alpha)$. Therefore, when the investor observes that the analyst's forecast is equal to $\alpha y/(\omega+\alpha)$, the investor conjectures that the analyst does not know signal x. On the other hand, when the analyst's forecast is not equal to $\alpha y/(\omega+\alpha)$, the investor guesses that the analyst does know signal x, unlike himself. As a result, the precision of the investor's forecast is $\omega+\alpha$ when all of the analysts submit $\alpha y/(\omega+\alpha)$, and is $\omega+\alpha+\beta$ when at least one analyst submits the forecast different from $\alpha y/(\omega+\alpha)$.

There are four stages in this game. In the first stage, each analyst i observes c_i and decides whether to collect signal x or not. In the second stage, analysts simultaneously release forecasts by relying on public information y (and signal x if it had been collected). In the third stage, the investor expects forthcoming earnings based on analysts' forecasts. In the final stage, the realization of $\tilde{\theta}$ (and x if manager offered) are disclosed. In this game, once analysts decide whether or not to collect x during the first stage, analysts and the investor do not face the situation afterwards where they make decisions strategically. Therefore, this study focuses on analysts' decision-making during the first stage.

Hereafter, the case is considered where Reg FD is in force.[6] Under Reg FD, selective disclosure by the firm is prohibited. Hence, if a firm provides information to particular market participants, the firm must simultaneously release the information to the public. In other words, if at least one analyst extracts signal x with a cost, other analysts can simultaneously acquire x without a cost. Therefore, the information set is $\{y,x\}$ for each analyst, and his estimated results are $(\alpha y+\beta x)/(\omega+\alpha+\beta)$. On the other hand, when no one acquires x, every analyst's information set is $\{y\}$ and the estimate is $\alpha y/(\omega+\alpha)$. Now, under Reg FD, the investor comes to know the same information as analysts, and an information disadvantage over analysts disappears. Therefore, note that the analyst's forecast can no longer have information content, and it becomes redundant for the investor under Reg FD.

An expected payoff of analyst i is studied in three different cases. First, when analyst i collects signal x by

[6] The case where Reg FD is not enforced is investigated in Section 3.

himself, the expected payoff is denoted as equation (5). Second, if not only analyst i but also any other analysts do not collect signal x, the expected payoff is represented by equation (6). Lastly, suppose that analyst i does not collect signal x but that someone else collects it. In other words, suppose that analyst i free-rides on others. Then, the expected payoff is represented by:

$$\mathrm{E}U_i = \Pi - \frac{1}{\omega + \alpha + \beta} \tag{7}$$

Free-riding on others makes it possible for an analyst to improve his reputation without the cost of information gathering. Consequently, the expected payoff of equation (7) is higher than that of equation (5).

During the first stage, each analyst i conjectures other analysts' actions and decides whether or not to collect signal x. In this game, if even just one analyst acquires signal x, each analyst's payoff will increase. However, the cost of information acquisition generates the incentive to be a free-rider among analysts. Hereafter, the Bayesian Nash equilibria, consisting of symmetric pure strategies in which each type c_i, with $c_i \leq c^*$, acquires x, whereas every other type does not acquire x, is solved. Consequently, the following Lemma is obtained.

Lemma *The Bayesian Nash equilibrium in this game is the pair of strategies in which each type c_i, with $c_i \leq c^*$, acquires x, whereas other types c_i, with $c_i > c^*$, do not acquire x.*[7] *In addition, there exists a unique $c^* \in (0, 1)$ that satisfies the following equation:*

$$\frac{(1 - c^*)^{n-1}}{c^*} - (\omega + \alpha + \beta)(\omega + \alpha)\beta^{-1} = 0 \tag{8}$$

[Proof] All proofs are described in the Appendix.

As shown in equation (8), it is difficult to solve for c^* explicitly with $n \geq 3$. However, the implicit function theorem shows the behavior of c^*. In the next section, the result of comparative statics that focus on the threshold c^* is shown.

(3) Analysis

1. The Impact on Information Acquisition

The following Proposition states how parameters (such as n, ω, α and β) affect analysts' information acquisition.

Proposition 1 *The sign of the partial derivative of c^* with respect to each of the parameters is represented by:*

$$\frac{\partial c^*}{\partial n} < 0, \quad \frac{\partial c^*}{\partial \omega} < 0, \quad \frac{\partial c^*}{\partial \alpha} < 0, \quad \frac{\partial c^*}{\partial \beta} > 0.$$

We can interpret the result of Proposition 1 as follows. First, the

[7] In the case of $c_i = c^*$, it is indifferent in terms of expected payoff whether or not to acquire signal x. In that case, the model assumes that analysts acquire signal x.

reason why $\partial c^*/\partial n < 0$ is that the larger n becomes, the more analysts rely on other analysts' information collection.[8] In other words, the motivation to be a free-rider arises among analysts, and the tolerable level of the cost of information gathering declines. Therefore, an increase of n leads analysts to neglect to extract information from the manager, so that analysts become dependent on public information only.[9]

Second, the reason why $\partial c^*/\partial \omega < 0$ is shown below. The payoff difference between collecting and not collecting information reduces as ω becomes large. Consequently, the incentive to acquire x in exchange for c_i weakens. In other words, analysts cease to gather additional information as the volatility of earnings decreases.

Third, the reason why $\partial c^*/\partial \alpha < 0$ is that an increase in α reduces the payoff difference between collecting and not collecting information, so that analysts lose the motivation to collect information. Accordingly, if sufficiently precise public information becomes available, additional information acquisition by analysts will be crowded out. Thus, an increase in the value of parameters (such as n, ω, and α) weakens analysts' incentive for information gathering, and increases their dependence on public information.

Finally, the reason why $\partial c^*/\partial \beta > 0$ is that an increase in β enhances the attractiveness of signal x, and hence the tolerable level of the cost of information gathering increases. Consequently, the quality of information activates analysts' collection. In that sense, the effect of β is in contrast to that of α.

2. The Impact on the Investor's Predictive Ability

The discussions are now extended to investigate the impact of parameters on the investor's predictive ability. It is evident that his predictive ability is dependent on analysts' information acquisition behavior. If all analysts do not collect x, then the investor accepts the analyst forecast $\alpha y/(\omega + \alpha)$ as estimate, or predicts by himself, based on signal y. Consequently, the precision of the prediction results in $\omega + \alpha$. On the other hand, if at least one analyst collects x, then the investor accepts the analyst forecast $(\alpha y + \beta x)/(\omega + \alpha + \beta)$ as estimate, or predicts by himself, based on signals y and x. Hence, the precision of the prediction increases to $\omega + \alpha + \beta$. The probability that all analysts do not collect x is $(1 - c^*)^n$, and the probability that at least one analyst collects x is $1 - (1 - c^*)^n$. Then the ex-ante expected precision of the forecast is represented by:

[8] Intrinsically, n is an integer. However, for convenience, it is assumed here to be a real number.

[9] In contrast, Frankel and Li (2004) show that, as the number of analysts covering a firm grows, confidential information leaks out and information asymmetry between insiders and investors diminishes.

$$(1 - c^*)^n \times (\omega + \alpha) + \{1 - (1 - c^*)^n\} \times (\omega + \alpha + \beta)$$

The above function can be rearranged to $\omega + \alpha + \beta - \beta(1 - c^*)^n$. Let it be function g. Hereafter, this study inquires how an increase in n affects the value of g.

Corollary 1 *The sign of $\partial g/\partial n$ depends on the value of threshold c^*. Specifically, when $c^* > 1/2$, then $\partial g/\partial n < 0$ is satisfied. When $c^* = 1/2$, then $\partial g/\partial n = 0$ holds. In addition, when $c^* < 1/2$, then $\partial g/\partial n > 0$ is satisfied.*

As stated above, the effect of n on g varies depending on the value of c^*. When c^* is high or, in other words, when analysts' motivation to collect additional information is weak, the value of g decreases in response to the growth of n. The growth of n has a two-sided effect. The one is negative: the growth of n lowers g, because analysts' incentive to collect information will be dampened. Another is positive: the growth of n increases g, because the possibility that at least one analyst collects x increases. When the threshold c^* is high, the negative effect outweighs the positive effect.[10]

Next, the partial derivative of g with respect to α is represented by;

$$\frac{\partial g}{\partial \alpha} = 1 + \beta n(1 - c^*)^{n-1} \frac{\partial c^*}{\partial \alpha} \tag{9}$$

The sign of $\partial g/\partial \alpha$ is not definite, because an increase in α directly increases g, while an increase in α reduces g due to the reduction of c^*. Here, it is shown that a set of parameters exists that satisfies $\partial g/\partial \alpha < 0$. For example, let $n = 2$, $\omega = 0.5$, $\alpha = 1$, and $\beta = 4$. For these parameter values, $c^* = 0.327$ and $\partial g/\partial \alpha = -0.187$. If the firm controls α to increase g, then the firm must reduce rather than increase α in this case. This result disputes the conventional view that high quality public information leads to improved decision-making by investors. Thus, under Reg FD, as the quality of public information improves, analysts' incentive to collect additional information becomes weaker, and the investor's predictive ability may decline.

Lastly, the partial derivative of g with respect to β is represented by:

$$\frac{\partial g}{\partial \beta} = 1 - (1 - c^*)^n + \beta n(1 - c^*)^{n-1} \frac{\partial c^*}{\partial \beta} > 0 \tag{10}$$

Therefore, the quality of signal x is positively correlated with the value of g. The improvement of β increases g not only directly, but also indirectly through an increase in the probability that signal x is acquired.

3. The Case where Reg FD is not Enforced

So far, the case where Reg FD is in force has been considered. Next, the case where Reg FD is not enforced is considered, and the difference between

[10] Now, $c^* = 1/2$ represents the mean of the probability function of c_i.

the cases is illustrated. In the absence of Reg FD, an analyst cannot free-ride on other's information, because signal x is not shared by analysts. Hence, analyst i collects x only if the value of equation (5) equals or exceeds that of (6). This condition can be simplified as follows:

$$c_i \leq \frac{\beta}{(\omega+\alpha)(\omega+\alpha+\beta)} \tag{11}$$

The right-hand side of equation (11) denotes the threshold of cost that determines an analyst's action.[11] Let the threshold be k^*. It is clear that k^* is independent of n. That is, when Reg FD is not enforced, the number of rivals is irrelevant to the analyst's decision-making.

Now, define an expected precision of the investor's forecast as function h. Then, the following Corollary is derived.

Corollary 2 *Suppose that Reg FD is not enforced. If* $k^* \geq 1$*,* $h = \omega + \alpha + \beta$ *holds regardless of* n*. Meanwhile, if* $k^* < 1$*,* $\partial h/\partial n > 0$ *is satisfied, where* $k^* = \beta/[(\omega+\alpha)(\omega+\alpha+\beta)]$.

Thus, h is a constant function independent of n, or an increasing function of n. That is, in the absence of Reg FD, an increase of n might increase h, but it will never reduce h. In contrast, Corollary 1 states that, under Reg FD, an increase in n may reduce g. Hence, the presence or absence of Reg FD brings about a significant difference in the investor's predictive ability. As described in 3. 2, an increase in n has both positive and negative effects under Reg FD. On the other hand, when Reg FD is not enforced, an increase in n does not bring about a negative effect. Accordingly, without Reg FD, an increase in the number of analysts has a nonnegative effect on the investor's predictive ability.

Lastly, the following Proposition evaluates Reg FD based on the investor's perspective.

Proposition 2 *With respect to the ex-ante expected precision of the investor's forecast,* $g < h$ *is satisfied.*

Thus, in terms of expectation, Reg FD reduces the precision of the investor's forecast. The reason for this is that $c^* < k^*$ or, in other words, Reg FD undermines analysts' incentive to collect information. It is noteworthy that Reg FD, which intends to improve the information environment surrounding security market participants, has these unintended consequences.

(4) Conclusion

This paper develops a model in which analysts, who observed public information, decide whether or not to collect costly information. Under Reg FD, which prohibits selective disclosure, when a firm provides information to a particular analyst, the firm must release the information to other

[11] In the case of $c_i = \beta/[(\omega+\alpha)(\omega+\alpha+\beta)]$, it is assumed that analysts acquire signal x.

analysts at the same time. Hence, individual analysts have the incentive to free-ride on information acquired by other analysts, rather than to collect by themselves.

The findings of this paper include, under Regulation FD, that as the number of analysts grows, their motivation to collect information becomes weaker, and they depend only on public information. Further, without Regulation FD, an increase in the number of analysts has a nonnegative effect on the investor's predictive ability. Finally, under Regulation FD, the investor's predictive ability is at a low level compared to a case without the regulation. Thus, under Reg FD, the motivation to be a free-rider arises among analysts, and impairs the investor's predictive ability. The results of this paper clarifies an aspect of Reg FD which has not been pointed out yet.

However, two considerations remain unexplored. The first relates to the endogeneity of parameters. It has been assumed that the number of analysts is an exogenous variable. However, analysts decide whether to enter the market while taking the competitive environment into consideration. Hence, endogenization of the number of analysts must be addressed in the future. The second consideration relates to additionally collected information. This study assumed that signal x is common to all analysts. How will conclusion be altered under the premise that a signal is different for each analyst? Further studies are required to clarify these considerations.

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Appendix

Proof of Lemma

It is assumed that any analyst i adopts a strategy in which he collects x only if $c_i \leq c^*$. Suppose that analyst i does not acquire signal x. In addition, suppose that other analysts do not acquire signal x. Then, a value of multiplying occurrence probabilities of the event by analyst i's expected payoff is represented by:

$$(1-c^*)^{n-1} \times \left(\Pi - \frac{1}{\omega+\alpha}\right)$$

Next, suppose that analyst i does not acquire x, but at least one analyst acquires x. Then, a value of multiplying occurrence probabilities of the event by analyst i's expected payoff is represented by:

$$\{1-(1-c^*)^{n-1}\} \times \left(\Pi - \frac{1}{\omega+\alpha+\beta}\right)$$

Lastly, suppose that analyst i acquires x by himself. Then his expected payoff is represented by:

$$\Pi - \frac{1}{\omega+\alpha+\beta} - c_i$$

Hereafter, I c^* is solved for using the same procedures as Osborne (2009, p.290). For any i, if $c_i \geq c^*$, the following inequality is satisfied:

$$
\begin{aligned}
&(1-c^*)^{n-1}\times\left(\Pi-\frac{1}{\omega+\alpha}\right)\\
&\qquad+\{1-(1-c^*)^{n-1}\}\\
&\qquad\times\left(\Pi-\frac{1}{\omega+\alpha+\beta}\right)\\
&\qquad\geq\Pi-\frac{1}{\omega+\alpha+\beta}-c_i
\end{aligned}
\tag{12}
$$

In contrast, if $c_i \leq c^*$, the following inequality is satisfied:

$$
\begin{aligned}
&(1-c^*)^{n-1}\times\left(\Pi-\frac{1}{\omega+\alpha}\right)\\
&\qquad+\{1-(1-c^*)^{n-1}\}\\
&\qquad\times\left(\Pi-\frac{1}{\omega+\alpha+\beta}\right)\\
&\qquad\leq\Pi-\frac{1}{\omega+\alpha+\beta}-c_i
\end{aligned}
\tag{13}
$$

Hence it follows that, if $c_i = c^*$, the following equation holds:

$$
\begin{aligned}
&(1-c^*)^{n-1}\times\left(\Pi-\frac{1}{\omega+\alpha}\right)\\
&\qquad+\{1-(1-c^*)^{n-1}\}\\
&\qquad\times\left(\Pi-\frac{1}{\omega+\alpha+\beta}\right)\\
&\qquad=\Pi-\frac{1}{\omega+\alpha+\beta}-c_i
\end{aligned}
\tag{14}
$$

Equation (14) can be simplified as follows:

$$(1-c^*)^{n-1}-(\omega+\alpha+\beta)(\omega+\alpha)\beta^{-1}c^*=0$$

Let the left-hand side of the above equation be $G(c^*)$. Then $G(c^*)$ is a function that is continuous on c^* and $\partial G/\partial c^* < 0$ for any $c^* \in \mathbb{R}$. In addition, $\lim_{c^*\to 0} G(c^*) = 1$ and $\lim_{c^*\to 1} G(c^*) < 0$ hold. Hence, there is a unique $c^* \in (0,1)$ that satisfies $G(c^*) = 0$.

■

Proof of Proposition 1

Let the left-hand side of equation (8) be function f. Then c^* of f is a function implicitly represented by n, ω, α, and β. Therefore, from the implicit function theorem, the following inequalities are derived:

$$
\begin{aligned}
&\frac{\partial c^*}{\partial n}=-\frac{\partial f/\partial n}{\partial f/\partial c^*}\\
&=\frac{(1-c^*)^{n-1}(c^*)^{-1}\log(1-c^*)}{(n-1)(1-c^*)^{n-2}(c^*)^{-1}+(1-c^*)^{n-1}(c^*)^{-2}}\\
&<0
\end{aligned}
\tag{15}
$$

$$
\begin{aligned}
&\frac{\partial c^*}{\partial \omega}=-\frac{\partial f/\partial \omega}{\partial f/\partial c^*}\\
&=-\frac{\beta^{-1}(2\omega+2\alpha+\beta)}{(n-1)(1-c^*)^{n-2}(c^*)^{-1}+(1-c^*)^{n-1}(c^*)^{-2}}\\
&<0
\end{aligned}
\tag{16}
$$

$$
\begin{aligned}
&\frac{\partial c^*}{\partial \alpha}=-\frac{\partial f/\partial \alpha}{\partial f/\partial c^*}\\
&=-\frac{\beta^{-1}(2\omega+2\alpha+\beta)}{(n-1)(1-c^*)^{n-2}(c^*)^{-1}+(1-c^*)^{n-1}(c^*)^{-2}}\\
&<0
\end{aligned}
\tag{17}
$$

$$
\begin{aligned}
&\frac{\partial c^*}{\partial \beta}=-\frac{\partial f/\partial \beta}{\partial f/\partial c^*}\\
&=\frac{\beta^{-2}(\omega+\alpha)^2}{(n-1)(1-c^*)^{n-2}(c^*)^{-1}+(1-c^*)^{n-1}(c^*)^{-2}}\\
&>0
\end{aligned}
\tag{18}
$$

■

Proof of Corollary 1

The partial derivative of g with respect to n is represented by:

$$
\begin{aligned}
\frac{\partial g}{\partial n}=-\beta(1-c^*)^n\Big\{&\log(1-c^*)\\
&-\frac{n}{1-c^*}\frac{\partial c^*}{\partial n}\Big\}
\end{aligned}
\tag{19}
$$

Equation (19) can be simplified as follows, by using (15):

$$\frac{\partial g}{\partial n} = \beta(1-c^*)^n \log(1-c^*)\frac{2-(c^*)^{-1}}{n-2+(c^*)^{-1}} \tag{20}$$

It is shown that, in the above equation, $\log(1-c^*)$ is negative, and the denominator $n-2+(c^*)^{-1}$ is positive. Therefore, the sign of $\partial g/\partial n$ depends on the sign of the numerator $2-(c^*)^{-1}$.

■

Proof of Corollary 2

When parameters satisfy the condition that $1 \leq \beta/[(\omega+\alpha)(\omega+\alpha+\beta)]$ or, in other words, $1 \leq k^*$, all of the analysts are sure to acquire signal x. Hence, $h = \omega+\alpha+\beta$ holds in this case, regardless of the value n. In contrast, when parameters satisfy the condition that $\beta/[(\omega+\alpha)(\omega+\alpha+\beta)] < 1$ or, in other word, $k^* < 1$, only analysts whose cost of information gathering is lower than k^* acquire signal x. If all n of the analysts do not collect x, the precision of the investor's prediction results in $\omega+\alpha$. On the other hand, if at least one analyst collects x, the precision of the investor's prediction rises to $\omega+\alpha+\beta$. The probability that the former state occurs is $(1-k^*)^n$, and the latter state occurs is $1-(1-k^*)^n$. Consequently, h is represented as follows:

$$\omega+\alpha+\beta-\beta(1-k^*)^n$$

The partial derivative of h with respect to n is represented by:

$$\frac{\partial h}{\partial n} = -\beta(1-k^*)^n \log(1-k^*) > 0 \tag{21}$$

■

Proof of Proposition 2

Suppose that $n=2$. Compare c^*, which is obtained by equation (8), and k^*. Then it is shown that the following inequality is satisfied:

$$c^* = \frac{\beta}{(\omega+\alpha)(\omega+\alpha+\beta)+\beta} < k^* = \frac{\beta}{(\omega+\alpha)(\omega+\alpha+\beta)}$$

Suppose that $n > 2$. Then $c^* < k^*$ is also satisfied.

The result follows from the fact that $\partial c^*/\partial n < 0$, as asserted in Proposition 1, and that threshold k^* is independent of the value n.

As we have seen, g is represented by $\omega+\alpha+\beta-\beta(1-c^*)^n$. On the other hand, Corollary 2 shows $h = \omega+\alpha+\beta-\beta(1-k^*)^n$ such that $0 < k^* < 1$, and $h = \omega+\alpha+\beta$ such that $1 \leq k^*$. Consequently, from $c^* < k^*$, the following inequalities are satisfied.

$$\omega+\alpha+\beta-\beta(1-c^*)^n < \omega+\alpha+\beta-\beta(1-k^*)^n < \omega+\alpha+\beta$$

That is, $g < h$ holds for $n \geq 2$.

■

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