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Product Market Competition and Optimal Voluntary Disclosure Policy——A Betrand Duopoly Perspective

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Abstract

This paper examines how the level of competition is associated with an informed firm's optimal voluntary disclosure policy under the settings of Bertrand duopoly. We show that proprietary cost due to competition between firms does not matter while the informed firm makes a disclosure policy. Without direct disclosing cost, sharing all information voluntarily is the dominant strategy when the informed firm faces uncertain demand, otherwise, with fixed disclosure cost, partial sharing maybe the firm's dominant strategy. Moreover, as partial disclosure occurs, the firm possesses private information is less likely(or with a low probability) to release the information when the level of competition increase.

Key words

competition, Bertrand duopoly, voluntary disclosure, proprietary cost, fixed disclosure cost

1. Introduction

"Unraveling result" developed by Grossman, Hart and Milgrom shows that an informed firm will disclose to public all private information it has known under a few assumptions, whether the information is "good" or "bad" does not matter at all[1,2,3]. In effect, this conclusion is in contradiction to what have been observed in practice. For example, A work carried out by Radhakrishnan et al. shows that only 37.59%(30.68%) of U.S.(non-U.S.) listed firms release management forecasts, an important form of voluntary disclosure, during 2004-2010[4]. Another work by Graham et al. shows 58.8% of 306 respondents link a firm's competitiveness in product market negatively with voluntary disclosure because it will result in a exposure of firm's secrets [5]. In most cases, all or part of the assumptions introduced by "unraveling result" are violated and there exists only partial disclosure or non-disclosure implemented by a firm voluntarily[6].

To explore the wedge between "unraveling result" and the reality, cost of disclosure has been employed to form the basis of many arguments that why full disclosure equilibrium could not achieve. Proprietary cost, a terminology introduced by Verrecchia shows that an informed firm always suffers from its rival's strategic using of information disclosed by itself[7]. When the loss or disutility for the informed firm is greater than extra income gains from the decision of disclosure, the firm's optimal policy is concealing proprietary information, even though the news is "favorable". The reason why non-disclosure exists in this situation is that the firm's competitors and investors cannot distinguish a firm faces "bad" news from one endowed with "good" news but associated with positive proprietary cost. In these cases, the informed firm would rather pretend to possess no proprietary information than disclose what it has known. Verrecchia shows there is a threshold of disclosure above which the informed firm will make a decision of disclosure and further offers a positive relationship between this threshold and proprietary cost. As a high proprietary cost is always linked with a high level of competition, this relationship implies that the threshold(quantity of disclosure) may also increase(decrease) when the intensity of competition increases.

Works by Verrecchia are independent of any specific competitive settings[7,8], but existing theoretical works has shown that a firm's voluntary disclosure policy may be concerned with the nature of competition(price or quantity) and the nature of information structure(uncertain demand or cost), beside these, competition from a potential entrant make different influence on the disclosure policy from that of an existing competitor[9-11]. For example, Darrough's paper models competition between existing firms in a product market and indicates that full disclosure is the equilibrium policy when two firms compete under the settings of Cournot/uncertain cost and Bertrand/uncertain demand, though there is endogenous proprietary cost among existing rivals, but non-disclosure strategy is always adopted by both firms when they compete at the presence of Cournot/uncertain demand and Bertrand/uncertain cost[11]. Clinch and Verrecchia make a model regarding competition between two firms(Cournot duopoly) and shows that firms withhold extreme part of proprietary information and disclose the rest[12]. Furthermore, when competition is maximized, no information is disclosed at all. In the above works, each firm's equilibrium strategy is a quantity of outputs, which is a function of precision of the signal it has decided. As it has noted, when the firm faces settings of Cournot/uncertain cost and Bertrand/uncertain demand, it discloses the true signal it has received and withholds all in other cases. In the sense of quality of disclosure, disclosure by the informed firm now can be characterized by "full" when the signal is accurate and "empty" the others. In contrast to the work by Gal-Or, Clinch and Verrecchia's work can be associated with quantity of disclosure and all the information is shared to the public when voluntary disclosure is "full"[10,11].

Li points out that when new signals are observed, the informed firm should first decide what kind of information should be disclosed, only after a decision of disclosure about the information has been made will the firm choose the accuracy of the signal that is to be sent out. Li call the first stage the decision on quantity of disclosure and the second stage the decision on quality of disclosure[13]. He also examines the impacts of competition on voluntary disclosures empirically, both quantity and quality, and finds that disclosure is depend upon the type of competitors. Most of the early literatures, theoretical and empirical, explore just issues about quality of an informed firm's voluntary disclosure and ignore the issues about quantity[7-10]. In this study, we address issues about how the quantity of disclosure is determined. Specifically, our work is different in type of competition between firms from the ones in Verrecchia's, which investigates how the intensity of competition influence the quantity of a firm's voluntary disclosure under settings of Cournot duopoly[14]. In our models, only one firm observed a random signal and the level of competition between firms is a continuum, furthermore, besides uncertain demand, the informed firm may face an uncertain cost, last, the firms compete under settings of Bertrand duopoly. The first character makes our analysis is different from work by Clinch and Verrecchia and the second character generalizing the key settings described in Verrecchia's work, the last character is different from both prior studies[12,14].

A general outline of the paper is listed as follows. In section 2 we detail elements in out models, and in section 3 shows the resulting equilibrium strategies. Section 4 examines the intensity of competition's effect on probability of equilibrium voluntary disclosure decisions and Section 5 concludes with a brief summary.

2. Details of the models

Consider an industry consists of two firms each producing a differentiated good this period based on demand for the product next period. Two firms, firm 1 and firm 2, compete in a Bertrand duopoly(price competition) which can be characterized by linear demand functions

$$Q_i = a + b\tilde{Y} - cP_i + ctP_j, \quad a, c > 0, i = 1, 2 \tag{1}$$

where Q_i is the quantity of products of firm i in this period and P_i is the price of this goods during next period, a and $b\tilde{Y}$ are the fixed and random part of the demand intercept, c is a positive coefficient which links the price per unit output from firm i (i.e. P_i) with quantity Q_i, ct links the price per unit of output of firm j (i.e. P_j) with the quantity Q_i too. Note that t $(0 < t < 1)$ is nearly the same one employed in a Cournot duopoly, it also measures the intensity of competition between two firms. When $t \to 0$, for example, Q_i is asymptotically independent of P_j such that firm i will be monopoly at last. When $t > 0$, Q_i is weighted simultaneously by both P_i and P_j, this indicates that both firms' products are partially substitutable in product market and the Q_i decreases when P_i increases, but Q_i increases when P_j increases. The random part of intercept of demand function, $\tilde{Y}$, a stochastic signal about demand of goods, its realization can only be observed by one of the two firms. The exact realization of $\tilde{Y}$ will be known to the public, such as the market and the uninformed firm if it is disclosed by the informed firm, otherwise it will be treated as a random variable that is distributed uniformly from $-k$ to k $(k > 0)$ by the market and the another firm. In this paper, $\tilde{Y}$ is observed exclusively by one of the two firms, this is different from the settings in Clinch and Verrecchia's model[12], there two firms observe part of $\tilde{Y}$ and each part is independent of the other, in other words, private information observed by firm 1 is different from that owned by firm 2. For the purpose of interpreting any realization of $\tilde{Y}$ as "good news", a is a positive constant which is greater than $|b|k$. Last, the informed firm in this model can only make a policy between truthfully disclosing and withholding for any realization of $\tilde{Y}$, if it is disclosed, a exogenous fixed proprietary cost C is associated with the choice. Without loss of generality, firm 1 is informed and firm 2 is uninformed in this paper. The details of equation (1) are shown in appendix.

In this model, when informed firm observes a random signal, $\tilde{Y} \to k$ is favorable when $\tilde{Y}$ contains information about uncertain demand, while $\tilde{Y} \to -k$ is favorable when $\tilde{Y}$ contains information about uncertain cost. For the purpose of simplicity and clarity, rewrite the demand function when firm 1 face an uncertain demand,

$$Q_i = a + b\tilde{Y} - cP_i + ctP_j, \quad a, b, c > 0, i = 1, 2 \tag{2}$$

and the form when firm 1 face an uncertain cost,

$$Q_i = a - b\tilde{Y} - cP_i + ctP_j, \quad a,b,c>0, i=1,2 \tag{3}$$

where $\tilde{Y} \sim \mathrm{U}(-k,k), k>0$. When favorable news is released by firm 1, it can be evaluated by the market correctly. Now firm 1 benefits from a correct evaluation but results in a fixed cost of C, together with a harm of its competition position and erosion of profit results from its rival's strategy behavior of boosting production. Naturally, firm 1 will trade off between benefits and costs of disclosure first. After the policy of disclosure is confirmed, both firms will then make their optimal price policies based on the demand functions determined by equation (2) and (3) under their own information circumstances.

3. Informed firm's equilibrium strategy

When firm 1 observes a random signal $\tilde{Y}$, it faces a sequence of two decisions: whether to share this proprietary information about demand or cost to the public and, subsequently, what the price of output is. Because each firm, the informed one or the uninformed one, chooses its optimal price of output based on all available information, this implies that firm 1's decision of disclosure or non-disclosure will influence its pricing schedule, then its revenue. Now, in order to examine whether firm 1 disclose its proprietary information or not, we first calculate its return when $\tilde{Y}=Y$ is disclosed, then the resulting return when $\tilde{Y}=Y$ is withheld. Once the return under decision of disclosure is greater than the one in non-disclosure, firm 1 will share information about $\tilde{Y}$, otherwise it will conceal the information. That is, firm 1's equilibrium strategy is solved in a way of backward induction.

3.1 Uncertain demand

When firm 1 observes a signal about uncertain demand, it makes a decision based on its available information and the demand function given in equation (2). Let P_1^{Dd}, P_2^{Dd} represents optimal price of output produced by firm 1 and firm 2 respectively, where D is the abbreviation of disclosure and d is the abbreviation of demand. After having disclosed information about $\tilde{Y}$, i.e. the uncertain demand, firm 1 choose P_1^{Dd} to maximize

$$\max P_1^{Dd}\,\mathrm{E}[\tilde{Q} \mid \tilde{Y} = Y] = P_1^{Dd}(a + bY - cP_1^{Dd} + ctP_2^{Dd})$$

By using the FOC condition, firm 1's products will be sold at a price of

$$P_1^{Dd} = (a + bY + ct\hat{P}_2^{Dd}) / 2c \tag{4}$$

where $\hat{P}_2^{Dd}$ is firm 1's conjecture about the price of outcome firm 2 produces. Similarly, price at which firm 2 sell its production is

$$P_2^{Dd} = (a + bY + ct\hat{P}_1^{Dd}) / 2c \tag{5}$$

where $\hat{P}_1^{Dd}$ is firm 2's conjecture about the price of outcome of firm 1 produces. As a result of firm 1's disclosure, solution of equation (4) and (5) shows that both firms' equilibrium pricing in this case are $P_1^{Dd} = P_2^{Dd} = (a + bY) / [c(2 - t)]$. Replacing P_1 and P_2 in equation (2) with P_1^{Dd} and P_2^{Dd}, the quantities of output of both firms are

$$Q_1^{Dd} = Q_2^{Dd} = a + bY - \frac{c}{c(2-t)}(a + bY) + \frac{ct}{c(2-t)}(a + bY) = \frac{1}{2-t}(a + bY)$$

after P_1^{Dd} and Q_1^{Dd} have been calculated, firm 1's optimal revenues next period it achieve when disclose the uncertain demand, is just a quadratic function of the realization of proprietary information Y

$$P_1^{Dd} Q_1^{Dd} = \frac{1}{c}\left[\frac{1}{2-t}(a + bY)\right]^2 = c(P_1^{Dd})^2 \tag{6}$$

When $\tilde{Y} = Y$ is not disclosed, let P_1^{Nd} represents firm 1's optimal pricing of its outcome and P_2^{Nd} is the optimal pricing of outcome produced by firm 2, where N is a synonym of non-disclosure and d holds the same meaning like that in case of firm 1 disclose $\tilde{Y} = Y$. Obviously, firm 1's pricing is similar to the one in equation (4)

$$P_1^{Nd} = (a + bY + ct\hat{P}_2^{Nd}) / 2c \tag{7}$$

where, $\hat{P}_2^{Nd}$ is still firm 1's conjecture about the pricing of firm 2's production. But firm 2 will make its decision about the price in a way which is differ from the above case: as firm 2 is uninformed, it conjectures rationally that after having observed private information, firm 1 will disclose $\tilde{Y}$ only when it is "good" enough, that is, the informed firm will disclose $\tilde{Y} = Y$ if $\tilde{Y}$ is above some threshold $\hat{Y}^d$. This implies that there exists a threshold below which the informed firm withholds information and vice versa. According to the above analysis, firm 2 choose Q_2^{Nd} to maximize the expectation of revenue condition on $\tilde{Y} \le \hat{Y}^d$,

$$\begin{aligned} \max P_2^{Nd} \mathrm{E}[\tilde{Q} \mid \tilde{Y} = Y \le \hat{Y}^d] &= P_2^{Nd} \mathrm{E}[(a + bY - P_2^{Nd} + t\hat{P}_1^{Nd}) \mid \tilde{Y} = Y \le \hat{Y}^d] \\ &= P_2^{Nd}(a + bV - P_2^{Nd} + t\hat{P}_1^{Nd}) \end{aligned}$$

where, $\hat{P}_1^{Nd}$ is firm 2's conjecture about the price of firm 1's production when there is no disclosure, V is firm 2' expectation of $\tilde{Y}$ condition on $\tilde{Y} \le \hat{Y}^d$, as $\tilde{Y}$ is assumed in this paper uniformly distributed between $-k$ and k, V can be calculated as follows,

$$V = \mathrm{E}[\tilde{Y} \mid \tilde{Y} = Y \le \hat{Y}^d] = \int_{-k}^{\hat{Y}^d} \frac{Y}{2k} \mathrm{d}Y \Big/ \int_{-k}^{\hat{Y}^d} \frac{1}{2k} \mathrm{d}Y = \frac{1}{2}(\hat{Y}^d - k)$$

Use FOC again and firm 2's pricing strategy is

$$P_2^{Nd} = (a + bV + ct\hat{P}_1^{Nd}) / 2c \tag{8}$$

Though the best pricing response functions are decided in equation (7) and equation (8), P_1^{Nd} and P_2^{Nd} could not be derived directly. This is because V is uncertain due to the unknown $\hat{Y}^d$, then P_2^{Nd} in equation (8) doesn't equal to $\hat{P}_1^{Nd}$ in equation (7) and it is unfeasible for us to get P_1^{Nd} and P_2^{Nd} the same way in case of $\tilde{Y}$ is shared.

It is usually presumed that P_1^{Nd} is a linear function of firm 1's real private information $\tilde{Y}$ and firm 2's belief of $\tilde{Y}$, and that P_2^{Nd} is a function which is dependent of $\tilde{Y}$, then take the linear forms into the above two equation, we get P_1^{Nd} and P_2^{Nd}

$$\begin{cases} P_1^{Nd} = [2(a+bY)+bt(V-Y)]/[2c(2-t)] \\ P_2^{Nd} = [a+bV]/[c(2-t)] \end{cases}$$

then Q_1^{Nd} is solved by using the demand function of firm 1

$$Q_1^{Nd} = [2(a+bY)+bt(V-Y)]/[2(2-t)]$$

Firm 1's revenues can now be presented as

$$P_1^{Nd}Q_1^{Nd} = \{[2(a+bY)+bt(V-Y)]/[2(2-t)]\}^2 / c = c(P_1^{Nd})^2$$

It has been described in section 2 that the original signal about $\tilde{Y}$ is only observed by firm 1, this indicates that if information about $\tilde{Y}$ was disclosed, market will value firm 1's revenues(i.e. $P_1^{Dd}Q_1^{Dd}$) exactly, but if the information was not disclosed, market could only value firm 1's revenues based on the expectation of $P_1^{Nd}Q_1^{Nd}$ condition on $\tilde{Y} = Y \le \hat{Y}^d$, In this sense, firm 1's revenues are valued by market follows the rule given formally in Lemma 1.

Lemma 1. When $\tilde{Y} = Y$ is proprietary information concerns uncertain demand, the market's expectation of firm 1's revenues next period is

$$\mathrm{E}[\tilde{P}_1^{Dd}\tilde{Q}_1^{Dd} \mid \tilde{Y} = Y] = \frac{1}{c}\left[\frac{1}{2-t}(a+bY)\right]^2$$

and when $\tilde{Y} = Y$ is not disclosed, the market's expectation of firm 1's revenues next period is

$$\begin{aligned}\mathrm{E}[\tilde{P}_1^{Nd}\tilde{Q}_1^{Nd} \mid \tilde{Y}=Y\le \hat{Y}^d] &= \mathrm{E}\ \{\{[2(a+bY)+bt(V-Y)]/[2(2-t)]\}^2/c \mid \tilde{Y}=Y\le \hat{Y}^d]\} \\ &= \frac{b^2((\hat{Y}^d)^2-k\hat{Y}^d+k^2)}{12c}+\frac{b(\hat{Y}^d-k)(4a-bkt+bt\hat{Y}^d)}{8c(2-t)}+\frac{(4a-btk+bt\hat{Y}^d)^2}{16c(2-t)^2} \\ &= F(\hat{Y}^d)\end{aligned}$$

Proof. The first part of Lemma 1 is obvious. Now take into account conditional expectation of $\tilde{Y}$, i.e. $\mathrm{E}[\tilde{Y} \mid \tilde{Y}=Y\le \hat{Y}^d]=V=(\hat{Y}^d-k)/2$ and that

$$\mathrm{E}[\tilde{Y}^2 \mid \tilde{Y}=Y\le \hat{Y}^d]=\int_{-k}^{\hat{Y}^d}\frac{Y^2}{2k}\mathrm{d}Y\Big/\int_{-k}^{\hat{Y}^d}\frac{1}{2k}\mathrm{d}Y=\frac{1}{3}[(\hat{Y}^d)^2-k\hat{Y}^d+k^2]$$

the second part of Lemma 1 is proved.

3.2 Uncertain cost

If $\tilde{Y}$ is proprietary information concerns uncertain cost, both firms' demand functions are specified by equation (3). Similarly, there also exists a threshold $\hat{Y}^c$ but below/above it the informed firm's strategy policy is disclosure/withholding, that is, $\hat{Y}^c$ makes the influence on firm 1's decision in a way opposite to that of $\tilde{Y}^d$. This reverse phenomenon occurs because the realization of $\tilde{Y}$ is now negatively associated with quantity of the products, thus the less the certain Y, the more the demand and the more the revenue firm 1 achieves.

Let P_1^{Dc}, Q_1^{Dc} be price and quantity of firm 1's products when $\tilde{Y}=Y$ is disclosed, P_1^{Nc}, Q_1^{Nc} denote price and quantity of firm 1's outputs when $\tilde{Y}=Y$ is not disclosed, respectively, where D/N is decision of disclosure/non-disclosure and c is uncertain cost. Similarly, firm 1's revenues are valued by market follows the rule given in Lemma 2.

Lemma 2. When $\tilde{Y}=Y$ is proprietary information about uncertain cost, market's expectation of firm 1's revenues next period is

$$\mathrm{E}[\tilde{P}_1^{Dc}\tilde{Q}_1^{Dc} \mid \tilde{Y}=Y]=\frac{1}{c}\left[\frac{1}{2-t}(a-bY)\right]^2$$

and when $\tilde{Y}=Y$ is not disclosed, the market's expectation of firm 1's revenues next period is

$$\mathrm{E}[\tilde{P}_1^{Nc}\tilde{Q}_1^{Nc} \mid \tilde{Y}=Y\geq \hat{Y}^c] = \mathrm{E}\,\{\{[2(a-bY)-bt(U-Y)]/[2(2-t)]\}^2/c \mid \tilde{Y}=Y\geq \hat{Y}^c]\} = F(\hat{Y}^c)$$

Proof. Proof of Lemma 2 is similar to proof of Lemma 1 but only notice that the different expectation of $\tilde{Y}$ condition on $\tilde{Y}=Y\geq \hat{Y}^c$ is

$$U=\mathrm{E}[\tilde{Y} \mid \tilde{Y}=Y\geq \hat{Y}^c]=\int_{\hat{Y}^c}^{k}\frac{Y}{2k}\mathrm{d}Y\Big/\int_{\hat{Y}^c}^{k}\frac{1}{2k}\mathrm{d}Y=\frac{1}{2}(\hat{Y}^c+k)$$

and different expectation of $\tilde{Y}^2$ condition on $\tilde{Y}=Y\geq \hat{Y}^c$ is

$$\mathrm{E}[\tilde{Y}^2 \mid \tilde{Y}=Y\geq \hat{Y}^c]=\int_{\hat{Y}^c}^{k}\frac{Y^2}{2k}\mathrm{d}Y\Big/\int_{\hat{Y}^c}^{k}\frac{1}{2k}\mathrm{d}Y=\frac{1}{3}[(\hat{Y}^c)^2+k\hat{Y}^c+k^2]$$

and the second part of Lemma 2 can be drawn.

4. Intensity of price competition and quantity of voluntary disclosure

In this section we explore what will happen in the case when intensity of competition is no long a constant(i.e. $t\neq 1$) which is considered in Verrecchia's model[14]. We first examine the case in which either disclosure or non-disclosure is indifferent to the informed firm 1. For the convenience of solving equation, we just ignore fixed cost about disclosure, i.e. let $C=0$ for a minute.

When firm 1 faces uncertain demand, $\hat{Y}^d=Y$ is just the exact value if the following equation holds,

$$\mathrm{E}[\tilde{P}_1^{Dd}\tilde{Q}_1^{Dd} \mid \tilde{Y}=Y]-\mathrm{E}[\tilde{P}_1^{Nd}\tilde{Q}_1^{Nd} \mid \tilde{Y}\leq Y]=0 \tag{9}$$

By using results in Lemma 1 and Lemma 2, this equation is equal to

$$(Y+k)\left(Y+\mathrm{K}_1\right)=0$$

where $K_1(t)=\dfrac{-bkt^2+4bkt+48a-16bk}{b(-t^2+4t+32)}$.

Theorem 1(Case of uncertain demand). When $C=0$ (i.e. there doesn't exist a fixed disclosure cost), the informed firm discloses all of its private information; As C increases, the likelihood of disclosure decreases, when C is large enough, the informed firm conceal these information completely.

Proof. Let $F(Y)=(Y+k)(Y+K_1)$, as quadratic coefficient of equation (9) is positive, firm 1 will disclose its uncertain demand when $F(Y)>0$. Note that

$$-K_1-(-k)=-\frac{48(a-bk)}{b(-t^2+4t+32)}<0$$

just because $a,b,k>0$, $a>|b|k$ and $t\in(0,1)$ are supposed. Now $F(Y)>0$ is equal to $Y<-K_1$ or $Y>-k$. In this case, Y is uncertain demand between $-k$ and k. Moreover, disclosure is indifferent to non-disclosure when $Y=-k$ (i.e. $F(Y)=1$). this implies that firm 1's optimal decision is full disclosure when $C=0$.

If $C>0$, a new criterion $F'(Y)=F(Y)-C=(Y+k')(Y+K_1')$ which is equivalent to the condition $F(Y)-C=0$ can be drawn and $Y<-K_1'$ or $Y>-k'$ is the necessary and sufficient condition under which the informed firm make a decision of disclosure. According to characters of a quadratic function, $-k'>-k$ and $-K_1'<-K_1$ hold, that is, firm 1 will withhold part of its proprietary information in the case of $-k\le Y<-k'$.

As C increases, $-k'$ moves to k increasingly. Once $-k'$ is greater than k, solves of $F(Y)-C>0$ is beyond the feasible interval $Y\in[-k,k]$ which is supposed in the model, and then all the information about Y is disclosed.

Theorem 1 is proved.

In theorem 1, Y is assumed to be a threshold above which firm 1 will make a decision of disclosure. The cost of disclosure, C is the key parameter which functions in the optimal voluntary disclosure policy about whether disclose the realization of Y. Next we will show that the intensity of C's effect on informed firm's strategy about disclosure is controlled by the intensity of competition between two firms.

Theorem 2(Case of uncertain demand). In the case of voluntary disclosure by the informed firm is partially, the quantity of disclosure decreases as the intensity of competition between two firms increases.

Proof. According to theorem 1, the informed firm disclose part of its private information $\mathrm{E}[\tilde{P}_1^{Dd}\tilde{Q}_1^{Dd} \mid \tilde{Y}=Y]-\mathrm{E}[\tilde{P}_1^{Nd}\tilde{Q}_1^{Nd} \mid \tilde{Y}\le Y]-C>0$ holds when $k>Y=-k^{'}>-k$ holds. Note that one solve of F(Y)=$\mathrm{E}[\tilde{P}_1^{Dd}\tilde{Q}_1^{Dd} \mid \tilde{Y}=Y]-\mathrm{E}[\tilde{P}_1^{Nd}\tilde{Q}_1^{Nd} \mid \tilde{Y}\le Y]=0$ is $Y=-k$ for any t, and that $F(Y)-C$ is just a translational transform of $F(Y)$. Then given a series of $t\in(-k,k)$, the relative positions of a series of $F(Y,t)-C$ keep in same order similar to those in $F(Y,t)$ at right of $Y=-k$.

As it has shown in the appendix, a,b,c in $F(Y,t)$ are all functions of t, specifically, $a=a(t)=\alpha/(1+t)>0, b=b(t)=\beta/(1+t)$ and $c=c(t)=1/(1-t^2)$, taking these into $F(Y)$ and then

$$\frac{\mathrm{d}F(Y,t)}{\mathrm{d}t}=\frac{(Y+k)(M_1+M_2+M_3+M_4)}{24(t+1)^2(t-2)^3}$$

where

$$\begin{cases} M_1 &= 48\alpha(1-t+t^2) \\ M_2 &= \beta Y(28-24t+30t^2) \\ M_3 &= -\beta k(18t^2-24t+20) \\ M_4 &= \beta t^3(k+Y) \end{cases}$$

Because $a>|b|k$, $Y\in[-k,k]$ is supposed in this paper, $\alpha>|\beta|k$ also holds. It can be easily drawn that $M_1+M_2+M_3\ge 0$ and $M_4>0$ for any $k>Y>-k$, $(t-2)^3<0$ for any $t\in(0,1)$. That is, $\mathrm{d}F(Y,t)/\mathrm{d}t$ is less than 0 and $F(Y)$ decreases when t increases.

Lemma 1 and Lemma 2 show us $\mathrm{E}[\tilde{P}_1^{Dd}\tilde{Q}_1^{Dd} \mid \tilde{Y}=Y]$ and $\mathrm{E}[\tilde{P}_1^{Nd}\tilde{Q}_1^{Nd} \mid \tilde{Y}\le Y]$ are two quadratic curves, then $F(Y)$ is a binomial expression too. Now $\mathrm{d}F(Y,t)/\mathrm{d}t<0$ can tell us that a curve with a large t is at the right of a curve with a small t for a given Y, i.e. $F(Y,t_{large})$ is greater than $F(Y,t_{small})$. Naturally, the large solve of $F(Y,t_{large})-C$, denoted as $k_{large}^{'}$ is at the right of the large solve of $F(Y,t_{small})-C$, which is denoted as $k_{small}^{'}$. Put differently, a large t gives a large $k^{'}$.

As we have known from theorem 1 that the informed firm withdraw information when $Y < k'$ and disclose information when $Y \in [k', k]$, a large t just leads to a small $k - k'$, or a small likelihood of voluntary disclosure.

Theorem 2 is proved.

Theorem 3(Case of uncertain cost). When there is no fixed disclosure cost C, the informed firm's disclosure is full, as this cost increases, the likelihood of voluntary disclosure about the uncertain cost decreases and at last non-disclosure occurs.

Proof. Similar to the proof of Theorem 1.

Theorem 4(Case of uncertain cost). When there is a fixed disclosure cost C on which the informed firm discloses uncertain cost partially, the probability of voluntary disclosure decreases as the level of competition increases.

Proof. Similar to the proof of Theorem 2.

In theorem (1) and (3), given $C = 0$, the informed firm discloses all of its proprietary information for any level of competition, whether the uncertain information is about demand or cost. Recall that we have presumed $a > |b| k$ in out model throughout the paper, this assumption tells the firm that demands of products always lead to an incentive of disclosure, or the value of firm 1 will be undervalued by the market. Thought the information can be strategically used by the rivals, sharing of the private information is still firm 1's optimal voluntary disclosure policy. In a word, proprietary cost does not function at all. This conclusion is different from the ones drawn from early literatures in which uncertain cost is always disclosed and uncertain demand is usually withheld[10,11]. Though the proprietary cost result from competition between two firms exists, proprietary information is still disclosed fully.

But when the fixed disclosure cost is greater than 0, this cost becomes one of the biggest obstacle to incentives of disclosure. Full disclosure is replaced by partial disclosure as the cost increases. At its worst extreme, there will be no disclosure if the cost is high enough. As $C > 0$ is usually a reasonable assumption, decision of partial disclosure in this paper tells us that "Unraveling result" doesn't hold in real world in most cases.

In addition, theorem (2) and (4) suppose that the level of competition will function when a partial disclosure exists. Specifically, a heavy competition discourages voluntary disclosure of proprietary information. This implies that withholding of proprietary information is helpful for the firm to keep specific advantages in the product market in this case[15]. This is different from early works in which competition is just negatively associated with the quality of disclosure of firms[16].

Conclusion

This paper formulated a two-step game under the settings of Bertrand duopoly, and then explored the optimal voluntary disclosure policy of the informed firm. To analysis how product market competition affect a firm's disclosure strategy of proprietary information, uncertain demand and uncertain cost are employed into the model as private stochastic signal which is only observed by the informed firm, together with the fixed cost of disclosure. All the conclusions are listed as follows:

(1) If favorable prospect is promised by the market, proprietary cost doesn't function when the informed firm makes its policy. Fixed cost of disclosure and the level of competition play important role during the decision of voluntary disclosure.

(2) As the fixed disclosure cost does not exist, the informed firm discloses all of its proprietary information, as the cost increase, the firm withdraws part of, and at last all the information. That is, non-disclosure is the unique equilibrium when the fixed disclosure cost is large enough.

(3) Optimal quantity of voluntary disclosure decreases as level of competition increases, no matter what the type of private uncertain information observed by the informed firm is.

Anyway, the circumstance of product market competition is crucial when a new financial policy concerned to voluntary disclosure is going to be achieved.

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Appendix

A.1 Demand function under price competition

Generally, a standard model of Cournot duopoly(quantity competition) can be characterized by a linear inverse demand function

$$P_i = \alpha - \beta Q_i - \beta t Q_j, \quad \alpha, \beta > 0$$

for firm $i(i=1,2)$, where P_i is price per unit of goods produced by firm i, a positive constant α denotes the intercept term, β is a positive slope coefficient which links P_i with the quantity of goods from firm i (denoted by Q_i), and βt in $\beta t Q_j$ is similar to β in βQ_i. The parameter $t(t \in [0,1])$ represents competitiveness between two firms in the product market. Rewrite the above equations without loss of generality, simplified form of demand function are shown as

$$P_i' = \alpha' - Q_i - tQ_j, \quad i = 1,2$$

where $\alpha' = \alpha / \beta > 0$. By solving the simplified equations, the demand function related to price(Bertrand) competition is expressed as

$$Q_i = a - bP_i + btP_j, \quad i = 1,2$$

where $a = \alpha / (1+t) > 0$, $b = 1/(1-t^2) > 0$ and $t \in [0,1)$. After a random part is added to the intercept term, a similar demand function under price competition is given

$$\tilde{Q}_i = a + b\tilde{Y} - cP_i + ctP_j, \quad a, c > 0$$

where $a = \alpha / (1+t) > 0, b = \beta / (1+t) > 0$, $c = 1/(1-t^2) > 0$ and $t \in [0,1)$. $\tilde{Y}$ is a random signal and b is the coefficient links $\tilde{Q}_i$ with $\tilde{Y}$. Suppose b is positive when $\tilde{Y}$ is a stochastic signal about demand of the market, otherwise b is negative(or b is replaced by $-b\,(b > 0)$) when $\tilde{Y}$ is signal about cost. Note that equations $\tilde{Q}_i = a + b\tilde{Y} - cP_i + ctP_j$ could not be rewritten in simplified forms because they are associated with $P_i = \alpha - Q_i - tQ_j$ directly.