# Information Acquisition and Disclosure: the Case of Differentiated Goods Duopoly*

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**Abstract**

We study the incentive of duopoly to acquire and disclose information on the unknown private costs. First, firms can precommit (or not) to full sharing or full concealment disclosure regime. Then in the first stage they decide whether to exert an effort to acquire information respectively. In the second stage, they disclose or conceal their acquired costs information according to different disclosure regimes they precommitted. If they cannot (or do not) precommit to particular regimes, they share or conceal their costs information acquired in the first stage voluntarily and strategically. In the final stage firms compete on the product market as a pair of differentiated duopoly. We examine each corresponding impact on the firms' profits, the consumer surplus, and the social total surplus, under different regimes. We find that under differentiated good's quantity competition, the information acquisition benefits both firms and consumers; yet information disclosure hurts the consumer surplus, though it benefits both the firms and the social welfare. The strategic information disclosure regime always gives firms the strongest incentive to acquire information; Moreover, it may even involve an inefficient over-investment on information acquisition especially when the market's demand potential is extremely large. Under price competition, the information acquisition benefits firms and consumers; yet the information disclosure is detrimental to both consumer surplus and firms' profit.

**Key words**: *Information acquisition*; *Information disclosure*; *Strategic information disclosure*; *Cournot competition*

**JEL classification**: D82; D83; L13; L40

# 1 Introduction

A firm that introduces a new product on a market does not always know its production cost at the time of making its production decision.[1] The firm can perform R&D on its potential technology to learn it. Doing so is both costly and risky. It is costly, because the firm needs to invest in the acquisition of relevant information. An investment in information acquisition is risky, since it may fail to generate the desired information. Yet the more time, effort and money is spent on the research, the more likely the firm gets to know the production cost of this new product beforehand.

We examine incentives of firms in a duopoly to acquire and disclose information about their unknown private production costs. There are also papers which studied information sharing on private costs, yet they assume the information is exogenously determined, e.g., Vives (1984, 1990). This paper endogenizes the information structure and takes one step further by studying the information gathering stage and the interaction between information gathering and disclosure.

In our model, each firm produces a differentiated product and faces a stochastic technology. The random shock that determines each firm's cost function is different and independent from that of its rival. Each firm gets to observe its private unit cost signal if its R&D effort succeeds. We consider different disclosure regimes for the informed firms, namely, full sharing, full concealment, or strategic disclosure based on their information acquired in the R&D phase. Before exerting efforts, firms know the corresponding disclosure regime that they will obey after their R&D results come out. The previous literature on information sharing without information acquisition in oligopolistic markets analyzes the incentives of firms that precommit to particular information sharing rules, e.g. by establishing a trade association. Typically, two extreme information disclosure regimes are compared: full information sharing, and no pooling of information (full concealment). Gal-Or (1985) shows, even if the firms are allowed to use partial information sharing, the optimal sharing rule is full disclosure or full concealment depending on the characteristics of the competition (Cournot or Bertrand) and the products (substitutes or complements). Naturally, in this paper when we take one step further to consider the information acquisition phase, we can ana-

[1]For instance, when a firm faces to produce (or not) a brand-new good with potentially high market demand, it will have to set up the factory production capacity according to the expectation of its own cost and the market's environment. Even if the firm will learn its cost information during the specific production process ex post, they cannot change their production in the short run, e.g., they cannot fire their employees or increase their production capacity immediately.

lyze the two precommitment regimes: full disclosure and full concealment. However, if firms cannot precommit to information disclosure rule ex ante, the decision to disclose or not information is endogenous. In this case, firms share or conceal voluntarily and strategically depending on what kind of private information they acquired in R&D. So, in the language of industrial organization modeling, the firms play a three-stage game in the strategic disclosure regime case. In stage 1 they decide whether to exert an effort to acquire information respectively. In stage 2 they share or conceal their costs information acquired in stage 1 according to different disclosure regimes. In stage 3 firms compete on the product market as a pair of differentiated good duopoly.

In contrast with earlier literature, e.g., Gal-Or (1985), Novshek and Sonnenschein (1982) and Jansen (2008), where uncertainty is about an unknown common demand intercept, the uncertainty in the present paper is about unknown private costs. With an uncertain demand, by exerting efforts, each firm observes a private signal of a parameter of the model, which affects everyone's payoff function in the same way. This is called a "common value" problem in the literature. While with uncertain costs, by exerting effort, each firm observes a private signal of a parameter which is different for each firm. And this environment is called a "private values" problem.

We assume that the disclosed information is verifiable, i.e., that a firm cannot lie or untruthfully report its type if it shares with its rival after being informed. This assumption is consistent with some empirical findings.[2,3]

Our paper finds that the information about the own and rival's production costs is always beneficial to a firm, and the value is non-decreasing with the substitutability of two goods on the market. More specifically, we can decompose the value of information into three parts: (1) the value of learning own cost; (2) the value of knowing the rival's cost; (3) the value of sharing own cost to the rival.[4] So, if the information acquisition cost is very low, then each firm has full incentive to exert efforts to investigate production cost, whether or not it shalls its private information with its rival; when R&D becomes costly, information acquisition happens only if information

[2] Doyle and Snyder (1999) find that US car makers' announcements of production plans are informative, and not mere cheap talk, since they affect market outcomes. Genesove and Mullin (1999) made a related observation on US sugar cane refiners participating in the Sugar Institute trade association between 1928 and 1936. The paper finds no indication that the association's members were making untruthful reports: truth-telling is the outcome of the information revelation game.

[3] The truth-telling problem of information sharing about private cost in oligopoly/duopoly may be the next step of research.

[4] We find that a firm's profit function is convex in the rival's output level, so making the latter contingent on the own cost is ex ante valuable.

sharing is possible.

Moreover, in the full disclosure regime, the two firms may prefer to commit an R&D cooperation in the phase of information acquisition, and then they can compete non-cooperatively on the product market. An interesting point is: the existence of an R&D league agreement is not necessarily an indication of collusion between firms on the market competition.

In the equilibrium under strategic information disclosure regime, due to the equilibrium belief under "unraveling effect",[5] more information about unknown cost may be acquired and disclosed before the market competition phase than in the equilibrium under mandatory information disclosure regime, especially when the information acquisition cost is quite high.

Regarding the consumer surplus and the social welfare, we find: the information gathering benefits the consumer, but the sharing between the firms erodes some benefits on consumer surplus. The intuition is: information acquisition benefits the firms' profits (under a reasonable R&D cost), and thus increases the equilibrium production, which enhances the consumer surplus; yet, information sharing lets the firms coordinate their production based on the revealed cost information, which hurts the consumer surplus. While the information acquisition and disclosure always benefit the total social surplus, and the benefits increase with the product substitutability. So, we find that the socially efficient R&D cost threshold is even higher than the firms' cooperative one. At last, when the market demand intercept is extremely high, some over-investment on information acquisition may happen in the strategic information disclosure regime.

In short, when we consider quantity competition (Cournot), allowing firms to share information has two effects on consumer surplus. On the one hand, as previous literature pointed out, there is a negative direct effect. Given information structure, allowing information sharing between firms has a negative effect (positive effect) on the consumer surplus (profits of the firms). However, on the other hand, there is a positive indirect effect of sharing information. This is due to the fact that the incentives of acquiring information are larger when firms are allowed to share information. The higher investments by firms that share information have a positive effect on the consumer surplus.

When we consider price competition (Bertrand), firms have no incentive to engage in agreement to share information (full disclosure regime is dominated). Firstly, full sharing agreement will give less incentive to acquire information. Secondly, given information structure, firms prefer not share their information. But under some cases (when R&D cost is higher), strate-

[5]Milgrom (1981), Milgrom and Roberts (1986).

gic disclosure regime is prefered, because it gives the strongest incentive to acquire information.

This paper is organized as follows. Section 2 describes the model. Section 3 derives the equilibrium in different information sharing regimes: full disclosure, full concealment, and strategic disclosure, respectively. Section 4 investigates the impacts on the consumer and welfare. Section 5 analyzes price competition. Section 6 concludes.

# 2 The model

A market consists of two firms, each producing a differentiated product. The market demand is linear, namely

$$p_i = a - x_i - \gamma x_j \text{ with } i,j \in \{1,2\} \text{ and } 0 \leq \gamma \leq 1. \tag{1}$$

Parameter $\gamma$ captures the degree of product substitutability. $x_{i(j)}$ is the production quantity of firm $i\,(j)$. If $\gamma = 1$, then goods are homogeneous, i.e., the market is a pure Cournot duopoly; while if $\gamma = 0$, then firms supply to independent markets, i.e., each firm is a monopoly. Firms are risk-neutral.

The technology for production is stochastic but it exhibits constant return to scale, $c_i = \theta_i x_i$ where $\theta_i \sim f(\theta_i)$ on $\left[0, \overline{\theta}\right]$, $i = 1,2$. The process of $\theta_i$ is independent with that of $\theta_j$.

We assume that

$$a > \frac{2\overline{\theta}}{2-\gamma}, \tag{2}$$

which will later on ensure interior solutions, i.e., $x_i, x_j > 0$ for any realization of the cost pair $(\theta_i, \theta_j)$ and any information disclosure structure.[6]

In the first stage, firms can learn their unit costs by acquiring information. Firms choose an investment of information acquisition, $r_i \in [0,1]$ for firm $i$, simultaneously and respectively. With probability $r_i$ firm $i$ observes its own cost $\theta_i$; but with probability $1 - r_i$ the firm learns nothing and continues holding the prior $f(\cdot)$ over its own cost when making its production decision. The success of $i$ and $j$'s R&D (information acquisition)[7] investment is independent with each other. A firm's information acquisition behavior is not observable by its rival. Firm $i$ only expects that its rival invests $r_j$ in

[6]Condition (2) comes from the fact that the worst realization of $(\theta_i, \theta_j)$ is profitable on behalf of firm $i$, i.e., $\theta_i = \overline{\theta}$ and $i$ has to disclose it to $j$, while $\theta_j = 0$ and $i$ knows it; by imposing $\left(\theta_i = \overline{\theta}, \theta_j = 0\right)$ into Lemma 4 and Lemma 1, we can get that the profit $\pi_i$ in this case is still strictly positive under (2).

[7]Henceforth, we call and interpret information acquisition as R&D too, since the investment is about a new product line development.

information acquisition. We assume that if firm $i$ decides to disclose, then $\theta_i$ is hard information to the public, i.e., it cannot manipulate $\theta_i$. The costs of information acquisition are linear: $\eta r_i > 0$ for $i = 1, 2$.

After the information acquisition stage, an informed firm discloses or conceals its private cost according to different information sharing regimes. We consider three information sharing regimes respectively: full concealment, full disclosure, and strategic disclosure. These different regimes constitute three different scenarios/games since we assume that firms precommit to a regime before they invest in R&D in the first stage. Full concealment means that, firms agree on not sharing or cannot share (e.g., technologically the information is not transmissible) their cost information in the second stage, respectively, if they learned in the first stage. Full disclosure means that, in the second stage firms agree on sharing the cost information respectively or it can be observed by the rival automatically so long as the firm learned it in the first stage. Strategic disclosure allows the firm to voluntarily disclose or conceal its cost information learned in the first stage. So the full concealment and full disclosure regimes serve as the two extreme benchmarks of the information disclosure problems.

Under strategic disclosure, firm $i$ is sure that firm $j$ has successfully learned $\theta_j$ only if $j$ discloses it before they compete on the product market; otherwise firm $i$ is not sure whether firm $j$ failed to acquire $\theta_j$ or successfully learned it but did not disclose (i.e., concealed) it. If an informed firm $i$ chooses sharing, it can only send the message $\theta_i$ since the information is verifiable. However, if an informed firm chooses to conceal its private cost, then it sends the uninformative message $\left[0, \overline{\theta}\right]$, which is the same as the message sent by an uninformed firm. Firms make their disclosure decisions simultaneously.

The first purpose of the paper is to investigate and compare the different equilibrium R&D intensity in different information disclosure regimes, as Jansen (2008) did when the pair of duopoly faces uncertain common demand.

In the final stage, firms simultaneously choose their output levels $x_i$, i.e. firms are differentiated Cournot competitors. Firm $i$'s expected profit can be written as:[8]

$$\pi_i(x_i; E_{f_j} x_j, \vartheta_i) = (a - x_i - \gamma E_{f_j} x_j - \vartheta_i) x_i. \tag{3}$$

[8] From this profit expression, we can also interpret $\theta_{i(j)}$ in an alternative way: $a$ is the common demand intercept on the two markets, while $\theta_{i(j)}$ can be regarded as the individual market demand shock specific to firm $i\,(j)$; in this case, we assume that the product cost of both firms is zero, as Vives (1990), where the firms' exogenous common and private demand shocks are considered separately and respectively, while all the production cost is normalized at zero. This explanation broadens the application of our model, since all the subsequent analysis and conclusions concerning private cost R&D are also valid to the individual market demand shock investigation.

where $E_{f_j}x_j$ is $i$'s equilibrium expectation over $j$'s strategy, and the subscript "$f_j$" represents $i$'s equilibrium belief over $j$'s type and "$E_{f_j}$" is the expectation operator over the distribution $f_j$; we notice that $f_j$ may be different from the prior $f$ since it's the updated posterior after the information acquisition ($r_j$) and disclosure decisions/regimes; $\vartheta_i$ equals either $\theta_i$ if firm $i$ is informed, or $E_f\theta$ if firm $i$ is not informed, where $E_f$ is the expectation operator over $f(\cdot)$ on $\left[0,\overline{\theta}\right]$.

Since both firms face a linear market demand, it's straightforward to obtain that $\pi_i^* = x_i^2$. The following lemma applies and comes from the firm's profit maximization.

**Lemma 1** $\pi_i^*(E_{f_j}x_j, \vartheta_i) = x_i^2(E_{f_j}x_j, \vartheta_i)$, $i = 1, 2$, *where* $x_i(E_{f_j}x_j, \vartheta_i)$ *and* $\pi_i^*(E_{f_j}x_j, \vartheta_i)$ *denote the output level and expected profits of firm i in the market competition phase under the information structure* ($\vartheta_i$) *and equilibrium belief* ($E_{f_j}x_j$)*, respectively.*

**Proof.** The first order condition of maximizing (3) with respect to $x_i$ gives the optimal output of firm $i$ under $(E_{f_j}x_j, \vartheta_i)$:

$$x_i(E_{f_j}x_j, \vartheta_i) = \frac{a - \gamma E_{f_j}x_j - \vartheta_i}{2}. \tag{4}$$

Insert (4) back into (3), we can get the conclusion. ■

# 3 The Equilibrium under Different Regimes

Before analyzing the three regimes, full concealment, full disclosure, and strategic disclosure, respectively, we characterize the market competition equilibrium under $r_i = r_j = 0$, i.e., neither R&D effort in the first stage, so no one has the cost information during production phase (no information to share or conceal), and the payoffs are only expected on the prior $f(\cdot)$ over $\left[0,\overline{\theta}\right]$.

**Lemma 2** *In the continuation game in which no firm exerted R&D investment, i.e., no one has the cost information during market production, the equilibrium output level is:*

$$x_i = x_j = \frac{a - E_f\theta}{2+\gamma}. \tag{5}$$

**Proof.** In the appendix. ■

Then, by Lemma 1, we know that the expected profit, i.e., the payoff under no R&D is

$$E\pi_{r_i=r_j=0} = \pi(f,f) = (\frac{a - E_f\theta}{2+\gamma})^2, \tag{6}$$

where $(f,f)$ denotes the continuation game in which $r_i = r_j = 0$, i.e., firms hold their prior beliefs about production costs.

## 3.1 Full Concealment Regime

First, we consider the regime in which firms cannot (or do not) share information in the second stage. This regime serves as one extreme benchmark of the information acquisition and disclosure problem. Firms precommit (or know and obey) "full concealment" before they make their R&D investment decisions. The consideration of this benchmark will help the decomposition of the value of information (the decomposition will be complete in the next two subsections). So, in this subsection, we ask the question: what is the net value of R&D under precommitted no information sharing?

Before answering, we look at the following lemma.

**Lemma 3** *For any information-disclosure choice of firm $i$, so long as firm $j$ does not disclose, then firm $i$ is indifferent whether firm $j$ knows it own type $\theta_j$.*

Since other information-disclosure choices appear in the subsequent subsections, we put the proof of this lemma in the appendix. The key property behind Lemma 3 is the linearity of the best response with respect to the rival's type, which is a result of constant return to scale setting.

So after Lemma 3, the ex ante profit of firm $i$ exerting $r_i$ is:

$$r_i E_f \pi^c(\theta_i, f) + (1 - r_i)\,\pi(f,f) - \eta r_i, \tag{7}$$

where $E_f$ represents the expectation over the prior $f$ on $\theta_i$ since the decision of $r_i$ is before the stage of market profits realization, and the superscript "$c$" stands for "concealment". By (7) and Lemma 3, we see that the ex ante payoff is independent of $r_j$, which tells us that the R&D extent is a unilateral decision rather than an interactive game, under a precommitted full concealment regime. From the linearity of $r_i$ in (7), we can infer that the R&D decision depends on the relative magnitude between the value of knowing own type $\theta_i$ and the full R&D cost $\eta$, and there is no equilibrium where $0 < r_i < 1$ except in a knife-edge case. The following proposition confirms this and depicts $E_f \pi^c(\theta_i, f)$.

**Proposition 1** $E_f\pi^c(\theta_i, f) = (\frac{a-E_f\theta}{2+\gamma})^2 + \frac{1}{4}\sigma_\theta^2$. *The information acquisition equilibrium under full concealment regime is:* $r_i = r_j = 1$ *(Resp.* $0$*) if* $\eta <$ *(Resp.* $>$*)*$\frac{1}{4}\sigma_\theta^2$*, where* $\sigma_\theta^2$ *is the variance of* $f(\cdot)$ *over* $[0, \overline{\theta}]$*. If* $\eta = \frac{1}{4}\sigma_\theta^2$ *(knife-edge case), then any* $r_i, r_j \in [0, 1]$ *can be the equilibrium.*

**Proof.** In the appendix. ■

By Proposition 1 and (6)(7), if the information is concealed in stage 2, then the net gain of information acquisition, i.e., the value of learning own type, is $\frac{1}{4}\sigma_\theta^2$, which is independent of the market structure ($\gamma$), and of the R&D strategy of the rival.

The value of information in this subsection (under information concealment) comes from the intuition: the linear demand, constant return to scale, and Lemma 1 give a convex profit function over the firm's own cost, so, when there is a lot of variance in $\theta_i$, then, ex ante, it's valuable for the firm to have the information on $\theta_i$ at the production stage.

## 3.2 Full Disclosure Regime

Now we consider the regime in which firms have to disclose its cost type information (if successfully learned) to the rival after the R&D stage. "Full disclosure" serves as another extreme benchmark (compared to "full concealment") of the information disclosure problem. We ask: has a firm more or less incentive to invest in cost information acquisition if precommitting to disclosure, compared to concealment regime? And in this subsection we will complete the decomposition of the value of information about the costs $(\theta_i, \theta_j)$.

First, we look at the following lemma of equilibrium market outputs of a pair of informed $(\theta_i, \theta_j)$ under full sharing, which is the standard Cournot competition result.

**Lemma 4** *If firms know their own and rivals' per-unit production costs* $\theta_i, \theta_j$*, respectively, during the market competition phase, then, the equilibrium outputs are:*

$$x_i^d(\theta_i, \theta_j) = \frac{a}{2+\gamma} - \frac{2\theta_i - \gamma\theta_j}{4-\gamma^2},\ i, j = 1, 2, \tag{8}$$

*where the superscript "d" stands for "disclosure".*

**Proof of Lemma 4.** In the appendix. ■

If firm $i$ expects the rival's R&D effort $r$ and exerts $r_i$, there are altogether four kinds of continuations during market competition: both R&Ds succeed, with probability $r_i r$; $i$ acquires and discloses $\theta_i$ but $j$ fails, with probability $r_i(1-r)$; $j$ succeeds but $i$ fails, with probability $r(1-r_i)$; both fail, with probability $(1-r_i)(1-r)$. So the payoff (ex ante profit) of $r_i$ based on the belief $r$ is:

$$r_i\left(rE_{f,f}\pi^d(\theta_i,\theta_j)+(1-r)E_f\pi^d(\theta_i,f)\right)+(1-r_i)\left(rE_f\pi(f,\theta_j)+(1-r)\pi(f,f)\right)-\eta r_i, \tag{9}$$

where the superscript "$d$" stands for "disclose" since as long as a firm knows its own type, the rival knows it too by mandatory sharing under this regime; the subscript "$f,f$" before $\pi^d(\theta_i,\theta_j)$ represents the joint expectation over $\theta_i$ and $\theta_j$; while the subscript "$f$" before $\pi^d(\theta_i,f)$ (Resp. $\pi(f,\theta_j)$) represents the expectation over $\theta_i$ (Resp. $\theta_j$).

By (9), unlike the full concealment regime, now the R&D decisions become an interactive game since the rival's strategy $r$ enters the payoff function of $i$; but the following proposition will tell us that $r_i$ and $r$ are separated in (9), which implies that there will be still no equilibrium with $0<r_i<1$ (except for knife-edge cases). From Lemma 1, we know that $\pi^d(\theta_i,\theta_j)=\left(x_i^d(\theta_i,\theta_j)\right)^2$, where the quantity is given by Lemma 4. And Proposition 2 characterizes $\pi^d(\theta_i,f)$, $\pi(f,\theta_j)$ and the equilibrium under full disclosure regime.

**Proposition 2** *If the firms commit to share information in the second stage, then:*

*(i)* $E_{f,f}\pi^d(\theta_i,\theta_j)=(\frac{a-E_f\theta}{2+\gamma})^2+\frac{(4+\gamma^2)\sigma_\theta^2}{(4-\gamma^2)^2}$.

*(ii)* $E_f\pi^d(\theta_i,f)=(\frac{a-E_f\theta}{2+\gamma})^2+\frac{4\sigma_\theta^2}{(4-\gamma^2)^2}$.

*(iii)* $E_f\pi(f,\theta_j)=(\frac{a-E_f\theta}{2+\gamma})^2+\frac{\gamma^2\sigma_\theta^2}{(4-\gamma^2)^2}$.

*(iv) the information acquisition equilibrium is: when* $\eta<$ *(Resp.* $>$*)* $\frac{4\sigma_\theta^2}{(4-\gamma^2)^2}$, $r_i=r_j=1$ *(Resp.* $0$*).*[9]

**Proof of Proposition 2.** In the appendix. ■

We see that the cost threshold of full information acquisition under full disclosure regime ($\eta<\frac{4\sigma_\theta^2}{(4-\gamma^2)^2}$) is less stringent than that under full concealment regime ($\eta<\frac{\sigma_\theta^2}{4}$), so a precommitted disclosure rule can lead to more information acquisition.

By referring to part (i) of Proposition 2 and Proposition 1, we can decompose the net gain of both full R&Ds ($r_i=r_j=1$) on $i$'s ex ante profit into three parts: (1) the value of knowing the rival's type, $\frac{\gamma^2\sigma_\theta^2}{(4-\gamma^2)^2}$; (2) the value of learning own type, $\frac{\sigma_\theta^2}{4}$ (from Proposition 1); (3) the value of sharing

[9] If $\eta=\frac{4\sigma_\theta^2}{(4-\gamma^2)^2}$ (knife-edge case), then any $r_i,r_j\in[0,1]$ can be the equilibrium.

own type to the rival, $\left(\frac{4}{(4-\gamma^2)^2}-\frac{1}{4}\right)\sigma_\theta^2$. All these three kinds of value of information come from: the profit function of firm $i$ is a convex function of both its own cost $\theta_i$ and its rival firm $j$'s cost $\theta_j$. So knowing its own cost and the rival's cost is valuable. Besides, from an ex ante point of view, firms prefer to disclose information to its rival even if the latter discloses nothing (because $i$'s profit function is also convex in the rival's output, $x_j$, making $x_j$ contingent on own $\theta_i$ is ex ante valuable too).

Moreover, the value of knowing the rival's type (part (1)) and the value of sharing own type (part (3)) depends on and increases with the market linkage $\gamma$. But a player is only willing to pay the sum of part (2) and part (3), i.e., $\frac{4\sigma_\theta^2}{(4-\gamma^2)^2}$, since part (1) of value comes from the decision of the rival, which is a "free lunch". This implies that, when $\frac{4\sigma_\theta^2}{(4-\gamma^2)^2}<\eta<\frac{(4+\gamma^2)\sigma_\theta^2}{(4-\gamma^2)^2}$ (the sum of three parts' gain), there would be an efficiency loss due to the non-cooperative R&Ds, i.e., prisoners' dilemma. The following corollary applies.

**Corollary 1** *Under full disclosure regime, the payoffs in the first stage (R&D game) can be abstracted as Table 1. When* $\frac{4\sigma_\theta^2}{(4-\gamma^2)^2}<\eta<\frac{(4+\gamma^2)\sigma_\theta^2}{(4-\gamma^2)^2}$*, the R&D interaction is a prisoners' dilemma game, i.e., the non-cooperative equilibrium is* $r_i=r_j=0$*, but the cooperative optimum is* $r_i=r_j=1$ *if the players can collude in R&D.*

Table 1: The First Stage R&D Game under Full Disclosure Regime

| | I ($r=1$) | N ($r=0$) |
|---|---|---|
| I ($r=1$) | $[(\frac{a-E_f\theta}{2+\gamma})^2+\frac{(4+\gamma^2)\sigma_\theta^2}{(4-\gamma^2)^2}-\eta,$ $(\frac{a-E_f\theta}{2+\gamma})^2+\frac{(4+\gamma^2)\sigma_\theta^2}{(4-\gamma^2)^2}-\eta]$ | $[(\frac{a-E_f\theta}{2+\gamma})^2+\frac{4\sigma_\theta^2}{(4-\gamma^2)^2}-\eta,$ $(\frac{a-E_f\theta}{2+\gamma})^2+\frac{\gamma^2\sigma_\theta^2}{(4-\gamma^2)^2}]$ |
| N ($r=0$) | $[(\frac{a-E_f\theta}{2+\gamma})^2+\frac{\gamma^2\sigma_\theta^2}{(4-\gamma^2)^2},$ $(\frac{a-E_f\theta}{2+\gamma})^2+\frac{4\sigma_\theta^2}{(4-\gamma^2)^2}-\eta]$ | $[(\frac{a-E_f\theta}{2+\gamma})^2,$ $(\frac{a-E_f\theta}{2+\gamma})^2]$ |

**Proof of Corollary 1.** If defining the action $I$ (investment) by $r=1$, and the action $N$ (no investment) by $r=0$, respectively, then the first stage game can be depicted by a 2×2 matrix $((N,N),(N,I),(I,N),(I,I))$ as in Table 1, where the payoffs can be obtained by inserting the corresponding combinations $(r_i=r=0),(r_i=0,r=1),(r_i=1,r=0),(r_i=r=1)$ into (9).

Regarding Table 1 as a static normal form, then clearly when $\frac{4\sigma_\theta^2}{(4-\gamma^2)^2}<$

$\eta < \frac{(4+\gamma^2)\sigma_\theta^2}{(4-\gamma^2)^2}$, it's a prisoners' dilemma game, i.e., $I$ is the dominated strategy so $(N, N)$ is the equilibrium, but $(I, I)$ is the mutually beneficial profile. ■

The intuition is: the rival's R&D generates positive externality on $i$'s profit (part (1): $\frac{\gamma^2\sigma_\theta^2}{(4-\gamma^2)^2}$), but this amount will not support the non-cooperative R&D since it's up to the decision of $j$ and the two firms' actions, $r_i, r_j$ are separated. So from a point of view of joint profits, it's valuable to exert both R&Ds when $\eta$ exceeds $\frac{4\sigma_\theta^2}{(4-\gamma^2)^2}$, but lower than $\frac{(4+\gamma^2)\sigma_\theta^2}{(4-\gamma^2)^2}$, i.e., to support joint R&Ds by the ex post externalities.

Overall, the total net gain of information acquisition and sharing is $\frac{(4+\gamma^2)\sigma_\theta^2}{(4-\gamma^2)^2}$, which is increasing in $\gamma$; when $\gamma = 0$, i.e., two independent markets, we see that the amount $\frac{(4+\gamma^2)\sigma_\theta^2}{(4-\gamma^2)^2}$ degenerates to $\frac{1}{4}\sigma_\theta^2$ and coincides with the net value of information in the full concealment regime, that is to say, when the two goods are more substitutable, firms have incentive to do R&D and to pre-commit to share the result. Figure 1 illustrates the decomposition of the total value of information acquisition and sharing globally when $\gamma$ evolves from 0 to 1. The vertical distance between the horizontal solid line and the horizontal axis represents the value of "knowing own type"; the vertical distance between the long dashed curve and the horizontal solid line is the value of "sharing own type to the rival"; while the vertical distance between the dot-dashed curve and the long dashed curve represents the value of "knowing the rival's type".

# Figure 1 is about here

On the other hand, Figure 1 expresses different maximum thresholds of R&D cost that a firm is willing to afford under different regimes/situations. The horizontal solid line, $\frac{1}{4}\sigma_\theta^2$, is the threshold under full concealment. The long dashed curve, $\frac{4\sigma_\theta^2}{(4-\gamma^2)^2}$, represents the threshold under full disclosure. When $\eta$ is larger than this threshold, but not too high (less than $\frac{(4+\gamma^2)\sigma_\theta^2}{(4-\gamma^2)^2}$), the prisoners' dilemma arises: though the unique equilibrium in the non-cooperative R&D game is $r_i = r_j = 0$; while $r_i = r_j = 1$ is the Pareto dominant allocation because of the value of knowing the rival's type, which benefits from the rival's R&D under full disclosure, $\frac{\gamma^2\sigma_\theta^2}{(4-\gamma^2)^2}$. If there exists an exterior commitment device to cooperate in the R&D phase, e.g., to sign the promise of R&D investment (on top of the disclosure agreement), and if its fulfillment is protected and monitored by law, then the cooperative optimum $r_i = r_j = 1$ can be realized. This conveys an interesting and important indication on real markets: the duopoly facing individual uncertainties may incline to cooperate on R&D, which may be mutually beneficial to their future products competition.

### 3.3 Strategic Disclosure

Now we relax the previous two extremes disclosure regimes in the second stage and allow an informed firm to strategically decide whether to disclose or conceal its cost information to the rival contingent on the cost type it learned. We call this "strategic disclosure" regime (without precommitted disclosure rule). Given an informed type $\theta_i$, is it willing to disclose? What does the disclosure incentive depend on? We have the following important lemma which is useful to derive the R&D equilibrium under strategic disclosure.

**Lemma 5** *If $i$ knows its cost $\theta_i$, as in (3) and Lemma 1, denote $f_i$ as the prior/posterior/equilibrium belief that $j$ holds for $\theta_i$, then no matter the information-disclosure choice of $j$, $\theta_i$ is willing to disclose if and only if $\theta_i < E_{f_i}\theta_i$, which is $j$'s expectation on $\theta_i$ under $f_i$, where $i, j = 1, 2$.*

**Proof.** In the appendix. ■

We notice that $f_i$ ($f_j$) may differ from the symmetric prior as the very beginning, $f$, since it may be the posterior/equilibrium belief that $j$ ($i$) holds.

Before characterizing the R&D equilibrium, we investigate the continuation after a symmetric information acquisition $(r, r)$.[10] Then the following proposition applies.

**Proposition 3** *Given the (symmetric) actions in the first stage $(r, r)$: if $r > 0$, then there exists a unique $\widetilde{\theta}(r) \in \left(E_f\theta, \overline{\theta}\right]$ such that an informed $\theta_i$ discloses if and only if $\theta_i < \widetilde{\theta}(r)$, where $\widetilde{\theta}'(r) > 0$ and $\widetilde{\theta}(1) = \overline{\theta}$, $\lim_{r\to 0}\widetilde{\theta}(r) = E_f\theta$.*

**Proof.** In the appendix. ■

First, if $r_i = r_j = 1$, then the "unraveling effect" leads to "full sharing" even if the disclosure is voluntary, i.e., the unique continuation equilibrium is "full disclosure", and the belief supporting "full disclosure" is that any unobservable/concealed rival's cost is regarded as the type $\overline{\theta}$, e.g. see Milgrom (1981), Milgrom and Roberts (1986), and Okuno-Fujiwara et al (1990). So in this case, the lower bound of concealment is $\overline{\theta}$, i.e., $\widetilde{\theta}(1) = \overline{\theta}$.

[10]This paper concentrates and restricts to the symmetric equilibria. Recall that we set the R&D extent, $r_i$,$r_j$, is not observable by the rival, which simplifies the analysis and rules out those arbitrary and non-symmetric continuations with $\forall 0 \leq r_i,r_j \leq 1$.

Second, if the continuation comes from $0 < r_i = r_j < 1$, then we know that the existence of uncertainty about one's own type (probability $1-r$) may destroy the "unraveling effect", i.e., firms can credibly conceal unfavorable news by hiding to be uninformed, see e.g. Farrell (1986). Hence, there exists a threshold $\widetilde{\theta} \in \left(E_f\theta, \overline{\theta}\right)$ such that all the informed types smaller (Resp. larger) than $\widetilde{\theta}$ will disclose (Resp. conceal). $\widetilde{\theta}$ satisfies each type's disclosure/concealment incentive in Lemma 5, i.e., $E_{\widetilde{f}}\theta = \widetilde{\theta}$, where $\widetilde{f}$ is the posterior distribution over $\left[0, \overline{\theta}\right]$ of an unobservable type: the informed but concealed ($\theta_i$ larger than a threshold $\widetilde{\theta}$) with probability $r$, plus the uninformed with probability $1-r$, as illustrated by Figure 2. By Bayes' rule, facing an unknown type of the rival, the updated (equilibrium) belief contains informed but concealed types (with probability $\frac{r\left(1-F\left(\widetilde{\theta}\right)\right)}{1-rF\left(\widetilde{\theta}\right)}$) and uninformed types (with probability $\frac{1-r}{1-rF\left(\widetilde{\theta}\right)}$).

# Figure 2 is about here

When $r_i = r_j = 0$, $\widetilde{\theta}(r)$ has no definition at $r = 0$, but by the continuity of $\widetilde{\theta}(\cdot)$, we can write $\lim_{r\to 0}\widetilde{\theta} = E_f\theta$ (see the proof of the proposition in the appendix), i.e., players do not update the prior belief $f$ when facing an unknown type of the rival after $r_i = r_j = 0$.

The uniqueness of $\widetilde{\theta}$ with respect to $r$ and $\widetilde{\theta}'(r) > 0$ tells us that the more R&D exerted in the first stage, the more information will be disclosed before the market competition.

After characterizing the complete continuation equilibrium in the disclosure stage by Proposition 3, we know that there are altogether six possibilities during market competition phase if exerting $r_i$ and expecting rival's $r$:

(1) $i$ is informed, discloses, and can observe $\theta_j$;

(2) $i$ is informed, discloses, but cannot observe $\theta_j$;

(3) $i$ is informed, conceals, and can observe $\theta_j$;

(4) $i$ is informed, conceals, and cannot observe $\theta_j$;

(5) $i$ is not informed and can observe $\theta_j$;

(6) $i$ is not informed and cannot observe $\theta_j$.

The corresponding probability and $i$'s payoff (expected profits) of each case are in Table 2.

The calculation of $\pi_i^{(1)}$ to $\pi_i^{(6)}$ in Table 2 is in the appendix; "$E_{f,f}$" before $\pi_i$ in the table is the joint expectation over $\theta_i$ and $\theta_j$ on their corresponding supports in different cases, respectively. Therefore, $i$'s ex ante expected payoff

Table 2: Six Information Structures of Firm $i$ during Market Competition under Strategic Disclosure Regime

| Case | Probability | $\pi_i$ |
|---|---|---|
| (1) | $r_i r \left(F\left(\widetilde{\theta}\right)\right)^2$ | $E_{f\left(\theta_i \mid \theta_i<\widetilde{\theta}\right), f\left(\theta_j \mid \theta_j<\widetilde{\theta}\right)}\left(\frac{a}{2+\gamma}-\frac{2\theta_i-\gamma\theta_j}{4-\gamma^2}\right)^2$ |
| (2) | $r_i F\left(\widetilde{\theta}\right)\left(1-rF\left(\widetilde{\theta}\right)\right)$ | $E_{f\left(\theta_i \mid \theta_i<\widetilde{\theta}\right)}\left(\frac{a}{2+\gamma}-\frac{2\theta_i-\gamma\widetilde{\theta}}{4-\gamma^2}\right)^2$ |
| (3) | $r_i r F\left(\widetilde{\theta}\right)\left(1-F\left(\widetilde{\theta}\right)\right)$ | $E_{f\left(\theta_i \mid \theta_i>\widetilde{\theta}\right), f\left(\theta_j \mid \theta_j<\widetilde{\theta}\right)}\left(\frac{a}{2+\gamma}-\frac{2\theta_i-\gamma\theta_j}{4-\gamma^2}+\frac{\gamma^2\left(\theta_i-\widetilde{\theta}\right)}{2(4-\gamma^2)}\right)^2$ |
| (4) | $r_i\left(1-F\left(\widetilde{\theta}\right)\right)\left(1-rF\left(\widetilde{\theta}\right)\right)$ | $E_{f\left(\theta_i \mid \theta_i>\widetilde{\theta}\right)}\left(\frac{a+\frac{\gamma}{2}\widetilde{\theta}}{2+\gamma}-\frac{\theta_i}{2}\right)^2$ |
| (5) | $\left(1-r_i\right) rF\left(\widetilde{\theta}\right)$ | $E_{f\left(\theta_j \mid \theta_j<\widetilde{\theta}\right)}\left(\frac{a}{2+\gamma}-\frac{2E_f\theta-\gamma\theta_j}{4-\gamma^2}-\frac{\gamma^2\left(\widetilde{\theta}-E_f\theta\right)}{2(4-\gamma^2)}\right)^2$ |
| (6) | $\left(1-r_i\right)\left(1-rF\left(\widetilde{\theta}\right)\right)$ | $\left(\frac{a}{2+\gamma}-\frac{2E_f\theta-\gamma\widetilde{\theta}}{4-\gamma^2}\right)^2$ |

of exerting $r_i$ with expecting the rival's $r$ is:

$$\begin{aligned}
& r_i\{F\left(\widetilde{\theta}\right)\left[rF\left(\widetilde{\theta}\right)\pi_i^{(1)}+\left(1-rF\left(\widetilde{\theta}\right)\right)\pi_i^{(2)}\right] \\
& +\left(1-F\left(\widetilde{\theta}\right)\right)\left[rF\left(\widetilde{\theta}\right)\pi_i^{(3)}+\left(1-rF\left(\widetilde{\theta}\right)\right)\pi_i^{(4)}\right]\} \\
& +\left(1-r_i\right)\{rF\left(\widetilde{\theta}\right)\pi_i^{(5)}+\left(1-rF\left(\widetilde{\theta}\right)\right)\pi_i^{(6)}\} \\
& -\eta r_i
\end{aligned} \tag{10}$$

The following proposition depicts the equilibrium in the R&D stage under strategic disclosure regime.

**Proposition 4** *If we restrict to the symmetric equilibria $r_i = r_j = r$, then:*

*(i) When $\eta < \frac{4\sigma_\theta^2}{(4-\gamma^2)^2}+\eta_1 \equiv \frac{4\sigma_\theta^2}{(4-\gamma^2)^2}+\frac{\gamma^2\left(\overline{\theta}-E_f\theta\right)}{4-\gamma^2}\left(\frac{a-E_f\theta}{2+\gamma}-\frac{\gamma^2\left(\overline{\theta}-E_f\theta\right)}{4(4-\gamma^2)}\right)$, $r=1$ is an R&D equilibrium, and both firms will fully disclose the information they learned (since $\widetilde{\theta}(1)=\overline{\theta}$).*

*(ii) When $\eta > \frac{4\sigma_\theta^2}{(4-\gamma^2)^2}+\eta_0 \equiv \frac{4\sigma_\theta^2}{(4-\gamma^2)^2}+(1-F(E_f\theta))\cdot E_{f\left(\theta_i \mid \theta_i>E_f\theta\right)}\left(\pi^c(\theta_i,f)-\pi^d(\theta_i,f)\right)$, where $F(\cdot)$ is the c.d.f. of $f$, $\pi^c(\theta_i,f)$ is the profit of an informed but concealed $\theta_i$ facing an uninformed $j$, $\pi^d(\theta_i,f)$ is the profit of an informed and disclosed $\theta_i$ facing an uninformed $j$, then, $r=0$ is an R&D equilibrium, i.e., no information acquired or disclosed, and both firms get the profit $(\frac{a-E_f\theta}{2+\gamma})^2$.*

*(iii) If $\eta_0 > \eta_1$, then, when $\frac{4\sigma_\theta^2}{(4-\gamma^2)^2} + \eta_1 < \eta < \frac{4\sigma_\theta^2}{(4-\gamma^2)^2} + \eta_0$, there exists an $r \in (0,1)$ being the R&D equilibrium,*[11] *and the information disclosure rule will follow Proposition 3 and $\widetilde{\theta}(r)$; if $\eta_0 < \eta_1$, then, when $\frac{4\sigma_\theta^2}{(4-\gamma^2)^2} + \eta_0 < \eta < \frac{4\sigma_\theta^2}{(4-\gamma^2)^2} + \eta_1$, there exists at least three equilibria, $r = 0$, $r = 1$, and an $r \in (0,1)$.*

**Proof.** In the appendix. ■

From the proof of Proposition 4, $\eta_1 > 0$, so the upper bound of full R&D ($r = 1$) in the voluntary disclosure regime is higher than that of mandatory disclosure, and the firms will share all the information they learned to the rival too. Hence, there is no necessity to regulate the firms to share information forcibly since the market result realizes it automatically even when the information acquisition cost is higher than the threshold of the full disclosure regime ($\frac{4\sigma_\theta^2}{(4-\gamma^2)^2}$).

The reason that the firms exert more R&D effort under strategic disclosure regime than that of full disclosure regime (part (i) of Proposition 4) is: deviating from $r_i = 1$ to $r_i < 1$ will not change firm $j$'s equilibrium belief (firm $j$ thinks $r_i = 1$ and $\widetilde{\theta}_i = \overline{\theta}$), which means that, if firm $i$ learns $\theta_i$, it will disclose it truthfully; if firm $i$ knows nothing, it will be perceived as $\theta_i = \overline{\theta}$. This concern drives the R&D more aggressive, compared to the full disclosure regime.

Part (ii) of Proposition 4 states that the threshold of no R&D ($r = 0$) under strategic disclosure regime is also higher than that of full disclosure regime. The explanation is: deviating from $r_i = r_j = 0$ for firm $i$, i.e. setting $r_i > 0$ will be profitable because there exists strategic value of cost information. The strategic value comes from the fact that firm $i$ can both hide unfavorable information effectively and disclose favorable one by setting $r_i > 0$. So at $\eta = \frac{4\sigma_\theta^2}{(4-\gamma^2)^2}$ where the R&D cost is equal to the value of information under full disclosure regime, incorporating this strategic value ($\eta_0$) will definitely make R&D more profitable.

In the case of $\eta_0 > \eta_1$, if the full R&D ($r = 1$) is not supportable ($\eta > \frac{4\sigma_\theta^2}{(4-\gamma^2)^2} + \eta_1$), then partial R&D ($r < 1$) equilibrium may arise (till $\eta > \frac{4\sigma_\theta^2}{(4-\gamma^2)^2} + \eta_0$). When $\eta_0 < \eta_1$, both $r = 1$ and $r = 0$ are equilibria if $\frac{4\sigma_\theta^2}{(4-\gamma^2)^2} + \eta_0 < \eta < \frac{4\sigma_\theta^2}{(4-\gamma^2)^2} + \eta_1$, then the coordination problem between the firms may arise. $\eta_1$ may be larger or smaller than $\eta_0$, which depends on the distribution

[11] There may exist multiple equilibria for $r \in (0,1)$. We have not proved (or disproved) the uniqueness.

of $\theta$, i.e., the prior $f$.[12]

So in the sense of information acquisition and disclosure extent, *the strategic disclosure regime dominates mandatory disclosure or concealment, given that the firms play a non-cooperative R&D game.* But from Corollary 1, under the full disclosure regime, when $\frac{4\sigma_\theta^2}{(4-\gamma^2)^2} < \eta < \frac{(4+\gamma^2)\sigma_\theta^2}{(4-\gamma^2)^2}$, if the firms can collude or the state (or industry union) has an exterior power to commit mutually the full R&D behavior of each firm, then the efficient cooperative information acquisition can be realized. In this case, which regime, full disclosure or strategic disclosure, will explore and disclose more information? It depends on the relative magnitude of their upper bound thresholds of full R&D ($r = 1$), i.e., $\frac{\gamma^2\sigma_\theta^2}{(4-\gamma^2)^2}$ versus $\eta_1$.

# 4 Welfare Analysis

In this section, we first develop the consumer surplus, and investigate the value and impact of information acquisition of the firms on the industry profits, the consumer surplus, and the social total welfare, which is the joint firm-consumer surplus. We also examine the impact of information sharing between the firms on the consumer and the society.[13] Second, we analyze the upper bound of full R&D ($r = 1$) threshold under the strategic disclosure regime, to see whether this regime promotes an efficient R&D toward social optimum when the industry commitment device on R&D is absent, or it involves an over-investment on R&D when the cost is socially inefficient ($\eta$ extremely high).

We assume that the linear demand system (1) is obtained from the optimizing behavior of a representative consumer which maximizes $U(x_i, x_j) - p_i x_i - p_j x_j$, where

$$U(x_i, x_j) = a(x_i + x_j) - \gamma x_i x_j - \frac{1}{2}\left(x_i^2 + x_j^2\right). \tag{11}$$

In (11), $\gamma$ represents the substitutability discount on the total consumption amount of $i$ and $j$. Consumer surplus (CS) in terms of quantities is

$$CS(x_i, x_j) = \frac{1}{2}\left(x_i^2 + x_j^2\right) + \gamma x_i x_j, \tag{12}$$

[12]The intuition for which one ($\eta_0$ or $\eta_1$) is larger is not very clear for the moment.

[13]Since the firms will fully disclose the information learned in a full R&D ($r = 1$) equilibrium under either strategic or mandatory disclosure regime, we can only focus on full sharing.

which is also equal to $U(x_i, x_j) - p_i x_i - p_j x_j$ and can be regarded and calculated as the average sum of two consumer surplus in the two markets.[14]

If there is no R&D investment ($r_i = r_j = 0$), then, using Lemma 1 and 2, one can derive the social surplus when $r = 0$:

$$\begin{aligned} EW_{r=0} &= CS_{r=0} + 2E\pi_{r=0} \\ &= (3+\gamma)\, x^2(f, f) \\ &= (3+\gamma)\,(\frac{a - E_f\theta}{2+\gamma})^2. \end{aligned} \tag{13}$$

If the firms learned the cost information, the social total surplus can be denoted as:

$$EW_{r=1} = EU(x_i, x_j) - E(\theta_i x_i) - E(\theta_j x_j) - 2\eta = ECS_{r=1} + 2E\pi_{r=1} - 2\eta. \tag{14}$$

Then we calculate the impacts on expected $CS$ and $W$ of information acquisition, with respect to disclosure and concealment.

**Proposition 5** *The value of information to the consumer and social surplus is:*

*(i) If the information is concealed in the second stage,*

$$ECS_{r=1} - CS_{r=0} = \frac{1}{4}\sigma_\theta^2;$$

$$EW_{r=1} - EW_{r=0} = \frac{3}{4}\sigma_\theta^2 - 2\eta.$$

*(ii) If the information is disclosed in the second stage,*

$$ECS_{r=1} - CS_{r=0} = \frac{4 - 3\gamma^2}{(4-\gamma^2)^2}\sigma_\theta^2,$$

*which is decreasing in $\gamma$;*

$$EW_{r=1} - EW_{r=0} = \frac{12 - \gamma^2}{(4-\gamma^2)^2}\sigma_\theta^2 - 2\eta, \tag{15}$$

*which is increasing in $\gamma$.*

**Proof.** In the appendix. ■

According to these results, when $\gamma = 0$, i.e., two independent markets, the value of information (net gain of R&D investment) in (i) and (ii) coincides,

[14] The surface below the inverse demand curve and above the price.

that is to say, there is no extra value (or hurt) of information sharing to the firm, consumer and social surplus, respectively, if the two goods are not related.

When $\gamma > 0$, sharing information benefits the firms mutually, while the consumer is hurt. And this hurt is increasing in $\gamma$, i.e., the value of information to the expected consumer surplus declines more under disclosure when $\gamma$ increases from 0 to 1. Though the consumer dislikes the disclosure of information, the value of information itself to the consumer surplus is nevertheless always positive, i.e., to acquire information is always beneficial to the consumer.

The intuition why the consumer prefers firms to acquire information but prefers them not to disclose it is: information acquisition will increase the equilibrium production therefore will enhance the consumer surplus. Yet information sharing between firms has detrimental effect to consumer surplus because firms could coordinate their production based on the revealed production costs. If they disclose their production costs, their production will be negatively correlated. Forbidding disclosure will break up this negative correlation and increase the total production, hence increase consumer surplus. Besides, the more substitutable are the products, the more effective are their coordination on the production. Hence, under full disclosure regime or the full R&D equilibrium under strategic disclosure regime, the information value on consumer surplus is decreasing with $\gamma$.

The benefits of information sharing to the firms' profits surpass the loss on the consumer surplus, so on behalf of social welfare, information disclosure is always valuable and the net social gain increases with the substitutability of the two markets. Figure 3 illustrates all these effects on the firm's profit, the consumer's surplus and the social welfare, respectively, when $\gamma$ evolves from 0 to 1.

# Figure 3 is about here

On behalf of social surplus, a socially efficient R&D cost threshold is larger than the firms' cooperative game result (comparing Proposition 5 with Corollary 1).[15] The short dotted curve in Figure 1 represents the socially efficient R&D cost upper bound and the following corollary specifies its value. Figure 1 also tells us that all kinds of R&D (full) threshold is non-decreasing in $\gamma$, i.e., when the markets are more related with each other, the information (R&D) becomes more valuable to the firms and the society.

[15]Even the cooperation between the firms cannot afford R&D ($\eta > \frac{(4+\gamma^2)\sigma_\theta^2}{(4-\gamma^2)^2}$, from Proposition 2 and Corollary 1), the consumer funding for R&D to acquire production costs for the firms is socially efficient.

**Corollary 2** *R&D is socially efficient (Resp. inefficient) if* $\eta <$ *(Resp.* $>$*)* $\frac{12-\gamma^2}{2(4-\gamma^2)^2}\sigma_\theta^2$.

**Proof.** Easily obtained from (15). ■

The interesting point is: when $\frac{(4+\gamma^2)\sigma_\theta^2}{(4-\gamma^2)^2} < \eta < \frac{12-\gamma^2}{2(4-\gamma^2)^2}\sigma_\theta^2$, a powerful industry union which can commit the information sharing and cooperative R&D will not do the R&D since the joint net gain on profits cannot afford the costs, but it's still valuable to extract a tax or payment from the consumer to support the firms' R&Ds on behalf of the social surplus; to realize this social efficiency when $\eta$ is very high, we need a mechanism to collect funds from the consumer (through tax, for instance). But when $\eta > \frac{12-\gamma^2}{2(4-\gamma^2)^2}\sigma_\theta^2$, any R&D (even partial R&D) is not worth doing.

We remember that if the state (or the industry union) lets the market be (do not regulate the pre-commitment of disclosure), i.e., the two firms play a voluntary strategic disclosure and acquisition game, then the full R&Ds can be even more easily obtained. But whether the strategic R&D threshold is welfare enhancing, we should compare it with the socially efficient upper bound $\frac{12-\gamma^2}{2(4-\gamma^2)^2}\sigma_\theta^2$.

**Corollary 3** *The upper bound of full R&D threshold under strategic disclosure regime is larger than that of the social efficient threshold if and only if*

$$a > E_f\theta + \frac{\gamma^2\left(\overline{\theta} - E_f\theta\right)}{4(2-\gamma)} + \frac{(2+\gamma)\,\sigma_\theta^2}{2\gamma^2\left(\overline{\theta} - E_f\theta\right)} \tag{16}$$

*and* $\gamma > 0$.

**Proof.** In the appendix. ■

First, when $\gamma = 0$, $\eta_1 = 0$, the upper bound of R&D cost threshold under strategic disclosure regime coincides with other two regimes, which is $\frac{1}{4}\sigma_\theta^2$. It is definitely lower than the social efficient upper bound ($\frac{3}{8}\sigma_\theta^2$) when the two markets are independent.

But when $\gamma > 0$, if (16) holds, then the strategic disclosure regime may involve some inefficient (on behalf of social surplus) R&D when its cost $\eta$ is extremely high, i.e., $\frac{12-\gamma^2}{2(4-\gamma^2)^2}\sigma_\theta^2 < \eta < \frac{4\sigma_\theta^2}{(4-\gamma^2)^2} + \eta_1$. We also notice that this (satisfaction of (16)) may happen especially when the market demand potential (the demand intercept $a$) is extremely large; in this case, the incentive for strategic R&D can be very strong and can endure a very high $\eta$. The intuition is: the party who deviates from $r = 1$ is afraid of being treated as the highest cost type; when the market's potential demand is quite large, the firms may over-invest in R&D for their market competition.

# 5 Concluding Remarks

In this paper, we take one step further to study the incentive to gather information and thus endogenize the information structure on the private cost information transmission in differentiated duopoly model. We restrict out attention to three information sharing regimes: full concealment, full disclosure, and strategic disclosure. The main findings are as follows.

The ranking of the three regimes with respect to the incentive to acquire information is: strategic disclosure $\succ$ full disclosure $\succ$ full concealment. If firms are subject to precommit the information sharing regimes before acquiring information, i.e., full disclosure or full concealment, then they prefer the full disclosure regime under which more information is acquired; moreover, on top of this, they prefer the cooperation in the information gathering phase even if they have to compete and cannot collude on the production market. In other words, precommitting to particular disclosure regime and even cooperating on information gathering are not indicators of collusion on production markets.

If firms can not precommit to particular regimes, then after information gathering, firms will choose to disclose information strategically, i.e. disclose favorable information (lower cost) while conceal unfavorable information (higher cost). Firms will take this strategic effect into account when they try to infer their competitor's cost using Bayes' rule. When there exists partial information acquisition, we prove that given the probability of information gathering, there exists a unique cutoff value of cost under (Resp. above) which cost information is disclosed (Resp. concealed). We also show that the incentive to acquire information under strategic regime is the strongest among the three. Two forces come into effect: the fear of being treated as the highest cost type when deviating from $r_i = r_j = 1$; and the strategic value of deviating from $r_i = r_j = 0$. Both effects enhance the incentive to gather more information comparing to the full disclosure case.

Regarding the welfare, consumers benefit from information gathering, yet prefer the firms to conceal their information after gathering it. Because under complete information, the production of the two firms will be negatively correlated, so forbidding information disclosure will break up this correlation and enhance the total production. The society as a whole prefers to disclose the information that the firms acquired. On behalf of the consumer surplus, full concealment regime is preferred if the cost of acquiring information is low; if is high, the consumers will prefer strategic disclosure regime.

On behalf of the firms and the social welfare, full concealment regime is dominated. If the state, the society, or the firms themselves have a commitment device to mutually cooperate on the R&D activity, then the full disclosure regime may be preferred. But, if firms can not cooperate on R&D, and the information acquisition cost is sufficiently high, the strategic disclosure regime may be preferred. At last, strategic disclosure regime may involve an over-incentive to gather information with respect to the socially efficient level, when the market's demand potential is quite large.

We model the market competition phase as a Cournot game. As a robustness test, we provide the price (Bertrand) competition structure and all its parallel results in the appendix. Special points of Bertrand competition are: full disclosure regime is dominated from perspective of both firms and consumers; yet when R&D cost is high enough, strategic disclosure regime is preferred comparing to full concealment regime, because the former give strongest incentive to acquire information.

# 6 Appendix.

**Proof of Lemma 2.** From (3), the expected profit of firm $i$ is

$$E\pi_i(x_i, x_j) = (a - x_i - \gamma x_j - E_f\theta)x_i. \tag{17}$$

First order condition gives the reaction function:

$$x_i(x_j) = \frac{a - E_f\theta - \gamma x_j}{2}.$$

Similarly, $x_j(x_i) = \frac{a - E_f\theta - \gamma x_i}{2}$. The equilibrium is determined by the intersection of the two reaction functions:

$$x_i^* = x_j^* = \frac{a - E_f\theta}{2+\gamma}. \tag{18}$$

■

**Proof of Lemma 3.** There are three information-disclosure choices of firm $i$: (i) $i$ is informed and discloses $\theta_i$; (ii) $i$ is informed but conceals $\theta_i$; (iii) firm $i$ is not informed and based on the prior $f_i$. With respect to each information-disclosure choice of firm $i$, given that firm $j$ does not disclose, i.e., $i$ cannot observe $\theta_j$, there are two possibilities of firm $j$: (a) $j$ is not informed and based on the prior $f_j$; (b) $j$ is informed but conceals $\theta_j$. So it suffices to prove that on behalf of firm $i$'s profit, the combination of (i) and (a) is equivalent to the combination of (i) and (b), the combination of (ii) and (a) is equivalent to the combination of (ii) and (b), and, the combination of (iii) and (a) is equivalent to the combination of (iii) and (b), respectively.

(i)-(a):

The first order conditions of firm $i$ and $j$ maximizing their profits in the market competition phase in this information structure are:

$$x_i = \frac{a - \gamma x_j - \theta_i}{2};\ x_j = \frac{a - \gamma x_i - E_{f_j}\theta_j}{2}.$$

The equilibrium quantity of $x_i^d(\theta_i, f_j)$, where the superscript "$d$" stands for "disclosure" and the second argument "$f_j$" means that $j$ is not informed, is determined by the intersection of two response functions, i.e.,

$$x_i^d(\theta_i, f_j) = \frac{a}{2+\gamma} - \frac{2\theta_i - \gamma E_{f_j}\theta_j}{4-\gamma^2}. \tag{19}$$

(i)-(b):

The first order condition of firm $i$ is $x_i = \frac{a-\gamma E_{f_j}x_j(\theta_j)-\theta_i}{2}$. Since firm $j$ knows its own type, its best response is $x_j(\theta_j) = \frac{a-\gamma x_i-\theta_j}{2}$. So $E_{f_j}x_j(\theta_j) = \frac{a-\gamma x_i-E_{f_j}\theta_j}{2}$, which can be put into the response of $x_i$ to determine $x_i^d\left(\theta_i, E_{f_j}x_j\right)$:

$$x_i^d\left(\theta_i, E_{f_j}x_j\right) = \frac{a}{2+\gamma} - \frac{2\theta_i - \gamma E_{f_j}\theta_j}{4-\gamma^2} = x_i^d\left(\theta_i, f_j\right). \tag{20}$$

So the equilibrium quantities in (i)-(a) and (i)-(b) coincide. By Lemma 1, we know that

$$\pi_i^d\left(\theta_i, f_j\right) = \left(x_i^d\left(\theta_i, f_j\right)\right)^2 = \left(x_i^d\left(\theta_i, E_{f_j}x_j\right)\right)^2 = \pi_i^d\left(\theta_i, E_{f_j}x_j\right).$$

(ii)-(a):

Compared to (i)-(a), the first order condition for $i$ does not change but that for $j$ changes since now $\theta_i$ is concealed:

$$x_i = \frac{a-\gamma x_j - \theta_i}{2};\; x_j = \frac{a-\gamma E_{f_i}x_i\left(\theta_i\right) - E_{f_j}\theta_j}{2}. \tag{21}$$

Taking expectation on both sides of $x_i$, we have $E_{f_i}x_i\left(\theta_i\right) = \frac{a-\gamma x_j - E_{f_i}\theta_i}{2}$. Taking this into account,

$$x_j^{\phi}\left(f_j, E_{f_i}x_i\right) = \frac{a}{2+\gamma} - \frac{2E_{f_j}\theta_j - \gamma E_{f_i}\theta_i}{4-\gamma^2} = \frac{a-E_f\theta}{2+\gamma}, \tag{22}$$

where the superscript "$\phi$" stands for "not informed".

Substituting this into the best response of $i$ in (21), we get

$$x_i^c\left(\theta_i, f_j\right) = \frac{a+\frac{\gamma}{2}E_f\theta}{2+\gamma} - \frac{\theta_i}{2}, \tag{23}$$

where the superscript "$c$" stands for "concealment".

(ii)-(b):

Compared to (ii)-(a), both first order conditions for $i$ and for $j$ change since on behalf of $j$, the information on $\theta_j$ becomes precise, but on behalf of $i$, $x_j$ becomes uncertain, so the best responses become:

$$x_i = \frac{a-\gamma E_{f_j}x_j\left(\theta_j\right) - \theta_i}{2};\; x_j = \frac{a-\gamma E_{f_i}x_i\left(\theta_i\right) - \theta_j}{2}. \tag{24}$$

Taking expectation on both sides of both, we have

$$E_{f_i}x_i\left(\theta_i\right) = \frac{a-\gamma E_{f_j}x_j\left(\theta_j\right) - E_{f_i}\theta_i}{2};\; E_{f_j}x_j\left(\theta_j\right) = \frac{a-\gamma E_{f_i}x_i\left(\theta_i\right) - E_{f_j}\theta_j}{2}. \tag{25}$$

The intersection in (25) determines

$$E_{f_j}x_j\left(\theta_j\right)=\frac{a}{2+\gamma}-\frac{2E_{f_j}\theta_j-\gamma E_{f_i}\theta_i}{4-\gamma^2}=\frac{a-E_f\theta}{2+\gamma}.$$

By (24), we can get

$$x_i^c\left(\theta_i,E_{f_j}x_j\right)=\frac{a+\frac{\gamma}{2}E_f\theta}{2+\gamma}-\frac{\theta_i}{2}. \tag{26}$$

which is exactly the same as (23), the quantity in (ii)-(a).

So by Lemma 1,

$$\pi_i^c\left(\theta_i,f_j\right)=\left(x_i^c\left(\theta_i,f_j\right)\right)^2=\left(x_i^c\left(\theta_i,E_{f_j}x_j\right)\right)^2=\pi_i^c\left(\theta_i,E_{f_j}x_j\right).$$

(iii)-(a):

By Lemma 2, when neither $i$ nor $j$ is informed,

$$x_i^\phi\left(f_i,f_j\right)=x_j^\phi\left(f_j,f_i\right)=\frac{a-E_f\theta}{2+\gamma}.$$

(iii)-(b):

This is the symmetric case as with (ii)-(a), so we just change $i,j$ in (22):

$$x_i^\phi\left(f_i,E_{f_j}x_j\right)=\frac{a}{2+\gamma}-\frac{2E_{f_i}\theta_i-\gamma E_{f_j}\theta_j}{4-\gamma^2}=\frac{a-E_f\theta}{2+\gamma}. \tag{27}$$

By Lemma 1 again,

$$\pi_i^\phi\left(f_i,f_j\right)=\left(x_i^\phi\left(f_i,f_j\right)\right)^2=\left(x_i^\phi\left(f_i,E_{f_j}x_j\right)\right)^2=\pi_i^\phi\left(f_i,E_{f_j}x_j\right).$$

■

**Proof of Proposition 1.** By Lemma 1, $\pi^c(\theta_i,f)=\left(x_i^c\left(\theta_i,f\right)\right)^2$, which has been depicted by (23) in the proof of Lemma 3:

$$x_i^c\left(\theta_i,f\right)=\frac{a+\frac{\gamma}{2}E_f\theta}{2+\gamma}-\frac{\theta_i}{2}. \tag{28}$$

So before observing $\theta_i$, the profit of $i$ is

$$\begin{aligned}
E_f\pi^c(\theta_i,f) &= E_f\left(\frac{a+\frac{\gamma}{2}E_f\theta}{2+\gamma}-\frac{\theta_i}{2}\right)^2\\
&= \frac{1}{4}E_f\theta^2+\frac{a^2-2aE_f\theta-\left(\gamma+\frac{\gamma^2}{4}\right)\left(E_f\theta\right)^2}{\left(2+\gamma\right)^2}\\
&= \left(\frac{a-E_f\theta}{2+\gamma}\right)^2+\frac{1}{4}\sigma_\theta^2\\
&= \pi(f,f)+\frac{1}{4}\sigma_\theta^2.
\end{aligned}$$

Substituting this back into (7), we get the ex ante profit of firm $i$ exerting $r_i$:

$$\pi(f,f) + r_i\left(\frac{1}{4}\sigma_\theta^2 - \eta\right). \tag{29}$$

Clearly $r_i = r_j = 1$ (Resp. 0) if $\eta <$ (Resp. $>$)$\frac{1}{4}\sigma_\theta^2$. And if $\eta = \frac{1}{4}\sigma_\theta^2$, $i$ is indifferent in $r_i$, then $\forall r_i \in [0,1]$ can be the equilibrium. ■

**Proof of Lemma 4.** When knowing $\theta_j$, the profit function of a $\theta_i$-type firm $i$ is:

$$\pi_i(x_i, x_j, \theta_i) = (a - x_i - \gamma x_j - \theta_i)x_i. \tag{30}$$

So the first order condition with respect to $x_i$ gives its reaction function: $x_i = \frac{a-\theta_i-\gamma x_j}{2}$. Similarly, $x_j = \frac{a-\theta_j-\gamma x_i}{2}$. The intersection of two reaction functions gives the equilibrium: $x_i = \frac{a}{2+\gamma} - \frac{2\theta_i-\gamma\theta_j}{4-\gamma^2}$. ■

**Proof of Proposition 2.** (i) By Lemma 1 and Lemma 4,

$$\begin{aligned}
E_{f,f}\pi^d(\theta_i,\theta_j) &= E_{f,f}\left(x_i^d(\theta_i,\theta_j)\right)^2 \\
&= E_{f,f}\left(\frac{a}{2+\gamma} - \frac{2\theta_i-\gamma\theta_j}{4-\gamma^2}\right)^2 \\
&= \frac{a^2(2-\gamma)^2 - 2a(2-\gamma)^2 E_f\theta + (4+\gamma^2)E_f\theta^2 - 4\gamma(E_f\theta)^2}{(4-\gamma^2)^2} \\
&= (\frac{a-E_f\theta}{2+\gamma})^2 + \frac{(4+\gamma^2)\sigma_\theta^2}{(4-\gamma^2)^2}.
\end{aligned}$$

(ii) When $i$ knows and discloses its type $\theta_i$ but $j$ is not informed about $\theta_j$, from (19) in the proof of Lemma 3,

$$x_i^d(\theta_i, f) = \frac{a}{2+\gamma} - \frac{2\theta_i - \gamma E_f\theta}{4-\gamma^2}. \tag{31}$$

By Lemma 1,

$$\begin{aligned}
E_f\pi^d(\theta_i,f) &= E_f\left(x_i^d(\theta_i,f)\right)^2 \\
&= E_f\left(\frac{a}{2+\gamma} - \frac{2\theta_i-\gamma E_f\theta}{4-\gamma^2}\right)^2 \\
&= \frac{a^2(2-\gamma)^2 - 2a(2-\gamma)^2 E_f\theta + 4E_f\theta^2 + (\gamma^2-4\gamma)(E_f\theta)^2}{(4-\gamma^2)^2} \\
&= (\frac{a-E_f\theta}{2+\gamma})^2 + \frac{4\sigma_\theta^2}{(4-\gamma^2)^2}.
\end{aligned}$$

(iii) It's symmetric with (ii) and also the case (i)-(a) in the proof of Lemma 3, i.e., now $i$ is not informed but $j$ knows and discloses $\theta_j$, so by exchanging $i$ and $j$ in the corresponding formulas of (i)-(a) in the proof of Lemma 3,

$$x_i = \frac{a - \gamma x_j - E_f\theta}{2};\ x_j = \frac{a - \gamma x_i - \theta_j}{2}. \tag{32}$$

The intersection of (32) determines

$$x_i\left(f, \theta_j\right) = \frac{a}{2+\gamma} - \frac{2E_f\theta - \gamma\theta_j}{4-\gamma^2}. \tag{33}$$

Then by Lemma 1,

$$\begin{aligned}
E_f\pi(f,\theta_j) &= E_f x_i^2\left(f,\theta_j\right) \\
&= E_f\left(\frac{a}{2+\gamma} - \frac{2E_f\theta - \gamma\theta_j}{4-\gamma^2}\right)^2 \\
&= \frac{a^2(2-\gamma)^2 - 2a(2-\gamma)^2 E_f\theta + \gamma^2 E_f\theta^2 + (4-4\gamma)(E_f\theta)^2}{(4-\gamma^2)^2} \\
&= (\frac{a - E_f\theta}{2+\gamma})^2 + \frac{\gamma^2\sigma_\theta^2}{(4-\gamma^2)^2}.
\end{aligned}$$

(iv) If we put (i)(ii)(iii) and (6) into (9), then $i$'s payoff (ex ante profit) of exerting $r_i$ based on the belief $r$ of $r_j$ becomes:

$$(\frac{a - E_f\theta}{2+\gamma})^2 + r\frac{\gamma^2\sigma_\theta^2}{(4-\gamma^2)^2} + r_i\left(\frac{4\sigma_\theta^2}{(4-\gamma^2)^2} - \eta\right). \tag{34}$$

Since $r_i$ and $r$ are separated, clearly the equilibrium is $r_i = r_j = 1$ (Resp. 0) if $\eta <$ (Resp. $>$)$\frac{4\sigma_\theta^2}{(4-\gamma^2)^2}$; and if $\eta = \frac{4\sigma_\theta^2}{(4-\gamma^2)^2}$, $\forall r_i \in [0,1]$ is indifferent and regardless of $r$, thus $\forall r_i, r_j \in [0,1]$ can be the equilibrium. ■

**Proof of Lemma 5.** Though there are altogether three information structures on the rival's (denoted by $j$) side, i.e., $j$ discloses, $j$ conceals, or $j$ is not informed, according to Lemma 3, $i$ is indifferent between that $j$ is informed but conceals and that $j$ is not informed. So it suffices to prove that the condition of willingness to disclose ($\theta_i <$ or $> E_{f_i}\theta_i$) is valid under two situations: $\theta_j$ is observable or not observable by $i$.

First, if $\theta_j$ is observable by $i$, then an informed $\theta_i$ has two choices: to disclose or to conceal. If $i$ chooses to disclose $\theta_i$, the equilibrium output can be characterized in Lemma 4, i.e.,

$$x_i^d(\theta_i, \theta_j) = \frac{a}{2+\gamma} - \frac{2\theta_i - \gamma\theta_j}{4-\gamma^2}. \tag{35}$$

If $i$ chooses to conceal $\theta_i$, the information structure is symmetric to the case (i)-(b) in the proof of Lemma 3. By exchanging the subscript $i$ and $j$ in (20), we have

$$x_j^d\left(\theta_j, f_i\right) = \frac{a}{2+\gamma} - \frac{2\theta_j - \gamma E_{f_i}\theta_i}{4-\gamma^2}, \tag{36}$$

where the second argument of $x_j^d$ represents that $j$ cannot observe $\theta_i$ and so $j$'s output can only base on its belief over $i$, $f_i$.

While we should also have the first order condition of $i$ as

$$x_i\left(\theta_i\right) = \frac{a - \gamma x_j - \theta_i}{2}. \tag{37}$$

Substituting (36) into (37), we get

$$x_i^c\left(\theta_i, \theta_j\right) = \frac{a}{2+\gamma} - \frac{2\theta_i - \gamma\theta_j}{4-\gamma^2} + \frac{\gamma^2\left(\theta_i - E_{f_i}\theta_i\right)}{2\left(4-\gamma^2\right)}. \tag{38}$$

By Lemma 1, we know

$$\pi_i^c\left(\theta_i, \theta_j\right) > \text{ (or } < \text{) } \pi_i^d\left(\theta_i, \theta_j\right) \Leftrightarrow x_i^c\left(\theta_i, \theta_j\right) > \text{ (or } < \text{) } x_i^d\left(\theta_i, \theta_j\right).$$

By comparing (35) and (38), clearly $i$ is willing to disclose $\theta_i$ voluntarily if and only if $\theta_i < E_{f_i}\theta_i$.

Second, if $\theta_j$ is not observable by $i$, then an informed $\theta_i$ has two choices too: to disclose or to conceal. If $i$ chooses to disclose, the equilibrium output and information structure for $i$ is exactly the same as the case (i)-(a) in the proof of Lemma 3, which gives us

$$x_i^d\left(\theta_i, f_j\right) = \frac{a}{2+\gamma} - \frac{2\theta_i - \gamma E_{f_j}\theta_j}{4-\gamma^2}. \tag{39}$$

If $i$ chooses to conceal, the case is exactly the same as (ii)-(a) in the proof of Lemma 3, so the first-order conditions for $i$ and $j$ are:

$$x_i = \frac{a - \gamma x_j - \theta_i}{2};\; x_j = \frac{a - \gamma E_{f_i} x_i\left(\theta_i\right) - E_{f_j}\theta_j}{2}. \tag{40}$$

Taking expectation on both sides of $x_i$, we have $E_{f_i} x_i\left(\theta_i\right) = \frac{a - \gamma x_j - E_{f_i}\theta_i}{2}$. Taking this into account, $x_j = \frac{a}{2+\gamma} - \frac{2E_{f_j}\theta_j - \gamma E_{f_i}\theta_i}{4-\gamma^2}$. Substituting this into the best response of $i$ in (40), we get

$$x_i^c\left(\theta_i, f_j\right) = \frac{a}{2+\gamma} - \frac{2\theta_i - \gamma E_{f_j}\theta_j}{4-\gamma^2} + \frac{\gamma^2\left(\theta_i - E_{f_i}\theta_i\right)}{2\left(4-\gamma^2\right)}. \tag{41}$$

So comparing (39) and (41), by Lemma 1, we obtain that $i$ is willing to disclose $\theta_i$ if and only if $\theta_i < E_{f_i}\theta_i$ under an unobservable $\theta_j$ too. ■

**Proof of Proposition 3.** First, if $r = 1$, then by the "unraveling effect", the unique continuation equilibrium is "full disclosure", and the belief supporting "full disclosure" is that any unobservable/concealed rival's cost is regarded as the type $\overline{\theta}$.

Second, if $0 < r < 1$, there will be the uncertainty on the knowledge of own type in the continuation game, which makes the "unraveling effect" invalid, i.e., the informed less favorable types can hide among the "uninformed population", which constitutes a new "no disclosure distribution" $\widetilde{f}$ over $\left[0, \overline{\theta}\right]$: the informed but concealed ($\theta_i$ larger than a threshold $\widetilde{\theta}$) with probability $r$, plus the uninformed with probability $1 - r$, as illustrated by Figure 2.

From Lemma 5, we know that the watershed of voluntary disclosure/concealment is $E_{\widetilde{f}}\theta$. So the validity of an equilibrium disclosure/concealment threshold $\widetilde{\theta}$ has to satisfy:

$$\widetilde{\theta} = E_{\widetilde{f}}\theta, \tag{42}$$

where $\widetilde{f}$ is the distribution generated by the disclosure/concealment threshold $\widetilde{\theta}$ and satisfies:

$$\widetilde{f}(\theta) = \begin{cases} \frac{f(\theta)}{1-rF\left(\widetilde{\theta}\right)} > f(\theta), \forall\theta > \widetilde{\theta} \\ \frac{(1-r)f(\theta)}{1-rF\left(\widetilde{\theta}\right)} < f(\theta), \forall\theta < \widetilde{\theta} \end{cases} \tag{43}$$

which means that the types $\theta > \widetilde{\theta}$ can be either "informed but concealed" or "uninformed", and the types $\theta < \widetilde{\theta}$ must be "uninformed", conditional on the "no disclosure" of $\theta$, i.e.: the total probability of "no disclosure" is $1-rF\left(\widetilde{\theta}\right)$, where $F(\cdot)$ is the c.d.f. of $f$; the probability of facing a $\theta < \widetilde{\theta}$ conditional on "no disclosure" is $\frac{(1-r)F\left(\widetilde{\theta}\right)}{1-rF\left(\widetilde{\theta}\right)}$, which is less than $F\left(\widetilde{\theta}\right)$ if $0 < r < 1$; and the probability of facing a $\theta > \widetilde{\theta}$ conditional on "no disclosure" is $\frac{1-F\left(\widetilde{\theta}\right)}{1-rF\left(\widetilde{\theta}\right)}$, which is larger than $1 - F\left(\widetilde{\theta}\right)$ if $0 < r < 1$. So

$$\widetilde{F}(\theta) = \begin{cases} \frac{F(\theta)-rF\left(\widetilde{\theta}\right)}{1-rF\left(\widetilde{\theta}\right)}, \forall\theta > \widetilde{\theta} \\ \frac{(1-r)F(\theta)}{1-rF\left(\widetilde{\theta}\right)}, \forall\theta \leq \widetilde{\theta} \end{cases}$$

where $\widetilde{F}(\cdot)$ is the c.d.f. of $\widetilde{f}$. The constitution of $\widetilde{f}$ is in fact introducing a discontinuous point (at $\widetilde{\theta}$) in $f$, i.e., a kink in $F$.

Substituting (43) into (42), we obtain that the equilibrium disclosure/concealment threshold $\widetilde{\theta}$ has to satisfy the following equation:

$$\widetilde{\theta}=\int_0^{\widetilde{\theta}}\frac{(1-r)\,\theta f(\theta)}{1-rF\left(\widetilde{\theta}\right)}d\theta+\int_{\widetilde{\theta}}^{\overline{\theta}}\frac{\theta f(\theta)}{1-rF\left(\widetilde{\theta}\right)}d\theta\equiv g\left(\widetilde{\theta}\right) \tag{44}$$

First we prove the existence of solutions of equation (44). When $\widetilde{\theta}\leq E_f\theta$, then $g\left(\widetilde{\theta}\right)>\widetilde{\theta}$; also we have $g\left(\overline{\theta}\right)=E_f\theta<\overline{\theta}$; obviously that $g(\cdot)$ is continuous. Thus by the intermediate value theorem, there exists a $\widetilde{\theta}\in\left(E_f\theta,\overline{\theta}\right)$ such that (44) is satisfied, i.e., "partial sharing" can be supported under $0<r<1$.

Next we prove the uniqueness of $\widetilde{\theta}$ given an $r\in(0,1)$. From (44),

$$g'\left(\widetilde{\theta}\right)=\frac{rf\left(\widetilde{\theta}\right)}{\left(1-rF\left(\widetilde{\theta}\right)\right)^2}\left(r\int_{\widetilde{\theta}}^{\overline{\theta}}\left(\theta-\widetilde{\theta}\right)f(\theta)\,d\theta+(1-r)\int_0^{\overline{\theta}}\left(\theta-\widetilde{\theta}\right)f(\theta)\,d\theta\right) \tag{45}$$

We define $k\left(\widetilde{\theta}\right)\equiv r\int_{\widetilde{\theta}}^{\overline{\theta}}\left(\theta-\widetilde{\theta}\right)f(\theta)\,d\theta+(1-r)\int_0^{\overline{\theta}}\left(\theta-\widetilde{\theta}\right)f(\theta)\,d\theta$. Then

$$k'\left(\widetilde{\theta}\right)=-r\left(1-F\left(\widetilde{\theta}\right)\right)-(1-r)<0 \tag{46}$$

While $\frac{rf(\widetilde{\theta})}{\left(1-rF(\widetilde{\theta})\right)^2}>0$ for all $r\in(0,1)$ and $\forall\widetilde{\theta}\in\left[E_f\theta,\overline{\theta}\right]$. $k(E_f\theta)=r\int_{E_f\theta}^{\overline{\theta}}(\theta-E_f\theta)\,f(\theta)\,d\theta>0$, $k\left(\overline{\theta}\right)=(1-r)\left(E_f\theta-\overline{\theta}\right)<0$. So there exists a unique $\theta_{\max}\in\left(E_f\theta,\overline{\theta}\right)$ such that $k(\theta_{\max})=0$, i.e., $g'(\theta_{\max})=0$, and $\forall\widetilde{\theta}<$ (Resp. $>$) $\theta_{\max}$, $k\left(\widetilde{\theta}\right)>$ (Resp. $<$) 0, i.e., $g'\left(\widetilde{\theta}\right)>$ (Resp. $<$) 0. Therefore, $\theta_{\max}$ is a unique maximum of $g\left(\widetilde{\theta}\right)$ in $\left(E_f\theta,\overline{\theta}\right)$ with

$$r\int_{\theta_{\max}}^{\overline{\theta}}(\theta-\theta_{\max})\,f(\theta)\,d\theta=(1-r)\int_0^{\overline{\theta}}(\theta_{\max}-\theta)\,f(\theta)\,d\theta,$$

which is equivalent to

$$r\left(1-F(\theta_{\max})\right)\left(E_{f(\theta|\theta>\theta_{\max})}\theta-\theta_{\max}\right)=(1-r)\left(\theta_{\max}-E_f\theta\right).$$

On the other hand, by the construction of $\widetilde{f}$ in (43), we can rewrite

$$E_{\widetilde{f}}\theta=g\left(\widetilde{\theta}\right)=\frac{1-r}{1-rF\left(\widetilde{\theta}\right)}E_f\theta+\frac{r\left(1-F\left(\widetilde{\theta}\right)\right)}{1-rF\left(\widetilde{\theta}\right)}E_{f\left(\theta|\theta>\widetilde{\theta}\right)}\theta. \tag{47}$$

So when $\widetilde{\theta} < \theta_{\max}$,

$$\begin{aligned} g\left(\widetilde{\theta}\right) - \widetilde{\theta} &= \frac{r\left(1 - F\left(\widetilde{\theta}\right)\right)\left(E_{f\left(\theta|\theta>\widetilde{\theta}\right)}\theta - \widetilde{\theta}\right) + (1-r)\left(E_f\theta - \widetilde{\theta}\right)}{1 - rF\left(\widetilde{\theta}\right)} \\ &= \frac{k\left(\widetilde{\theta}\right)}{1 - rF\left(\widetilde{\theta}\right)} \\ &> 0 \end{aligned}$$

This means that we shrink the interval appearing the fixed point(s) in (44) from $\left(E_f\theta, \overline{\theta}\right)$ to $\left(\theta_{\max}, \overline{\theta}\right)$. And $g(\cdot)$ is decreasing in the interval $\left(\theta_{\max}, \overline{\theta}\right)$. So the solution of $\widetilde{\theta}$ satisfying (44) is unique.

The uniqueness of $\widetilde{\theta}$ given an $r \in (0,1)$ constitutes the function $\widetilde{\theta}(r)$. Now we prove $\widetilde{\theta}'(r) > 0$. By (44) and the implicit function theorem, at $\widetilde{\theta}(r)$,

$$\widetilde{\theta}'(r) = \frac{\frac{\partial g\left(\widetilde{\theta}\right)}{\partial r}}{1 - g'\left(\widetilde{\theta}\right)}. \tag{48}$$

Since $\widetilde{\theta}(r) \in \left(\theta_{\max}, \overline{\theta}\right)$, $g'\left(\widetilde{\theta}\right)$ at $\widetilde{\theta}(r)$ is negative. While we can rewrite $g\left(\widetilde{\theta}\right)$ as

$$g\left(\widetilde{\theta}\right) = E_{f\left(\theta|\theta>\widetilde{\theta}\right)}\theta \cdot \frac{1 - F\left(\widetilde{\theta}\right)}{1 - rF\left(\widetilde{\theta}\right)} + E_{f\left(\theta|\theta<\widetilde{\theta}\right)}\theta \cdot \frac{(1-r)F\left(\widetilde{\theta}\right)}{1 - rF\left(\widetilde{\theta}\right)}, \tag{49}$$

where $E_{f\left(\theta|\theta>\widetilde{\theta}\right)}\theta$ and $E_{f\left(\theta|\theta<\widetilde{\theta}\right)}\theta$ are not the direct functions of $r$, so by (49),

$$\frac{\partial g\left(\widetilde{\theta}\right)}{\partial r} = \left(E_{f\left(\theta|\theta>\widetilde{\theta}\right)}\theta - E_{f\left(\theta|\theta<\widetilde{\theta}\right)}\theta\right) \cdot \frac{\left(1 - F\left(\widetilde{\theta}\right)\right)F\left(\widetilde{\theta}\right)}{\left(1 - rF\left(\widetilde{\theta}\right)\right)^2} > 0. \tag{50}$$

Hence, $\widetilde{\theta}'(r) > 0$.

By (44), $\lim_{r\to 0}\widetilde{\theta} = E_f\theta$, but $\widetilde{\theta}(r)$ has no definition at $r = 0$. When $r \to 1$, the right hand side of the equation (44) tends to $E_{f\left(\theta|\theta>\widetilde{\theta}\right)}\theta$, where the only solution of (44) is $\widetilde{\theta} = \overline{\theta}$, thus $\widetilde{\theta}(1) = \overline{\theta}$, which is also an illustration of "unraveling effect". ■

**The calculation of $\pi_i^{(1)}$ to $\pi_i^{(6)}$ in Table 2.** (1) By Lemma 1 and Lemma 4,

$$\pi_i^{(1)} = E_{f\left(\theta_i|\theta_i<\widetilde{\theta}\right),f\left(\theta_j|\theta_j<\widetilde{\theta}\right)} \left(x_i^d(\theta_i,\theta_j)\right)^2 = E_{f\left(\theta_i|\theta_i<\widetilde{\theta}\right),f\left(\theta_j|\theta_j<\widetilde{\theta}\right)} \left(\frac{a}{2+\gamma} - \frac{2\theta_i - \gamma\theta_j}{4-\gamma^2}\right)^2. \tag{51}$$

(2) By Lemma 3, this information structure is equivalent to the case (i)-(a) of Lemma 3 and the posterior of $i$ on $j$ is $\widetilde{f}$ now. So,

$$\pi_i^{(2)} = E_{f\left(\theta_i|\theta_i<\widetilde{\theta}\right)} \left(x_i^d(\theta_i,\widetilde{f})\right)^2 = E_{f\left(\theta_i|\theta_i<\widetilde{\theta}\right)} \left(\frac{a}{2+\gamma} - \frac{2\theta_i - \gamma\widetilde{\theta}}{4-\gamma^2}\right)^2. \tag{52}$$

(3) First, we know that the support of types for this case is $\theta_i > \widetilde{\theta}$ and $\theta_j < \widetilde{\theta}$. The equilibrium output of $i$ concealing a $\theta_i$ and observing a $\theta_j$ has been depicted by (38) in the proof of Lemma 5, with substituting $f_i$ by $\widetilde{f}$ since the posterior belief of $j$ on $i$ is $\widetilde{f}$ now. So,

$$\begin{aligned}\pi_i^{(3)} &= E_{f\left(\theta_i|\theta_i>\widetilde{\theta}\right),f\left(\theta_j|\theta_j<\widetilde{\theta}\right)} \left(x_i^c(\theta_i,\theta_j)\right)^2 \qquad (53)\\ &= E_{f\left(\theta_i|\theta_i>\widetilde{\theta}\right),f\left(\theta_j|\theta_j<\widetilde{\theta}\right)} \left(\frac{a}{2+\gamma} - \frac{2\theta_i - \gamma\theta_j}{4-\gamma^2} + \frac{\gamma^2\left(\theta_i - \widetilde{\theta}\right)}{2\left(4-\gamma^2\right)}\right)^2.\end{aligned}$$

(4) This information structure is similar to (41) in the proof of Lemma 5 except that we can impose $E_{f_i}\theta_i = E_{f_j}\theta_j = \widetilde{\theta}$ since $i$ and $j$ cannot observe each other and put a common posterior $\widetilde{f}$. So, after simplifying (41),

$$\pi_i^{(4)} = E_{f\left(\theta_i|\theta_i>\widetilde{\theta}\right)} \left(x_i^c(\theta_i,\widetilde{f})\right)^2 = E_{f\left(\theta_i|\theta_i>\widetilde{\theta}\right)} \left(\frac{a + \frac{\gamma}{2}\widetilde{\theta}}{2+\gamma} - \frac{\theta_i}{2}\right)^2. \tag{54}$$

(5) In this case, $j$'s information structure and equilibrium output has been depicted by (36) in the proof of Lemma 5 except that we can impose $E_{f_i}\theta_i = \widetilde{\theta}$ since $j$'s posterior belief on $i$ is $\widetilde{f}$ now, i.e.,

$$x_j^d\left(\theta_j,\widetilde{f}\right) = \frac{a}{2+\gamma} - \frac{2\theta_j - \gamma\widetilde{\theta}}{4-\gamma^2}. \tag{55}$$

While the first order condition of an uninformed $i$ is $x_i = \frac{a - E_f\theta - \gamma x_j}{2}$; substituting $x_j$ by (55), we get

$$x_i\left(f,\theta_j\right) = \frac{a}{2+\gamma} - \frac{2E_f\theta - \gamma\theta_j}{4-\gamma^2} - \frac{\gamma^2\left(\widetilde{\theta} - E_f\theta\right)}{2\left(4-\gamma^2\right)}. \tag{56}$$

So

$$\pi_i^{(5)} = E_{f(\theta_j|\theta_j<\widetilde{\theta})}\left(x_i\left(f,\theta_j\right)\right)^2 = E_{f(\theta_j|\theta_j<\widetilde{\theta})}\left(\frac{a}{2+\gamma} - \frac{2E_f\theta - \gamma\theta_j}{4-\gamma^2} - \frac{\gamma^2\left(\widetilde{\theta} - E_f\theta\right)}{2\left(4-\gamma^2\right)}\right)^2. \tag{57}$$

(6) $i$ is not informed and cannot observe $j$. By Lemma 3, $i$ can regard $j$ as an uninformed firm; but the difference is: $i$ knows that its own type is based on the prior $f$ while $j$ is based on the posterior $\widetilde{f}$. So from the proof of Lemma 2,

$$x_i = \frac{a - E_f\theta - \gamma x_j}{2}, x_j = \frac{a - \widetilde{\theta} - \gamma x_i}{2}. \tag{58}$$

The intersection of (58) determines

$$x_i\left(f,\widetilde{f}\right) = \frac{a}{2+\gamma} - \frac{2E_f\theta - \gamma\widetilde{\theta}}{4-\gamma^2}. \tag{59}$$

So

$$\pi_i^{(6)} = \left(x_i\left(f,\widetilde{f}\right)\right)^2 = \left(\frac{a}{2+\gamma} - \frac{2E_f\theta - \gamma\widetilde{\theta}}{4-\gamma^2}\right)^2. \tag{60}$$

■

**Proof of Proposition 4.** First, we complement the definition of $\widetilde{\theta}(0)$. When $r = 0$, since no information acquisition, the posterior over the rival is still $f$, i.e., $\widetilde{\theta}(0) = E_f\theta$. In the proof of Proposition 3, we have proved $\lim_{r\to 0}\widetilde{\theta} = E_f\theta$. So the definition of $\widetilde{\theta}(0) \equiv E_f\theta$ is reasonable.

Second, if $i$ expects the rival's strategy is $r$, then the expected payoff of playing $r_i$ is given by (10). We intend to characterize the first order condition of (10) with respect to $r_i$. If $j$ follows the equilibrium strategy and equilibrium belief, then in the second stage, the posterior of $j$ on $i$ is $f_i = \widetilde{f}$, which is generated by $\widetilde{\theta}(r)$. Lemma 5 ensures that any type of $i$ in the second stage is not willing to change the disclosure/concealment rule according to $j$'s belief, i.e., if $\theta_i >$ (Resp. $<$) $\widetilde{\theta}(r)$, then $i$ conceals (Resp. discloses). Hence, even if $i$ deviates from $r$ to $r_i$ in the first stage, it is not willing to deviate from $\widetilde{\theta}(r)$ in the second stage, i.e., $\widetilde{\theta}$ is not a function of $r_i$. So $\pi_i^{(1)}$ to $\pi_i^{(6)}$ are not affected by the deviation from $r$ to $r_i$, which simplifies the first order condition of (10) with respect to $r_i$:

$$\begin{aligned} & F\left(\widetilde{\theta}\right)\left[rF\left(\widetilde{\theta}\right)\pi_i^{(1)}+\left(1-rF\left(\widetilde{\theta}\right)\right)\pi_i^{(2)}\right] \\ & +\left(1-F\left(\widetilde{\theta}\right)\right)\left[rF\left(\widetilde{\theta}\right)\pi_i^{(3)}+\left(1-rF\left(\widetilde{\theta}\right)\right)\pi_i^{(4)}\right] \\ & -rF\left(\widetilde{\theta}\right)\pi_i^{(5)}-\left(1-rF\left(\widetilde{\theta}\right)\right)\pi_i^{(6)}-\eta \\ \equiv\; & \eta\left(r\right) \end{aligned} \tag{61}$$

If $\eta(1) > 0$, then $r = 1$ is an equilibrium; if $\eta(0) < 0$, then $r = 0$ is an equilibrium; if an $r \in (0,1)$ is such that $\eta(r) = 0$, then according to our restriction of symmetric equilibria, this $r \in (0,1)$ is an equilibrium.

(i) If $r = 1$, then $\widetilde{\theta}(1) = \overline{\theta}$, thus (61) degenerates to

$$\eta\left(1\right)=\pi_i^{(1)}\left(\widetilde{\theta}=\overline{\theta}\right)-\pi_i^{(5)}\left(\widetilde{\theta}=\overline{\theta}\right)-\eta. \tag{62}$$

By Proposition 2,

$$\pi_i^{(1)}\left(\widetilde{\theta}=\overline{\theta}\right)=(\frac{a-E_f\theta}{2+\gamma})^2+\frac{\left(4+\gamma^2\right)\sigma_\theta^2}{\left(4-\gamma^2\right)^2}. \tag{63}$$

Substituting (57) into $\pi_i^{(5)}\left(\widetilde{\theta}=\overline{\theta}\right)$:

$$\pi_i^{(5)}\left(\widetilde{\theta}=\overline{\theta}\right)=E_f\left(\frac{a}{2+\gamma}-\frac{2E_f\theta-\gamma\theta_j}{4-\gamma^2}-\frac{\gamma^2\left(\overline{\theta}-E_f\theta\right)}{2\left(4-\gamma^2\right)}\right)^2. \tag{64}$$

By the proof of Proposition 2, the RHS of (64) becomes:

$$\begin{aligned} & E_f\pi(f,\theta_j)-\frac{\gamma^2\left(\overline{\theta}-E_f\theta\right)}{\left(4-\gamma^2\right)}\cdot\frac{a-E_f\theta}{2+\gamma}+\left(\frac{\gamma^2\left(\overline{\theta}-E_f\theta\right)}{2\left(4-\gamma^2\right)}\right)^2 \\ =\; & (\frac{a-E_f\theta}{2+\gamma})^2+\frac{\gamma^2\sigma_\theta^2}{\left(4-\gamma^2\right)^2}-\eta_1 \end{aligned} \tag{65}$$

where

$$\begin{aligned} \eta_1 \;\equiv\; & \frac{\gamma^2\left(\overline{\theta}-E_f\theta\right)}{4-\gamma^2}\left(\frac{a-E_f\theta}{2+\gamma}-\frac{\gamma^2\left(\overline{\theta}-E_f\theta\right)}{4\left(4-\gamma^2\right)}\right) \\ > \; & \frac{\gamma^2\left(\overline{\theta}-E_f\theta\right)}{4\left(4-\gamma^2\right)^2}\left(a-E_f\theta-\gamma^2\left(\overline{\theta}-E_f\theta\right)\right) \\ > \; & 0 \end{aligned} \tag{66}$$

Substituting (64)(65)(63) into (62), we can get the condition supporting an $r=1$ equilibrium:

$$\eta < \frac{4\sigma_\theta^2}{\left(4-\gamma^2\right)^2} + \eta_1. \tag{67}$$

(ii) If $r=1$, then $\widetilde{\theta}\,(0) = E_f\theta$, thus (61) degenerates to

$$\eta\,(0) = F\,(E_f\theta)\,\pi_i^{(2)} + (1 - F\,(E_f\theta))\,\pi_i^{(4)} - \pi_i^{(6)} - \eta.$$

If imposing $\widetilde{\theta} = E_f\theta$ and $\widetilde{f} = f$ into $\pi_i^{(2)}$, $\pi_i^{(4)}$ and $\pi_i^{(6)}$, we can get the condition supporting an $r=0$ equilibrium:

$$\begin{aligned}
& \eta \qquad\qquad (68)\\
> \; & F\,(E_f\theta)\,E_{f\left(\theta_i \middle| \theta_i < E_f\theta\right)}\pi^d(\theta_i, f) + (1 - F\,(E_f\theta))\,E_{f\left(\theta_i \middle| \theta_i > E_f\theta\right)}\pi^c(\theta_i, f) - \pi(f, f)\\
= \; & E_f\pi^d(\theta_i, f) - \pi(f, f) + (1 - F\,(E_f\theta))\,E_{f\left(\theta_i \middle| \theta_i > E_f\theta\right)}\left(\pi^c(\theta_i, f) - \pi^d(\theta_i, f)\right)\\
= \; & \frac{4\sigma_\theta^2}{\left(4-\gamma^2\right)^2} + \eta_0
\end{aligned}$$

where the difference between $E_f\pi^d(\theta_i, f)$ and $\pi(f, f)$ comes from Proposition 2, and

$$\eta_0 \equiv (1 - F\,(E_f\theta))\,E_{f\left(\theta_i \middle| \theta_i > E_f\theta\right)}\left(\pi^c(\theta_i, f) - \pi^d(\theta_i, f)\right).$$

By Lemma 5, $\eta_0 > 0$.

(iii) If $\eta_1 < \eta_0$, we know that there exists neither $r=1$ equilibrium nor $r=0$ equilibrium when $\frac{4\sigma_\theta^2}{(4-\gamma^2)^2} + \eta_1 < \eta < \frac{4\sigma_\theta^2}{(4-\gamma^2)^2} + \eta_0$. But $\eta\,(r)$ defined in (61) is continuous in $r$, so $\exists r \in (0,1)$ such that $\eta\,(r) = 0$; therefore, this $r \in (0,1)$ is a symmetric equilibrium.

If $\eta_1 > \eta_0$ and $\frac{4\sigma_\theta^2}{(4-\gamma^2)^2} + \eta_0 < \eta < \frac{4\sigma_\theta^2}{(4-\gamma^2)^2} + \eta_1$, then both (67) and (68) are satisfied, thus both $r=1$ and $r=0$ are equilibria. By the intermediate value theorem, there exists at least one $r \in (0,1)$ such that $\eta\,(r) = 0$; therefore, this $r \in (0,1)$ is a symmetric equilibrium too. ■

**Proof of Proposition 5.** By the definition of consumer surplus in (12),

$$CS_{r=0} = (1+\gamma)\,\pi(f, f) = (1+\gamma)\,(\frac{a - E_f\theta}{2+\gamma})^2,$$

where the first equality is from the symmetry between the firms and Lemma 1.

(i) full concealment

$ECS_{r=1} = E_{f,f}CS(x_i, x_j) = E_f\pi^c(\theta_i, f) + \gamma E_{f,f}\left(x_i^c(\theta_i, f) \cdot x_j^c(\theta_j, f)\right)$. From the proof of Proposition 1, $x_i^c(\theta_i, f) = \frac{a+\frac{\gamma}{2}E_f\theta}{2+\gamma} - \frac{\theta_i}{2}$, $i = 1, 2$, which means that $x_i^c(\theta_i, f)$ is independent with $x_j^c(\theta_j, f)$ in the continuation of $r = 1$, so

$$E_{f,f}\left(x_i^c(\theta_i, f) \cdot x_j^c(\theta_j, f)\right) = (E_f x_i^c(\theta_i, f))^2 = (\frac{a - E_f\theta}{2+\gamma})^2. \tag{69}$$

Still by Proposition 1, $E_f\pi^c(\theta_i, f) = (\frac{a-E_f\theta}{2+\gamma})^2 + \frac{1}{4}\sigma_\theta^2$. Thus

$$ECS_{r=1} = (1+\gamma)\,(\frac{a - E_f\theta}{2+\gamma})^2 + \frac{1}{4}\sigma_\theta^2. \tag{70}$$

By (70) and (14), $EW_{r=1} = (3+\gamma)\,(\frac{a-E_f\theta}{2+\gamma})^2 + \frac{3}{4}\sigma_\theta^2 - 2\eta$.
(ii) full disclosure
Lemma 4 gives the expression of $x_i^d(\theta_i, \theta_j)$ and $x_j^d(\theta_j, \theta_i)$ after $r = 1$. So

$$\begin{aligned}
& E_{f,f}\left(x_i^d(\theta_i, \theta_j) \cdot x_j^d(\theta_j, \theta_i)\right) \\
= \;& E_{f,f}\left(\frac{a}{2+\gamma} - \frac{2\theta_i - \gamma\theta_j}{4-\gamma^2}\right)\left(\frac{a}{2+\gamma} - \frac{2\theta_j - \gamma\theta_i}{4-\gamma^2}\right) \\
= \;& E_{f,f}\left((\frac{a}{2+\gamma})^2 - \frac{a\,(\theta_i + \theta_j)}{(2+\gamma)^2} + \frac{(4+\gamma^2)\,\theta_i\theta_j - 2\gamma\left(\theta_i^2 + \theta_j^2\right)}{(4-\gamma^2)^2}\right) \\
= \;& (\frac{a}{2+\gamma})^2 - \frac{2aE_f\theta}{(2+\gamma)^2} + \frac{(4+\gamma^2)\,(E_f\theta)^2 - 4\gamma E_f\theta^2}{(4-\gamma^2)^2} \\
= \;& E_{f,f}\pi^d(\theta_i, \theta_j) - \frac{(4+\gamma^2)\,E_f\theta^2 - 4\gamma\,(E_f\theta)^2}{(4-\gamma^2)^2} + \frac{(4+\gamma^2)\,(E_f\theta)^2 - 4\gamma E_f\theta^2}{(4-\gamma^2)^2} \\
= \;& E_{f,f}\pi^d(\theta_i, \theta_j) - \frac{\sigma_\theta^2}{(2-\gamma)^2}.
\end{aligned}$$

Thus

$$\begin{aligned}
ECS_{r=1} &= (1+\gamma)\,E_{f,f}\pi^d(\theta_i, \theta_j) - \frac{\gamma\sigma_\theta^2}{(2-\gamma)^2} \\
&= (1+\gamma)\left((\frac{a - E_f}{2+\gamma})^2 + \frac{(4+\gamma^2)\,\sigma_\theta^2}{(4-\gamma^2)^2}\right) - \frac{\gamma\sigma_\theta^2}{(2-\gamma)^2} \\
&= CS_{r=0} + \frac{4 - 3\gamma^2}{(4-\gamma^2)^2}\sigma_\theta^2.
\end{aligned}$$

$\frac{d}{d\gamma}\left(\frac{4-3\gamma^2}{(4-\gamma^2)^2}\right) = \frac{-2\gamma\left(3\left(\gamma-\frac{4}{3}\right)^2 + \frac{20}{3}\right)}{(4-\gamma^2)^3} < 0.$

By (14),

$$\begin{aligned} EW_{r=1} &= ECS_{r=1} + 2E_{f,f}\pi^d(\theta_i,\theta_j) - 2\eta \\ &= CS_{r=0} + \frac{4-3\gamma^2}{(4-\gamma^2)^2}\sigma_\theta^2 + 2\left(\pi(f,f) + \frac{(4+\gamma^2)\,\sigma_\theta^2}{(4-\gamma^2)^2}\right) - 2\eta \\ &= EW_{r=0} + \frac{12-\gamma^2}{(4-\gamma^2)^2}\sigma_\theta^2 - 2\eta. \end{aligned}$$

$\frac{d}{d\gamma}\left(\frac{12-\gamma^2}{(4-\gamma^2)^2}\right) = \frac{2\gamma\left(20-\gamma^2\right)}{(4-\gamma^2)^3} \geq 0$, where the equality holds only when $\gamma = 0$.
■

**Proof of Corollary 3.** From Corollary 2, this is the comparison between $\frac{12-\gamma^2}{2(4-\gamma^2)^2}\sigma_\theta^2$ and $\frac{4\sigma_\theta^2}{(4-\gamma^2)^2} + \frac{\gamma^2\left(\overline{\theta}-E_f\theta\right)}{4-\gamma^2}\left(\frac{a-E_f\theta}{2+\gamma} - \frac{\gamma^2\left(\overline{\theta}-E_f\theta\right)}{4(4-\gamma^2)}\right)$. If $\gamma = 0$, $\frac{12-\gamma^2}{2(4-\gamma^2)^2}\sigma_\theta^2$ is definitely larger than the latter. If $\gamma > 0$, the comparison is equivalent to

$$\begin{aligned} & a - E_f\theta \\ & \text{v.s.} \\ & \frac{\gamma^2\left(\overline{\theta}-E_f\theta\right)}{4(2-\gamma)} + \frac{\sigma_\theta^2(2+\gamma)}{2\gamma^2\left(\overline{\theta}-E_f\theta\right)}. \end{aligned} \tag{71}$$

■

**Bertrand Competition**

Now we analyze the effects of changing from Cournot competition to Bertrand competition. With Bertrand competition the product market s-trategies are strategic complements. At the Bertrand equilibria the strate-gy of each firm consists of the information gathering effort $r_i$ and price $p_i$ ($i = 1, 2$). If firms choose prices $p_1$, $p_2$, the output levels are determined from equation (1) as follows:

$$x_i = \frac{a}{1+\gamma} + \frac{\gamma p_j - p_i}{1-\gamma^2}, \qquad i \neq j; \quad i,j = 1,2 \tag{72}$$

Hence, the payoff of firm $i$ is:

$$\pi_i = (p_i - \vartheta_i)\left(\frac{a}{1+\gamma} + \frac{\gamma E_{f_j}p_j - p_i}{1-\gamma^2}\right) \tag{73}$$

The notation here can be explained as before.

The first order condition for the payoff function is

$$p_i = \frac{1}{2}a(1-\gamma) + \frac{\vartheta_i}{2} + \frac{1}{2}\gamma E_{f_j}p_j \tag{74}$$

We now consider the value of cost information under three different dis-closure regimes: full concealment, full disclosure and strategic disclosure.

**Lemma 6** *The value of cost information under full concealment (from an ex ante perspective):*

$$E\pi_i(\theta_i) - \pi_i(E\theta_i) = \frac{\sigma_\theta^2}{4(1-\gamma^2)}$$

**Proof.** Plug (62) into (61), we can easily get the result ■

**Lemma 7** *If both firms know his own and his competitor's cost parameter, each price is*

$$p_i = \frac{2a(1-\gamma)(1+\frac{1}{2}\gamma)}{4-\gamma^2} + \frac{2\theta_i}{4-\gamma^2} + \frac{\gamma\theta_j}{4-\gamma^2},\ i = 1, 2 \tag{75}$$

**Proposition 6** *The value of his own cost information under full disclosure is*

$$E\pi_i(\theta_i) - \pi_i(E\theta_i) = \frac{(2-\gamma^2)^2\sigma_\theta^2}{(1-\gamma^2)(4-\gamma^2)^2}$$

**Proof.** Plug (63) into (61), we can get the result. ■

Here, we can compare the incentive to gather information in the full concealment and full disclosure regime: $\frac{(2-\gamma^2)^2\sigma_\theta^2}{(1-\gamma^2)(4-\gamma^2)^2} < \frac{\sigma_\theta^2}{4(1-\gamma^2)}$ which means the information is more valuable in full concealment regime than that under full disclosure. This result is contrary to the quantity competition scenario. Here, the profit function of firm $i$ is a convex function of his own cost parameter $\theta_i$ and is also a convex function of his competitor's cost $\theta_j$. Therefore, knowing both cost information is valuable in general, however, firms prefer not share his cost information to his competitor (in fact, sharing $\theta_i$ to $j$ will make $i$'s profit function less convex in $\theta_i$) even if he want to know his competitor's cost. This result is also contrary to the quantity competition scenario where each firm want to know his competitor's cost information and also want to share his information with his competitor.

In short, firms have less incentive to acquire cost information with full disclosure regime than with full concealment regime. When $\eta$ is small enough, firms will acquire information under both regimes. we now compare which regime is more profitable. Under FC, we already see that $E\pi_i(\theta_i, E\theta_j) - \pi_i(E\theta_i, E\theta_j) = \frac{\sigma_\theta^2}{4(1-\gamma^2)}$. Under FD, $E\pi_i(\theta_i, \theta_j) - \pi_i(E\theta_i, E\theta_i) = \frac{(2-\gamma^2)^2\sigma_\theta^2}{(1-\gamma^2)(4-\gamma^2)^2} + \frac{\gamma^2\sigma_\theta^2}{(1-\gamma^2)(4-\gamma^2)^2}$, the second term is the value of knowing his competitor's cost information. Comparing the two terms, we can easily see that under full concealment regime firms can get more profit.

Now we turn to the strategic disclosure regime.

First consider symmetric equilibrium in which both firms acquire information with $(r, r)$. After knowing his own cost information, each firm has an incentive to hide low cost information and reveal high one. This is the case because here firms' strategy are complementary. Hiding low cost information effectively will make his competitor's price higher which is beneficial. If $r = 1$, unraveling effect makes hiding cost information impossible and all information is revealed at equilibrium. When $0 < r < 1$, we have the following result which is similar to the case of quantity competition:

**Proposition 7** *For $0 < r < 1$, there exists a unique $\widetilde{\theta}(r) \in (\underline{\theta}, Ef)$ such that an informed $\theta$ is disclosed if $\theta \geq \widetilde{\theta}(r)$ and $\widetilde{\theta}'(r) < 0$. $\widetilde{\theta}(0) = Ef$; $\widetilde{\theta}(1) = \underline{\theta}$.*

**Proof.** The proof is similar as Proposition 3 and is omitted henceforth. ■

Here, we also have that under strategic disclosure, firms have more incentive to acquire information than under full concealment regime. This is again because of strategic value of acquiring information when $r_1 = r_2 = 0$. And the equilibrium $r_1 = r_2 = 1$ is also sustainable even when $r_1 = r_2 = 0$. In sum, under strategic disclosure regime, firms have the strongest incentive to acquire information.

Consumer surplus under Bertrand competition

As before, we assume consumers maximize $U(x_i, x_j) - p_i x_i - p_j x_j$, where

$$U(x_i, x_j) = a(x_i + x_j) - \gamma x_i x_j - \frac{1}{2}\left(x_i^2 + x_j^2\right). \tag{76}$$

In (76), $\gamma$ represents the substitutability discount on the total consumption amount of $i$ and $j$. Consumer surplus (CS) in terms of quantities is

$$CS(x_i, x_j) = \frac{1}{2}\left(x_i^2 + x_j^2\right) + \gamma x_i x_j, \tag{77}$$

If there is no R&D investment ($r_i = r_j = 0$), then, using Lemma 1 and 2, one can derive the social surplus when $r = 0$:

$$\begin{aligned} EW_{r=0} &= CS_{r=0} + 2E\pi_{r=0} \\ &= (3+\gamma)\, x^2(f, f) \\ &= (3+\gamma)\, \left(\frac{a - E\theta}{(1+\gamma)(2-\gamma)}\right)^2. \end{aligned} \tag{78}$$

where we can get $x(f, f) = \frac{a - E\theta}{(1+\gamma)(2-\gamma)}$ from (1)

If the firms learned the cost information, the social total surplus can be denoted as:

$$EW_{r=1} = EU(x_i, x_j) - E(\theta_i x_i) - E(\theta_j x_j) - 2\eta = ECS_{r=1} + 2E\pi_{r=1} - 2\eta. \tag{79}$$

If both firms knows $(\theta_i, \theta_j)$, we can get $x_i(\theta_i, \theta_j) = \frac{a}{(1+\gamma)(2-\gamma)} + \frac{\gamma}{(1-\gamma^2)(4-\gamma^2)}\theta_j - \frac{2-\gamma^2}{(1-\gamma^2)(4-\gamma^2)}\theta_i$, so we can get $EW_{r=1}$ . we can show that

$$EW_{r=1} - EW_{r=0} = \frac{12 - 13\gamma^2 + 5\gamma^4}{(1-\gamma^2)^2(4-\gamma^2)^2}\sigma_\theta^2 - 2\eta$$

$$ECS_{r=1} - CS_{r=0} = \frac{4 - 7\gamma^2 + 3\gamma^4}{(1-\gamma^2)^2(4-\gamma^2)^2}\sigma_\theta^2$$

If the information is concealed, each firm will produce with cost information $(\theta_{i(j)}, E\theta)$ when $r_i = r_j = 1$ . And we get:

$$EW_{r=1} - EW_{r=0} = \frac{3(2-\gamma^2)^2}{(1-\gamma^2)^2(4-\gamma^2)^2}\sigma_\theta^2 - 2\eta$$

$$ECS_{r=1} - CS_{r=0} = \frac{(2-\gamma^2)^2}{(1-\gamma^2)^2(4-\gamma^2)^2}\sigma_\theta^2$$

We can see that $\frac{4-7\gamma^2+3\gamma^4}{(1-\gamma^2)^2(4-\gamma^2)^2}\sigma_\theta^2 < \frac{(2-\gamma^2)^2}{(1-\gamma^2)^2(4-\gamma^2)^2}\sigma_\theta^2$, thus consumers prefer not sharing information by the firms. We know also that information sharing decrease firms' incentive to acquire information.

■

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Figure 1

The threshold of R&D cost and the decomposition of net gain of information

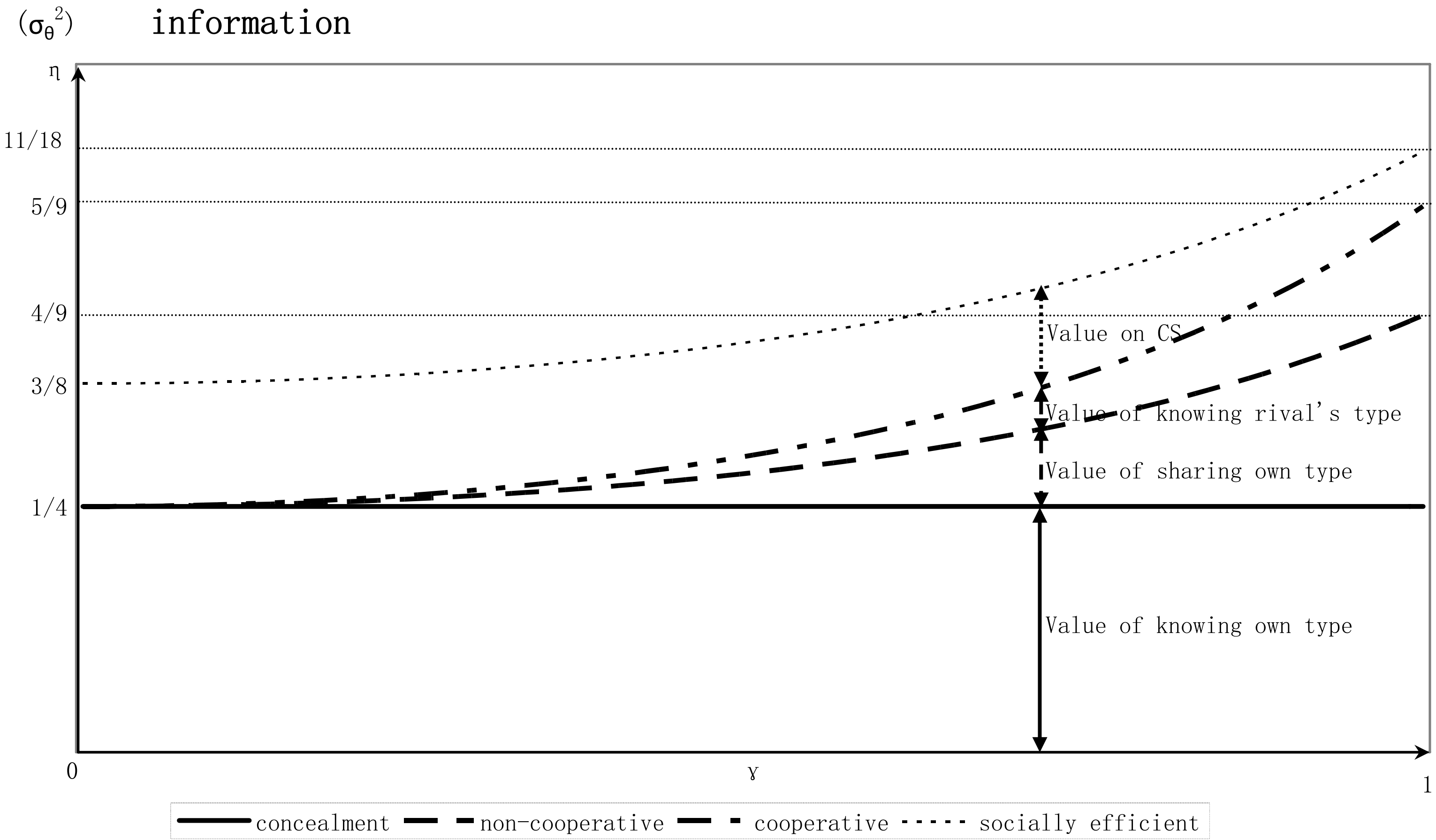

Figure 2. Illustration of Partial Disclosure under Partial R&D

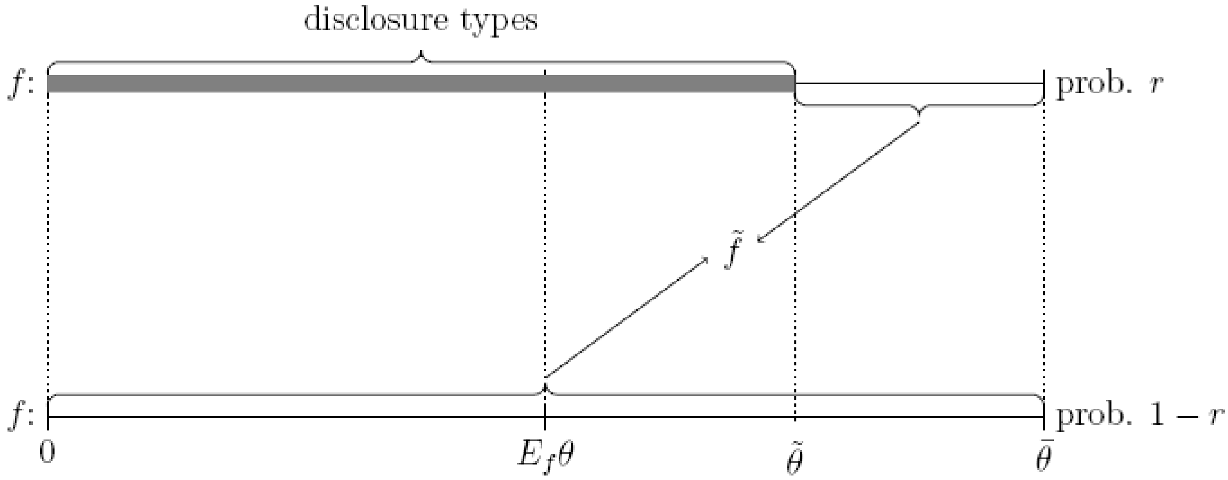


Figure 3