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《論　説》

Disclosure Policy, and Competition and Cartelization in R&D: Cournot and Bertrand Competition

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1. Introduction

Since the seminal paper of D'Aspremont and Jacquemin (1988), many papers investigate R&D strategies of firms in the organization of either R&D competition or R&D cooperation and the effects of R&D investment on market performances when R&D spillovers take place. Generally, it is presumed in these papers that such spillovers are parameters determined exogenously, not endogenously. In other words, firms cannot appropriate their outcomes created by their own R&D activities, and then the outcomes inevitably leak out to their rivals. However, Poyago–Theotoky (1999) makes a complete volte–face in the conventional treatment about transfer of R&D outcomes. Namely, she presumes that R&D transfer or disclosure rates are endogenously chosen by firms, and considers whether firms voluntarily disclose in the absence of any compensation or withhold the information that they create in their R&D activities under either R&D competition or R&D cooperation. Her model is a non–tournament model. In contrast, De Fraja (1993) considers whether firms involving patent races have incentives to disclose or withhold their R&D knowledge in a tournament model.

In order for firms to be able to strategically use information or knowledge such as patents and know–how acquired through R&D activities they must be able to appropriate such information or knowledge. Nevertheless, the possibility of appropriation is not always secured, because there are, more or less, spillovers as to the outcomes of R&D investment among firms and countries, as pointed out by some papers, e.g., Bernstein and Nadiri (1989), Bernstein and Yan (1997), and Cow and Helpman (1995). Thus one might have some doubts about taking R&D disclosure rates as strategic variables. However, when we take account of the fact that intellectual property rights are strictly protected in developed countries, and patent licensing and cross licensing are actively made among firms, it seems that the idea that the disclosure rates are internally determined by firms is not necessarily inappropriate. In the following discussion we need to distinguish voluntary disclosure and inevitable spillover: namely, spillover is a kind of involuntary disclosure.

Poyago–Theotoky (1999) employs a three–stage game model in which duopolistic firms choose R&D expenditures in the first stage, R&D disclosure rates in the second stage, and outputs in the final stage. The originality of her model consists in introducing the R&D disclosure rates as decision variables, different from

D'Aspremont and Jacquemin (1988) and Kamien et al. (1988). She derives the following results under the assumption that products are perfect substitutes. Namely, when the firms operate under R&D competition, they have no incentives to disclose any information of R&D activities: they never make the information public. Alternatively, when they cooperatively choose R&D expenditures, their optimal policies are to perfectly disclose the information. This is because both their profits increase more by sharing the results of R&D investments. This result gives the reason why firms want to form research joint ventures concerning R&D investment some answer. Thus R&D cartels are likely to be transformed to research joint ventures.

The results of Poyago–Theotoky (1999) are of great interest. However, since the inverse demand functions employed in her model are very simple, we reexamine whether her results also hold under more general inverse demand functions, focusing on whether firms have incentives to disclose all or part of knowledge yielded by R&D investment. Moreover, we extend the realm of investigation from the Cournot–quantity setting models to Bertrand–price setting models. The comparisons of market performances among four modes (e.g. Cournot competition with R&D competition and R&D cooperation, and Bertrand competition with R&D competition and R&D cooperation) are made. Through the comparisons we can provide implications for R&D policy, including disclosure policy of R&D information. The relationship between an efficient R&D organization and the types of competition and product and whether disclosure of information is beneficial to producers and consumers are elucidated. Our extension is meaningful enough when we take account of the fact that in a lot of industries firms engage in price competition á la Bertrand.

The remainder of this article is organized as follows. In the next section a basic model of duopoly for analyses in the following sections is provided. We employ more general inverse demand functions than the Poyago–Theotoky model. In addition, product differentiation is introduced, e.g. products are either substitutes or complements for firms according to the type of competition in their markets. In Section 3, in a three–stage game model of duopoly under Cournot competition we also consider whether or not the firms make a disclosure of information concerning the results of R&D activities in the organization of either R&D competition or R&D cooperation. In Section 4 we present a three–stage game model of duopoly under Bertrand competition, and consider whether there are incentives for firms in the presence of either R&D competition or R&D cooperation to disclose the information. In Section 5 we make comparisons of market performances such as R&D investments, prices and profits in the Cournot–quantity setting and Bertrand–price setting models. The final section concludes the paper.

2. The Model

We consider three–stage games of duopolists by invoking the Poyago–Theotoky (1999) model. In the first stage of the games two identical firms simultaneously choose R&D investments to curtail their production costs. In the second stage each firm decides how much of knowledge or technology acquired by its R&D activities to disclose to its rival. Like the Poyago–Theotoky model, we assume that the firms use disclosure policy as strategic methods, not exogenous ones as in previous papers, e.g., D'Aspremont and Jacquemin (1988) and Kamien et al. (1992). Finally, in the third stage the firms play Cournot–quantity competition or Bernard–price competition in product markets.

The costs of firm i are originally given by $c(q_i) = Aq_i$, $A > 0$, $i = 1, 2$, where q_i stands for the output of firm i. It is possible for the firms to reduce their production costs by making an investment in R&D. Now firm i must expend by $\gamma x_i/2$, $\gamma > 0$, in reducing the costs by x_i. Each of the firms may be able to utilize the outcome of its rival's R&D investment in addition to that of its own R&D investment. It has been traditionally supposed that when a firm invests in R&D, part or all of the outcome created by its investment leaks out to its rivals: that is, the firm cannot appropriate all of its outcome[1]. In contrast, Poyago–Theotoky (1999) supposes that it can perfectly manage or control the outcome created by its R&D investment. Following her model, we suppose that the firms use their disclosure as strategic variables[2 3]. They endogenously have the choices of whether to leak out or withhold innovative R&D information or knowledge to their rivals.

When we take account of both R&D investment and its disclosure, the unit cost functions of firms i and j are given by $c_i(x_i, x_j, \beta_j) = A - x_i - \beta_j x_j$ and $c_j(x_i, x_j, \beta_i) = A - x_j - \beta_i x_i$, $i \neq j$, respectively, where β_i is the rate of the knowledge as to R&D that firm i discloses to rival j, and is called the disclosure rate of firm i, $0 \leq \beta_i \leq 1$. For example, if $\beta_i = 0$, then firm i never discloses the amount of its own knowledge to the rival at all, while if $\beta_i = 1$, then it voluntarily discloses all the amount. Now x_i denotes the personal R&D knowledge level of firm i. On the other hand, $x_i + \beta_j x_j$ is the effective R&D knowledge level or effective R&D for firm i resulted from innovative activities in the duopoly industry, which is composed of its own R&D level, x_i, and its competitor's R&D level that spills over to it, $\beta_j x_j$. If each firm keeps its own R&D knowledge to the rival secret, then the rival's R&D investment and effective R&D coincide. Finally, the output costs of firm i are given by $c(q_i) = c_i(x_i, x_j, \beta_j) \cdot q_i$.

The two firms produce heterogeneous (differentiated) outputs. Then their inverse demand functions are given by

$$
\begin{aligned}
p_1 &= a - bq_1 - eq_2 \\
p_2 &= a - eq_1 - bq_2,\ a > 0, b > 0, b \geq |e|, e \neq 0.
\end{aligned}
\tag{1}
$$

To simplify, we assume that the demand functions are symmetric. Parameter e denotes the cross–price effect: given $e > 0$, products are substitutes for the firms in terms of Cournot (–quantity) competition, while, given

1 There are a lot of the following channels through which R&D innovative information diffuses, e.g. movement of personnel from one firm to another, professional and academic meetings, informal communication networks among engineers and scientists, and reverse engineering (Mansfield [1985]).

2 For example, patent licensing and cross–licensing are close to disclosure of R&D information.
It is assumed that the firms truthfully disclose their R&D information or knowledge to their rivals if they do it.

3 In her two–stage game models with demand or cost information she considers the disclosure strategies of Cournot–quantity setting and Bertrand–price setting firms.

$e < 0$, they are complements. The value of e^2/b^2, in general, expresses an index of product differentiation. In contrast, in the Poyago–Theotoky model it is assumed that $b = e = 1$: namely, her discussion is limited to the case in which products are perfect substitutes under Cournot competition. In what follows, it is assumed that $a > c_i$, where $c_i = c_i(x_i, x_j, \beta_j)$.

The profit function of the firm is expressed by

$$\pi_i = [p_i(q_i, q_j) - c_i]q_i - \frac{\gamma x_i^2}{2}, \; i \neq j, \; i, j = 1, 2, \tag{2}$$

where $p_i(q_i, q_j) = a - bq_i - eq_j$.

3. R&D competition and R&D cooperation in the Cournot–quantity setting model

When the firms engage in Cournot competition in the final stage, we have their output reaction functions from the first–order conditions for profit maximization:

$$\begin{aligned} &a - c_1 - 2bq_1 - eq_2 = 0 \\ &a - c_2 - eq_1 - 2bq_2 = 0. \end{aligned} \tag{3}$$

The slope of each reaction curve depends on the sign of e. When firm 1 increases its disclosure rate on R&D knowledge, this causes the reaction curve of its rival to move upwards. Now, solving (3), we have the equilibrium outputs of the firms in the third stage:

$$\hat{q}_i = \frac{2b(a - c_i) - e(a - c_j)}{4b^2 - e^2}, \; i \neq j. \tag{4}$$

These solutions are obtained, irrespective of whether the firms compete or cooperate in the R&D stage. As mentioned above, if a firm reveals its own R&D knowledge to the rival, then this is to the latter's benefit, because its revelation contributes to a reduction in the latter's cost. The equilibrium in this stage is locally stable.

In the following section we also consider the voluntary disclosure (spillover) strategies of the firms in two cases of R&D competition and R&D coordination.

3.1 R&D competition

The firms non–cooperatively choose their R&D investments so as to maximize their own profits, competing in the production stage as well. Particularly, before going forward, we rewrite (2) by using (4) as follows:

$$\pi_i = \frac{b\left[2b(a - c_i) - e(a - c_j)\right]^2}{(4b^2 - e^2)^2} - \frac{\gamma x_i^2}{2} = bq_i^2 - \frac{\gamma x_i^2}{2}, \; i \neq j. \tag{2$'$}$$

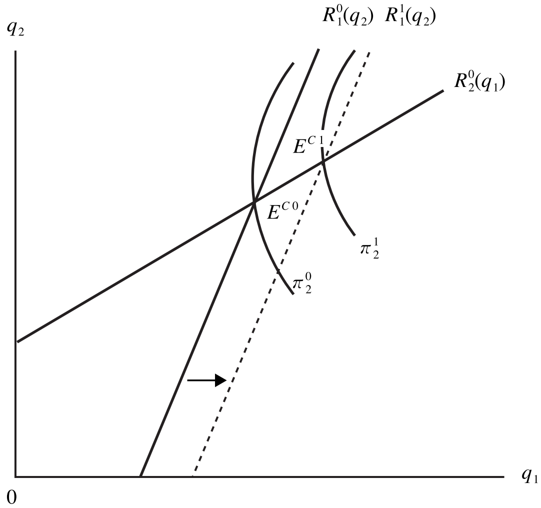

Figure 1 Disclosure and Output Reaction Curves

First we consider the firms' disclosure strategies in the second stage. Their strategies are to choose the optimal ones maximizing their own profits. As the first–order and second–order conditions for maximization $\partial\pi_i/\partial\beta_i = 0$ and $\partial^2\pi_i/\partial\beta_i^2 < 0$ are both satisfied whenever there are interior solutions[4]. However, in differentiating (2)' with respect to β_i, instead of them we have the following results:

$$\frac{\partial\pi_i}{\partial\beta_i} = -\frac{4b^2 e x_i q_i}{4b^2 - e^2} < (>)\ 0 \text{ as } e > (<)\ 0$$

$$\frac{\partial^2\pi_i}{\partial\beta_i^2} > 0. \tag{5}$$

These inequalities demonstrate that the solutions are corner ones, as shown by Poyago–Theotoky (1999): that is, the optimal choice of β_i is reduced to either $\hat{\beta}_i = 0$ or 1 and depends on whether products are substitutes ($e > 0$) or complements ($e < 0$)[5]. Thus, if they are substitutes, then the choice of firm i is $\hat{\beta}_i = 0$, because even if it discloses a little information created by its R&D activities, this gives firm j a cost advantage over firm i, which, in turn, decreases the latter's profits. Therefore, each firm withholds the R&D information. This result has been already derived by her. Meanwhile, if they are complements, then its choice is $\hat{\beta}_i = 1$. This implies that the firm voluntarily discloses all of its knowledge on R&D to the rival. This is well explained by using the output reaction curves. In Figure 1, given no disclosure, the two reaction curves, $R_1^0(q_2)$ and $R_2^0(q_1)$, with

4 We assume throughout the paper that there are subgame–perfect Nash equilibria in the games.

5 Darrough (1993) demonstrates that the disclosure policies of firms depend on the type, e.g. Cournot or Bertrand, of competition they are engaged in and the type of private information, e.g. demand or cost, although she considers whether the firms have incentives to disclose their private information.

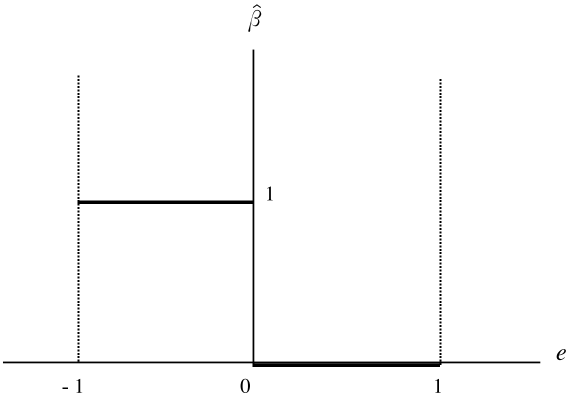

Figure 2 Relationship between Disclosure Rates and the Value of Cross–Price Effects

upward slopes are illustrated. Intersection E^{C0} of the curves is the (Cournot–Nash) equilibrium in the production stage, and π_2^{C0} denotes the isoprofit curve of firm 2 at the equilibrium. From now on we call the case of R&D competition under Cournot competition case C. When firm 2 increases the amount of its disclosure, the reaction curve of firm 1 is shifted to the lower right, $R_1^1(q_2)$, and then the equilibrium is changed to E^{C1}, and, simultaneously, the isoprofit curve moves to π_2^{C1}. Consequently, it follows that the profits of firm 2 increase, i.e. $\pi_2^{C1} > \pi_2^{C0}$. This is because the products are complements. Thus it is profitable for each of them to provide its own R&D information to the rival. Figure 2 illustrates the relationship between disclosure rates and the value of e.

In the case of $e < 0$, although the result that the firms set their disclosure rates to unity shows that they form a research joint venture (RJV), they do not coordinate their R&D expenditures. This corresponds to RJV competition in terms of the taxonomy of Kamien et al. (1992). RJV competition means that firms form RJVs, but do not coordinate their R&D expenditures. Our result provides a theoretical basis for the existence of RJV competition supposed in Kamien et al. But no theoretical basis for its existence will be provided if the effects are positive.

We proceed to the R&D stage of the game. When setting $\hat{\beta} = \hat{\beta}_1 = \hat{\beta}_2$ and differentiating (2)' with respect to x_i, we get the first–order and second–order conditions for maximization[6]:

$$\frac{\partial \pi_i}{\partial x_i} = \frac{2b(2b - e\hat{\beta})}{(4b^2 - e^2)^2}\left[2b(a - c_i) - e(a - c_j)\right] - \gamma x_i = 0, \tag{6}$$

$$\frac{\partial^2 \pi_i}{\partial x_i^2} = \frac{2b(2b - e\hat{\beta})^2}{(4b^2 - e^2)^2} - \gamma < 0, \quad i \neq j. \tag{7}$$

6 As the Poyago–Theotoky model, given $b = e = 1$, the second–order conditions are satisfied when $\gamma > 8/9$ for $e > 0$ and $\gamma > 2/9$ for $e < 0$.

The slopes of the reaction curves in R&D space rely on the sign of e: that is, given $e > (<)\ 0$, the curves are sloping downwards (upwards). Put it differently, x_1 and x_2 become strategic substitutes or strategic complements according as its sign is positive or negative. When we return to the choice of whether the firms disclose or withhold R&D information, it seems that their choices are closely related with the slopes of the R&D reaction curves rather than those of the output reaction curves.

Substituting (6) into (1)', we obtain the equilibrium profits of the firm:

$$\hat{\pi}^C = \frac{\gamma x^2}{4b\left(2b - e\hat{\beta}\right)^2}\left[\gamma\left(4b^2 - e^2\right)^2 - 2b\left(2b - e\hat{\beta}\right)^2\right].$$

When we substitute either $\hat{\beta} = 0$ or 1 into (4) and solve it, the R&D investments under the symmetric equilibrium are derived, depending on the sign of e, as follows:

$$\hat{x}^C = \hat{x}_1^C = \hat{x}_2^C = \frac{4b^2(a - A)}{\gamma(2b + e)(4b^2 - e^2) - 4b^2} \qquad \text{for } e > 0$$

$$\hat{x}^C = \hat{x}_1^C = \hat{x}_2^C = \frac{2b(a - A)}{\gamma(2b + e)^2 - 4b} \qquad \text{for } e < 0.$$

Note that R&D expenditure is less under $e > 0$ than under $e < 0$. R&D expenditure (effective R&D) increases in the case of $e < 0$ although the firms perfectly disclose their R&D results. Thus the disclosure of innovative information has some incentives to conduct R&D. Result 5 summarized by De Bondt (1996) is not always the case.

We examine the stability of the equilibrium in R&D space. The conditions for it to be locally stable are

$$\left(\frac{\partial^2 \pi_i}{\partial x_i^2}\right)\left(\frac{\partial^2 \pi_j}{\partial x_j^2}\right) - \left(\frac{\partial^2 \pi_i}{\partial x_j \partial x_i}\right)\left(\frac{\partial^2 \pi_j}{\partial x_i \partial x_j}\right) > 0, \quad i \neq j,$$

where $\partial^2 \pi_i / \partial x_j \partial x_i = \partial^2 \pi_j / \partial x_i \partial x_j = 2b(2b - e\hat{\beta})(2b\hat{\beta} - e)/\left(4b^2 - e^2\right)^2$ [7]. When we follow the Poyago–Theotoky model and set $b = e = 1$, the following conditions for stability must be satisfied: namely, $0 < \gamma < 4/9$ or $4/3 < \gamma$ [8]. It is intuitively reasonable that the equilibrium is stable when a rate of increase in the

7 The stability conditions are given as follows:

$$8b^3 - \gamma(4b^2 - e^2)^2 + 4b^2 e < 0 \qquad \text{for } e > 0$$

$$4b - \gamma(2b + e)^2 < 0 \qquad \text{for } e < 0.$$

For example, if there is perfect complementarity between products, i.e. $b = 1$ and $e = -1$, then the stability condition is reduced to $\gamma > 4$. Incidentally, in this case the second–order conditions are $\gamma > 2$.

8 Henriques (1990) describes the relationship between the stability of the equilibrium in R&D space and R&D spillovers under the D'Aspremont and Jacquemin (1989) model. When these spillovers are given exogenously, she demonstrates that its stability in R&D space depends crucially on the magnitudes of spillovers: specifically, if they are small, then the equilibrium is unstable.

marginal costs of R&D investment is great[9]. But it is counter–intuitive that the equilibrium is also stable even if that rate is small. Taking account of the second–order conditions, we note that condition $4/3 < \gamma$ must hold for the existence and stability of the equilibrium. Different from Henriques (1990), there is no evidence that the existence of spillovers (i.e. concealment or disclosure) especially makes equilibria in R&D space unstable.

When we use the equilibrium R&D investments, the amounts of outputs in both cases of $e > 0$ and $e < 0$ are obtained, respectively, as

$$\hat{q}^C = \hat{q}_1^C = \hat{q}_2^C = \frac{2\gamma(a - A)(4b^2 - e^2)}{\gamma(2b + e)(4b^2 - e^2) - 4b^2} \qquad \text{for } e > 0$$

$$\hat{q}^C = \hat{q}_1^C = \hat{q}_2^C = \frac{2\gamma(a - A)(2b + e)}{\gamma(2b + e)^2 - 4b} \qquad \text{for } e < 0.$$

From the comparison of both outputs we find that output under $e > 0$ is less than or equal to output under $e < 0$, where the equality holds only at $b = e$. Thus it follows that price under $e > 0$ is higher than or equal to price under $e < 0$.

Examine the effect of product differentiation on R&D. Then we obtain that, with $e > 0$, $d\hat{x}_0^C/de < 0$ for $0 < e < 2b/3$, and $d\hat{x}_0^C/de > 0$ for $2b/3 < e \le b$. Given $2b/3 < e \le b$, if product–market competition is less intense, then this makes the firms decrease their R&D expenditures, but given $0 < e < 2b/3$, it conversely makes them increase their R&D expenditures. In other words, whereas the advance of product differentiation increases R&D expenditure if the degree of product differentiation e^2/b^2 is less than 4 / 9, its advance decreases R&D expenditure if it is larger than 4 / 9. It appears that this threshold deeply relates to the number of firms in the industry and rises as the number increases. In general, it is recognized that it leads to a decrease in strategic R&D expenditure since a rise in product differentiation lightens competition among firms. This recognition, however, is not the case in the presence of R&D commitment. The outcome that the advance of product differentiation functions so as to reduce output through its commitment is of interest in comparison with the result without it that the advance always causes output to increase. On the other hand, provided there exists strategic investment, as the indirect effect its advance causes the amount of R&D investment to increase for region $4/9 < e^2/b^2 \le 1$. Therefore, the advance might lead to the opposite of the result derived in the case without strategic investment.

Let us turn to the case in which there is a complementary relationship between products, i.e. $e < 0$. An advance in such a relationship leads to an increase in R&D expenditure, i.e. $d\hat{x}_1^C/de < 0$: that is, a firm increases its expenditure as product–market complementarity strengthens. Alternatively, we consider the effect of e on output which is divided into two effects, i.e. a direct and an indirect effects, $\partial q/\partial e$ and $(\partial q/\partial x)(\partial x/\partial e)$, respectively. In the case of $e > 0$ we have $d\hat{q}^C/de < 0$ for $0 < e \le 2b/3$, but the effect is

9 Now γ is the second derivative of the R&D expenditure function, $\gamma x_i^2/2$, which measures the curvature of the function.

ambiguous for $2b/3 < e \leq b$ because both direct and indirect effects move in opposite directions, while we have $d\hat{q}^C/de < 0$ for $e < 0$. Except for the case of $2b/3 < e \leq b$, the more complementary products are, the larger the amount of output becomes.

3.2 R&D cooperation

Now the firms form a cartel in the R&D stage and coordinate their R&D expenditures, maintaining quantity competition in the production stage. We consider the choices of disclosure in the second stage and R&D investments under the R&D cartel in the first stage: that is, they choose them so as to maximize joint profits $\Pi = \pi_1 + \pi_2$.

First, we investigate whether they intend to withhold or disclose their outcomes obtained by R&D investments each other. In order for disclosure rates to have interior solutions, conditions $\partial\Pi/\partial\beta_i = 0$ and $\partial^2\Pi/\partial\beta_i^2 < 0$ must be satisfied. However, when differentiating the joint profits with respect to the disclosure rates, we have

$$\frac{\partial\Pi}{\partial\beta_i} = \frac{\partial\pi_i}{\partial\beta_i} + \frac{\partial\pi_j}{\partial\beta_i} = \frac{2bx_i}{(4b^2 - d^2)^2}(-eq_i + 2bq_j) > 0$$

$$\frac{\partial^2\Pi}{\partial\beta_i^2} = 2b\left(\frac{\partial q_i}{\partial\beta_i}\right)^2 + 2b\left(\frac{\partial q_j}{\partial\beta_i}\right)^2 > 0, \quad i \neq j. \tag{8}$$

The conditions for the interior solutions are not satisfied, so that there exist corner solutions. Thus the optimal choices are reduced to either $\hat{\beta} = 0$ or 1. Since there is a symmetric equilibrium in the second stage, the profits at $\hat{\beta} = 1$ obviously exceeds those at $\hat{\beta} = 0$. It follows that the firms choose to disclose the R&D information, $\hat{\beta} = 1$, but their choices are suboptimal. Hence the firms voluntarily disclose all information concerning R&D, irrespective of whether products are substitutes or complements for them. This implies that making all their research results public yields more joint profits for them rather than concealing their results. Therefore, the result of Poyato–Theotoky (1999) also holds for more general inverse demand functions. Furthermore, her result carries over to the case in which products are complements. It seems that our result also provides some theoretical basis for the fact that if firms cooperate on their R&D investment decisions, then RJV cartelization in terms of Kamien et al. (1992) is created, regardless of the type of product, e.g. substitutes or complements, as she mentions. In other words, if firms form cartels in terms of R&D investment, this has the mechanisms to create RJVs among them voluntarily. In addition, the disclosure of R&D information will eliminate wasteful duplication.

Second, the first–order conditions for maximization of the joint profits in the R&D stage are

$$\frac{\partial\Pi}{\partial x_i} = \frac{\partial\pi_i}{\partial x_i} + \frac{\partial\pi_j}{\partial x_i} = \frac{2b(2b - e\hat{\beta})}{(4b^2 - e^2)^2}\left[2b(a - c_i) - e(a - c_j)\right] - \gamma x_i + \tag{9}$$

$$\frac{2b(2b\hat{\beta}-e)}{(4b^2-e^2)^2}\left[2b(a-c_j)-e(a-c_i)\right]=0,\ \ i\neq j.$$

The second–order conditions are given by

$$\frac{\partial^2\Pi}{\partial x_i^2}=\frac{4b}{(2b+e)^2}-\gamma<0,$$

where $\hat{\beta}=1$. When we substitute (9) into the profit function of each firm, the equilibrium profits under symmetry are obtained:

$$\hat{\pi}^{CC}=\frac{\gamma x^2}{16b}\left[\gamma(2b+e)^2-8b\right],$$

where $\hat{\beta}=1$. In the following we call the case of R&D cooperation under Cournot competition case CC.

Since the subgame–perfect Nash equilibrium is symmetric, by solving (9) the amount of R&D investment of each firm is given[10]:

$$\hat{x}^{CC}=\hat{x}_1^{CC}=\hat{x}_2^{CC}=\frac{4b(a-A)}{\gamma(2b+e)^2-8b}.$$

These are the solutions under the R&D cartel. R&D investment is greater under R&D competition than under R &D cooperation, i.e. $\hat{x}^{CC}>\hat{x}^{C}$, for any e[11]. This is the same as the result of Poyago–Theotoky (1999).

We have assumed that the firms collude in determining their R&D investments. When D'Aspremont and Jacquemin (1988), Kamien et al. (1992), and Poyago–Theotoky (1999) consider the R&D investment and disclosure strategies of firms under R&D cartels, they implicitly assume that the equilibrium solutions under the cartels are internally stable. Output cartels are, however, faced with the risk of its collapsing from the inside, as well known. Therefore, we should pay attention to the problem of internal stability of the cartel. Consider what happens when firm i contemplates increasing its R&D investment by some amount, but firm j maintaining the cartel agreement level of its R&D investment. Then, evaluating (9) at the cartel level and using $\hat{\beta}=1$, we obtain

$$\frac{\partial\pi_i}{\partial x_i}=-\frac{\partial\pi_j}{\partial x_i}=-\frac{2b(2b\hat{\beta}-e)}{(4b^2-e^2)^2}\left[2b(a-c_j)-e(a-c_i)\right]<0,\ \ i\neq j.$$

This demonstrates that even if firm i is sure that the rival will stick to the cartel R&D investment on which they were agreed, it would not be beneficial for firm i to increase R&D investment secretly: namely, each firm has

10 Now the second–order conditions are assumed to be satisfied.

11 Conventionally, as mentioned by De Bondt (1996), cooperative R&D also exceeds non–cooperative R&D if spillover rates are relatively large (see, e.g., D'Aspremont and Jacquemin [1988]).

an incentive to repeal the cartel agreement. Thus the R&D cartels will be internally stable, but output cartels are not. It is meaningful to consider the choices of disclosure rates whenever the cartels possess internal stability.

Let us examine the effect of e on R&D expenditure. Now since $d\hat{x}^{CC}/de < 0$, the amount of $\hat{x}^{CC}$ increases as e decreases: namely, a firm increases its R&D expenditure when product differentiation advances or the complementary relationship between products strengthens. In particular, when they are perfect substitutes, cooperative R&D expenditure is reduced to the minimum.

Substituting the equilibrium R&D investment into (4), we obtain the equilibrium output

$$\hat{q}^{CC} = \frac{2\gamma(a-A)(2b+e)}{\gamma(2b+e)^2 - 8b}.$$

Since $d\hat{q}^{CC}/de < 0$, the more intense product–market competition is, the more the output of each firm increases. This result is different from that under R&D competition.

Comparing the amounts of both outputs under R&D competition and R&D cooperation by using (4), we obtain that $\hat{q}^{CC} > \hat{q}^{C}$ for any e, regardless of whether or not the firms disclose their own R&D knowledge. This is owing to result $\hat{x}^{CC} > \hat{x}^{C}$. As a result, prices are higher under R&D competition than under R&D cooperation, so that consumer's surplus is larger under R&D cooperation than under R&D competition, i.e. $\hat{p}^{CC} < \hat{p}^{C}$, for any e, as shown in Poyago–Theotoky (1999)[12]. Let us turn to producer's surplus denoted by (2) or (2)'. When the cross–price effects are positive, $e > 0$, we cannot compare between $\hat{\pi}^{CC}$ and $\hat{\pi}^{C}$, although she derives the result that producer's surplus is greater under R&D cooperation than under R&D competition in the case in which products are perfect substitutes. This implies that her result does not necessarily hold in more general models. Incidentally, the condition for $\hat{\pi}^{CC} > (<)\ \hat{\pi}^{C}$ is $\gamma > (<)\ 6b^3/(2b+e)^2\left[(2b-e)(b-e)+b^2\right]$, and, in particular, in the case of $b = e$ it is reduced to $\gamma > 8/9b$ [13]. If the marginal costs of R&D investment rapidly (slowly) increase, then it follows that profits in the presence of R&D cooperation exceed (fall short of) profits in the absence of it. Like this, cost parameter γ of R&D investment plays an important role in determining the ranking of both profits. We conclude that the result of Poyago–Theotoky is, generally, not relevant. More important, profits in the absence of R&D cartelization may exceed those in the presence of it although firms never share their R&D information in the former case.

Alternatively, when the cross–price effects are negative, and if firms form a cartel on R&D, producer's surplus increases in comparison with the case of R&D competition, i.e. $\hat{\pi}^{CC} > \hat{\pi}^{C}$. This is caused by two effects: first, the firms can share R&D information and reduce their R&D costs each other as a result of R&D cooperation, and then their outputs increase; and second, increases in the outputs enhance the demands for

12 Katz (1985) describes that cooperate research is likely to raise consumer's surplus. Kamien et al. (1992) also obtain that price is lower in the presence of R&D cooperation than in the absence of it if spillovers are relatively large.

13 $\gamma > 8/9b$ is the second–order conditions for maximization in the first stage under R&D competition. Incidentally, $\gamma > 6b^3/(2b+e)^2\left[(2b-e)(b-e)+b^2\right]$ is apparently different from our second–order conditions. Kamien et al. (1992) derive the result that R&D cooperation (cartel) leads to higher profits, compared with the profits without it. In fact, in the Poyago–Theotoky model it is assumed that $b = e = 1$, and, moreover, $\gamma > 8/9$ is satisfied.

them, because they are complements. Consequently, R&D cooperation increases more welfare than R&D competition as long as they are complements. In this case the effect of R&D cooperation is to lower prices and to raise both consumer's and producer's surpluses. Thus to form R&D cartels is of benefit to both consumers and producers.

4. R&D competition and R&D cooperation in the Bertrand–price setting model

We consider the output and R&D investment behavior of firms in Bertrand's model of price–setting duopoly. In the production stage the firms set their prices so as to maximize their own profits, but in the first and second stages they behave in the same way as in the previous section.

By solving inverse demand functions (1), the corresponding demand functions are derived as follows:

$$\begin{aligned} q_1 &= \alpha - \delta p_1 + \varepsilon p_2 \\ q_2 &= \alpha + \varepsilon p_1 - \delta p_2, \end{aligned} \tag{1$'$}$$

where $\alpha = a/(b+e)$, $\delta = b/(b^2 - e^2)$, and $\varepsilon = e/(b^2 - e^2)$ [14]. The signs of both e and ε are the same: that is, ε is positive or negative according as the cross–price effects are positive or negative.

We can express the profits of firm i as

$$\pi_i = (p_i - c_i) q_i(p_i, p_j) - \frac{\gamma x_i^2}{2}, \quad i \neq j, \tag{10}$$

where $q_i(p_i, p_j) = \alpha - \delta p_i + \varepsilon p_j$. This profit function is the counterpart of (2). The firms set prices so as to maximize their own profits in the third stage, given R&D investments and the rates of R&D disclosure chosen in the previous stages, respectively. From the first–order conditions for maximization we have price reaction functions as[15]

$$\begin{aligned} \alpha + \delta c_1 - 2\delta p_1 + \varepsilon p_2 &= 0 \\ \alpha + \delta c_2 + \varepsilon p_1 - 2\delta p_2 &= 0. \end{aligned} \tag{11}$$

The slopes of these reaction curves depend on the sign of ε: that is, given $\varepsilon > (<)\ 0$, the reaction curves are sloping upwards (downwards). Thus products are complements for the firms if $\varepsilon > 0$, while they are substitutes if $\varepsilon < 0$.

From (11) the equilibrium prices for both outputs are derived as

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14 In this section it is assumed that $b \neq e$.

15 In this stage the second–order conditions are satisfied, and the equilibirum is locally stable.

$$\hat{p}_i = \frac{\alpha(2\delta+\varepsilon)+\delta(2\delta c_i+\varepsilon c_j)}{4\delta^2-\varepsilon^2},\ i \neq j. \tag{12}$$

4.1 R&D competition

Using (12) and making a tedious calculation, we can rewrite (10) as follows:

$$\pi_i = \frac{\delta\left[\alpha(2\delta+\varepsilon)-(2\delta^2-\varepsilon^2)c_i+\delta\varepsilon c_j\right]^2}{\left(4\delta^2-\varepsilon^2\right)^2} - \frac{\gamma x_i^2}{2} = \frac{q_i^2}{\delta} - \frac{\gamma x_i^2}{2},\ i \neq j. \tag{10'}$$

In the second stage each of the firms chooses its R&D disclosure rate so as to maximize its own profits. Then the first–order and second–order conditions for maximization must be $\partial\pi_i/\partial\beta_i = 0$ and $\partial^2\pi_i/\partial\beta_i^2 < 0$ in order for optimal R&D disclosure rate $\hat{\beta}_i$ to have an interior solution. However, instead of both conditions we obtain

$$\frac{\partial\pi_i}{\partial\beta_i} = -\frac{2\delta\varepsilon x_i q_i}{4\delta^2-\varepsilon^2} > (<)\ 0 \ \text{as} \quad \varepsilon < (>)\ 0$$

(13)

$$\frac{\partial^2\pi_i}{\partial\beta_i^2} = \frac{2\delta^3\varepsilon^2 x_i^2}{\left(4\delta^2-\varepsilon^2\right)^2} > 0,$$

where $q_i = \delta\left[\alpha(2\delta+\varepsilon)-(2\delta^2-\varepsilon^2)c_i+\delta\varepsilon c_j\right]/(4\delta^2-\varepsilon^2)$. These inequalities demonstrate that the equilibrium in the second stage holds at the corner. Concretely, if $\varepsilon > 0$, then optimal disclosure rate for firm i is either $\hat{\beta}_i = 0$ or 1 as $\partial\pi_i/\partial\beta_i < 0$, while if $\varepsilon < 0$, then it is $\hat{\beta}_i = 1$ as $\partial\pi_i/\partial\beta_i > 0$. In the former case let us compare profit levels at $\hat{\beta}_i = 0$ and 1. The profits are less at $\hat{\beta}_i = 1$ than at $\hat{\beta}_i = 0$ when we take into consideration the fact that the equilibrium is symmetric. In effect, the optimal behavior as to R&D disclosure is to appropriate (disclose) their information of R&D investment as long as products are complements (substitutes). These results are explained as follows. First, if they are complements ($\varepsilon > 0$), then a rise in β_i causes the upward sloping price reaction curve of firm j to move downwards in that the profits of firm i decrease. Second, if they are substitutes ($\varepsilon < 0$), then its rise causes the downward sloping reaction curve of firm j to move downwards. Put is differently, if firm 1 provides more its own information on R&D to its rival than ever, then this leads to a decrease in the price of product 2, i.e. an increase in its output, and, simultaneously, to an increase in the price of product 1 in that firm 1's profits increase. This is illustrated in Figure 3, where $\Psi_i(p_j), i \neq j$, denotes the price reaction curve of firm i. If firm 1 raises the rate of disclosure, then its reaction curve is kept unchanged, but the reaction curve of the rival is shifted from $\Psi_2^0(p_1)$ to $\Psi_2^1(p_1)$, so that the Bertrand equilibrium moves from E^{B0} to E^{B1}. Both π_1^{B0} and π_1^{B1} are the isoprofit curves of firm 1. Superscript B denotes the case of R&D competition under Bertrand competition, and superscript 0 (1) variables before (after) its rate changes. It seems that an increase in its profits is due to a rise in its price. From these two cases we note that the firms should choose different strategies about R&D disclosure by a difference in the type of product.

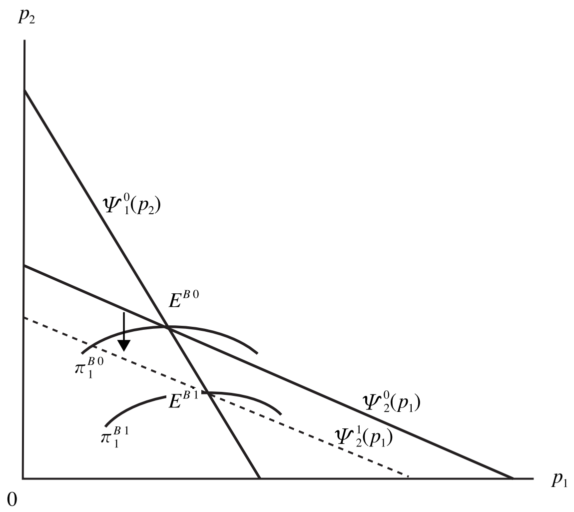

Figure 3 Disclosure and Price Reaction Curves

The optimal choices as to R&D disclosure rates are finally determined only by the sign of the cross–price effects (e), and are independent of whether the firms compete with each other in quantity or price. Namely, given $e > 0$, they will have the incentives to fully appropriate their knowledge newly acquired by R&D activities, while given $e > 0$, they will have those to share all of their R&D knowledge each other. The result in the latter case shows that the selfish decisions of firms lead to the formation of RJVs in R&D, so that RJV competition in terms of Kamien et al. (1992) takes place under Bertrand competition as well as under Cournot competition.

We proceed to the decisions of R&D investment. When we differentiate profit function (10) with respect to x_i, the first–order and second–order conditions are given as

$$\frac{\partial \pi_i}{\partial x_i} = \frac{2\delta}{\left(4\delta^2 - \varepsilon^2\right)^2}\left[\alpha(2\delta+\varepsilon) - (2\delta^2 - \varepsilon^2)c_i + \delta\varepsilon c_j\right]\left[(2\delta^2 - \varepsilon^2) - \delta\varepsilon\hat{\beta}\right] - \gamma x_i = 0$$

(6)'

$$\frac{\partial^2 \pi_i}{\partial x_i^2} = \frac{2\delta}{(4\delta^2 - \varepsilon^2)}\left[(2\delta^2 - \varepsilon^2) - \delta\varepsilon\hat{\beta}\right]^2 - \gamma < 0, \ \ i \neq j,$$

where $\hat{\beta}$ stands for the optimal R&D disclosure rate, because the firms are symmetric. The slopes of the reaction curves in R&D space derived from (6)' reply on the sign of ε, i.e., as a consequence, e: that is, given $\varepsilon > (<)\ 0$, both curves are sloping downwards (upwards)[16]. This shows that whether x_1 and x_2 are strategic substitutes or strategic complements also relies on the sign of e, not the type of competition in the third stage. We may conclude that whether the firms disclose or withhold their R&D information is closely related with the

16 We assume that the equilibrium in R&D space is locally stable.

slopes of the R&D reaction curves, because the same indication is made in Section 3.1 as well.

Using first–order conditions (6)' and arranging them, we can derive the equilibrium profits of the firm[17]:

$$\hat{\pi}^B = \frac{\gamma x^2}{4\delta\left[(2\delta^2-\varepsilon^2)-\delta\varepsilon\hat{\beta}\right]^2}\left\{\gamma\,(4\delta^2-\varepsilon^2)^2 - 2\delta\left[(2\delta^2-\varepsilon^2)-\delta\varepsilon\hat{\beta}\right]^2\right\}.$$

Under symmetry the R&D investments are derived from (6)':

$$\hat{x}^B = \hat{x}_1^B = \hat{x}_2^B = \frac{2\delta(2\delta^2-\varepsilon^2)\left[\alpha - A\,(\delta-\varepsilon)\right]}{\gamma(2\delta+\varepsilon)\,(2\delta-\varepsilon)^2 - 2\delta(\delta-\varepsilon)(2\delta^2-\varepsilon^2)} \qquad \text{for } \varepsilon > 0$$

$$\hat{x}^B = \hat{x}_1^B = \hat{x}_2^B = \frac{2\delta(\delta-\varepsilon)\left[\alpha - A\,(\delta-\varepsilon)\right]}{\gamma\,(2\delta-\varepsilon)^2 - 4\delta\,(\delta-\varepsilon)^2} \qquad \text{for } \varepsilon < 0.$$

Different from the result in the Cournot–quantity setting model, it is indeterminate whether disclosure of innovative information has an incentive to conduct R&D investment. It is, furthermore, difficult to determine the effect of ε on R&D expenditures, differently from the case of Cournot competition.

The equilibrium prices are given by

$$\hat{p}^B = \hat{p}_1^B = \hat{p}_2^B = \frac{\gamma(\alpha + A\,\delta)(2\delta+\varepsilon)\,(2\delta-\varepsilon)^2 - 2\alpha\delta(1+\delta)(2\delta^2-\varepsilon^2)}{\gamma(2\delta+\varepsilon)\,(2\delta-\varepsilon)^2 - 2\delta(\delta-\varepsilon)(2\delta^2-\varepsilon^2)} \qquad \text{for } \varepsilon > 0$$

$$\hat{p}^B = \hat{p}_1^B = \hat{p}_2^B = \frac{\gamma(2\delta-\varepsilon)(\alpha + A\,\delta) - 4\alpha\delta(\delta-\varepsilon)}{\gamma\,(2\delta-\varepsilon)^2 - 4\delta\,(\delta-\varepsilon)^2} \qquad \text{for } \varepsilon < 0.$$

Since the effect on the prices of a change in ε also remains indeterminate, we cannot specify the effects of changes in product differentiation on R&D investments and prices.

4.2 R&D cooperation

The firms now determine both their R&D expenditures in the first stage and their disclosure rates in the second stage so as to maximize their joint profits, $\Pi = \pi_1 + \pi_2$, determining their prices in the final stage. This subsection is the counterpart of Subsection 3.2. In order for the second stage equilibrium to have interior solutions, both $\partial\Pi/\partial\beta_i = 0$ and $\partial^2\Pi/\partial\beta_i^2 < 0$ must be satisfied. However, instead of these conditions we get the following results:

17 The conditions for the equilibrium in R&D space to be stable are

$$\left(\frac{\partial^2\pi_i}{\partial x_i^2}\right)\left(\frac{\partial^2\pi_j}{\partial x_j^2}\right) - \left(\frac{\partial^2\pi_i}{\partial x_j\,\partial x_i}\right)\left(\frac{\partial^2\pi_j}{\partial x_i\,\partial x_j}\right) > 0,\ \ i \neq j.$$

$$\frac{\partial \Pi}{\partial \beta_i} = \frac{\partial \pi_i}{\partial \beta_i} + \frac{\partial \pi_j}{\partial \beta_i} = \frac{2\delta\left[(2\delta^2 - \varepsilon^2)x_j - \delta\varepsilon x_i\right]}{(4\delta^2 - \varepsilon^2)^2} H > \left(\begin{smallmatrix}\leq\\=\\>\end{smallmatrix}\right) 0 \qquad \text{for } \varepsilon < (>)\ 0 \tag{14}$$

$$\frac{\partial^2 \Pi}{\partial \beta_i^2} = \frac{\partial^2 \pi_i}{\partial \beta_i^2} + \frac{\partial^2 \pi_j}{\partial \beta_i^2} > 0, \quad i \neq j,$$

where $H = \left[\alpha(2\delta + \varepsilon) - (2\delta^2 - \varepsilon^2)c_i + \delta\varepsilon c_j)\right]$. In the case of $\varepsilon < 0$ there apparently exist corner solutions such as $\hat{\beta} = 1$, because the model is symmetric. In the case of $\varepsilon > 0$, $\partial\Pi/\partial\beta_i > 0$ is derived, so that $\hat{\beta}_i = 1$[18]. Thus the joint profits are an increasing function of the R&D disclosure rates in any case, so the (sub) optimal rates are $\hat{\beta}\,(= \hat{\beta}_i) = 1$. As in the previous section, the optimal choice as to disclosure is to share all amount of its knowledge on R&D activities to the other. In doing so, their joint profits are maximized. Thus, in both cases of $e > 0$ and $e < 0$, RJV cartelization in terms of the taxonomy of Kamien et al. (1992) is unconsciously yielded. These results also provide some theoretical basis for the reason why firms form RJVs in the presence of price competition as well as in the presence of quantity one.

Using the first–order conditions as to R&D investment, we have the equilibrium profits under R&D cooperation[19]:

$$\hat{\pi}^{BC} = \frac{\gamma x^2}{16\delta(\delta - \varepsilon)^2}\left[\gamma(2\delta - \varepsilon)^2 - 8\delta(\delta - \varepsilon)^2\right].$$

Under the symmetric subgame–perfect Nash equilibrium the amount of R&D investment is given by solving the first–order conditions:

$$\hat{x}^{BC} = \hat{x}_1^{BC} = \hat{x}_2^{BC} = \frac{4\delta(\delta - \varepsilon)\left[\alpha - A(\delta - \varepsilon)\right]}{\gamma(2\delta - \varepsilon)^2 - 8\delta(\delta - \varepsilon)^2}.$$

These are the solutions under the R&D cartel. The cartel is also internally stable as in case CC.

When we express $\hat{x}^B$ and $\hat{x}^{BC}$ by a, b, and e in place of α, δ, and ε and make a comparison between non–cooperative R&D and cooperative R&D investments, the following results are derived. If the cross–price effects are positive, i.e. $e > 0$, then $\hat{x}^{BC} > \hat{x}^B$ holds. The intuition behind this result is straightforward. This is because

18 If the symmetric equilibrium is not assumed, then it is not clear whether the optimal disclosure rate of firm i is unity, i.e. $\hat{\beta}_i = 1$.

19 The first–order conditions for maximization of the joint profits are

$$\frac{\partial \Pi}{\partial x_i} = \frac{\partial \pi_i}{\partial x_i} + \frac{\partial \pi_j}{\partial x_i} = \frac{2\delta}{(4\delta^2 - \varepsilon^2)^2}\left[\alpha(2\delta + \varepsilon) - (2\delta^2 - \varepsilon^2)c_i + \delta\varepsilon c_j\right]\left[(2\delta^2 - \varepsilon^2) - \delta\varepsilon\hat{\beta}\right] - \gamma x_i$$

$$+ \frac{2\delta}{(4\delta^2 - \varepsilon^2)^2}\left[\alpha(2\delta + \varepsilon) - (2\delta^2 - \varepsilon^2)c_j + \delta\varepsilon c_i\right]\left[\hat{\beta}(2\delta^2 - \varepsilon^2) - \delta\varepsilon\right] = 0, \quad i \neq j.$$

Furthermore, we assume that the second–order and stability conditions are all satisfied.

a reduction in production costs exceeds that in price when R&D cartels are organized. On the other hand, if the effects are negative, then $\hat{x}^{BC} > \hat{x}^{B}$ as long as $b - e/3 < \sqrt{11}/3\sqrt{2} \fallingdotseq 0.782$, and $\hat{x}^{BC} < \hat{x}^{B}$ as long as $b - e/3 > \sqrt{11}/3\sqrt{2} \fallingdotseq 0.782$. The condition of $b - e/3 < 0.782$ means that the difference between the own price and cross–price effects is relatively small, in short the price elasticity of demand is large. Therefore, if the own price effects are not small, then there will be few combinations of (b, e) to satisfy inequality $b - e/3 < 0.782$. In contrast, there will be a lot of such combinations to satisfy $b - e/3 > 0.782$. Thus R&D cooperation typically has the effect to diminish R&D investment. If firms can cooperate on R&D, then they choose to keep their R&D investments at a moderate level rather than increase R&D investments uselessly, because increases in the investments lower prices and profits. This result is obviously different from the result in the Cournot–quantity setting model in which products are complements.

By substituting $\hat{x}^{BC}$ into (12), we obtain the equilibrium prices

$$\hat{p}^{BC} = \hat{p}_1^{BC} = \hat{p}_2^{BC} = \frac{\gamma(\alpha + A\delta) - 8\alpha(\delta - \varepsilon)}{\gamma(2\delta - \varepsilon)^2 - 8\delta(\delta - \varepsilon)^2}.$$

We now turn to welfare comparisons. Prices are decreasing functions of R&D investment, as shown in (12). Hence, if $e > 0$, then we have $\hat{p}^{B} > \hat{p}^{BC}$ because $\hat{x}^{BC}$ is larger than $\hat{x}^{B}$. On the other hand, if $e < 0$, then the following results are obtained by the direct comparison of $\hat{p}^{B}$ and $\hat{p}^{BC}$, that is, we have $\hat{p}^{B} < \hat{p}^{BC}$ as long as $b - e/3 < 0.782$ (i.e. the price elasticity of demand is large), so that consumer's surplus decreases by R&D cooperation; and in contrast we have $\hat{p}^{B} > \hat{p}^{BC}$ as long as $b - e/3 > 0.782$. Consumer's surplus increases by R&D cooperation as long as $e > 0$, and, moreover, $e < 0$ and $b - e/3 > 0.782$ [20]. We find that cartelization in R&D activities is typically beneficial to consumers. We also get the following result with respect to producer's surplus: $\hat{\pi}^{BC} > \hat{\pi}^{B}$. In particular, as long as products are complements in terms of Bertrand competition and the price elasticity of demand is small, R&D cooperation, not R&D competition, leads to a rise in welfare. This is the same as the result obtained in the Cournot–quantity setting model.

5. A Comparison between Cournot and Bertrand competition

We compare and rank R&D investments, prices, and profits among four modes yielded by combining one of two types of competition, Cournot and Bertrand, and one of two types of R&D organization, competition and cooperation, e.g. C, CC, B, and BC.

5.1 Comparison of R&D investments

First, we compare both R&D investments, $\hat{x}^{C}$ and $\hat{x}^{B}$, under R&D competition. Then we have

20 Given $e > 0$, the optimal disclosure rates are zero in the presence of R&D competition. So the cost per unit is $A - x$. In this case we obtain that $\hat{x}^{B} < \hat{x}^{BC}$ as long as $\delta > (1 + \sqrt{3})\varepsilon$. Those in the presence of R&D cooperation are unity, so that the cost is $A - 2x$. When taking account of this result and calculating, we have that $\hat{x}^{B} < \hat{x}^{BC}$.

$$\hat{x}^{C} > \hat{x}^{B} \quad \text{for } e > 0$$
$$\hat{x}^{C} < \hat{x}^{B} \quad \text{for } e < 0. \tag{15}$$

These results show that R&D investment is larger (smaller) in the Cournot–quantity setting model than in the Bertrand–price setting model if products are substitutes (complements) in terms of Cournot competition, i.e. $e > (<)\ 0$. See the Appendix for the derivation of (15).

Let us proceed to the comparison of both R&D investments under R&D cooperation. Consequently, we have

$$\hat{x}^{CC} > \hat{x}^{BC} \quad \text{for } e > 0$$
$$\hat{x}^{CC} < \hat{x}^{BC} \quad \text{for } e < 0. \tag{16}$$

When the firms coordinate their R&D expenditures, whether $\hat{x}^{CC}$ is larger or smaller than $\hat{x}^{BC}$ depends on the type of product, as shown above. See the Appendix for the derivation of (16). We find from (15) and (16) that firms facing Cournot competition invest in more (less) R&D than firms facing Bertrand competition when the cross–price effects are positive (negative), irrespective of whether the firms cooperate on their R&D decisions. This is due to the fact that products are reduced to substitutes under Cournot competition or Bertrand competition when the effects are positive or negative, respectively.

Let us, moreover, compare R&D levels among the four modes. When arranging the results concerning R&D investment in the previous sections, (15) and (16), we obtain

$$\hat{x}^{CC} > \hat{x}^{BC} > \hat{x}^{B} \text{ and } \hat{x}^{CC} > \hat{x}^{C} > \hat{x}^{B} \quad \text{for } e > 0.$$

The largest R&D investment level among the four modes is attained in case CC in which firms engage in Cournot competition in the third stage and choose their R&D investments cooperatively in the first stage. In contrast, given $e < 0$, we obtain

$$\hat{x}^{B} > \hat{x}^{BC} > \hat{x}^{CC} > \hat{x}^{C} \quad \text{for } b - e/3 > 0.782$$
$$\hat{x}^{BC} > \hat{x}^{CC} > \hat{x}^{C} \text{ or } \hat{x}^{BC} > \hat{x}^{B} > \hat{x}^{C} \quad \text{for } b - e/3 < 0.782. \tag{17}$$

The largest R&D level may be attained in case B in which firms engage in Bertrand competition in the third stage and choose their R&D investments non–cooperatively in the first stage[21]. What is of interest is that the ranking of $\hat{x}^{B}$ and $\hat{x}^{BC}$ is changed by the magnitude of $b - e/3$. Although these results are derived under the assumption that the inverse demand functions are symmetric, the same results will also hold even if this

21 Strictly speaking, if $b - e/3 < 0.782$, then the R&D investment level is the largest among the four cases when Bertrand–price setting firms form cartels on R&D. However, this case seldom takes place.

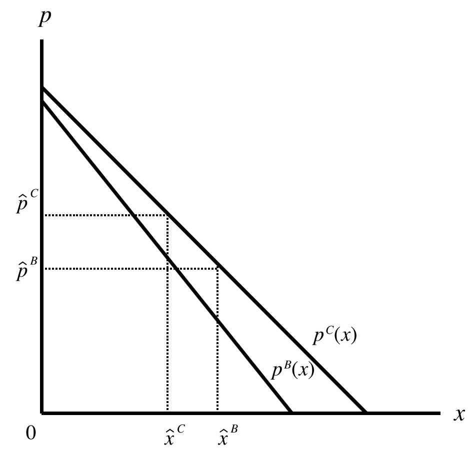

Figure 4 Cournot Price and Bertand Price Curves

assumption is loosened.

5.2 Comparison of prices

Each of output prices p^C and p^B under both Cournot and Bertrand competition is a decreasing function of R&D investment. In order to compare these prices in the presence of R&D competition we use the price functions such as $p^C = p^C(x)$ and $p^B = p^B(x)$, where $p^C(x) = [ab + A(b+e) - (1+\hat{\beta})x]/(2b+e)$ and $p^B(x) = [a(b-e) + Ab - (1+\hat{\beta})x]/(2b-e)$. As illustrated in Figure 4, price curve $p^C(x)$ under Cournot competition is always above $p^B(x)$ under Bertrand competition for any R&D investment, that is $p^C(x) > p^B(x)$ for any x.

First, we make a comparison between Cournot and Bertrand prices under R&D competition. Taking the result of (15) into consideration and the relationship between the two prices, we have

$$\hat{p}^C \lesseqgtr \hat{p}^B \qquad \text{for } e > 0$$

$$\hat{p}^C > \hat{p}^B \qquad \text{for } e < 0.$$

For example, the second result is illustrated in Figure 4. As for output we straightforwardly obtain that $\hat{q}^C \lesseqgtr \hat{q}^B$ for $e > 0$ and $\hat{q}^C < \hat{q}^B$ for $e < 0$. If the cross–price effects are negative, then competition is fiercer in the Bertrand–price setting model than in the Cournot–quantity setting model, so that the price is lower in the former. In contrast, when the effects are positive, output under Cournot competition might exceed output under Bertrand competition. As well known, if there is no strategic R&D investment, prices are higher under Cournot competition than under Bertrand competition. The conventional result is the same as that in the case of $e < 0$, but apparently different from that in the case of $e > 0$. This difference will be due to the fact that the existence of strategic R&D investment leads to more increased output under Cournot competition than under Bertrand competition as long as $e > 0$. Incidentally, consumer's surplus is obviously larger in the Cournot–quantity setting model than in the Bertrand–price setting model whenever the cross–price effects are negative.

We find from (15) and (16) that the same results as under R&D competition hold under R&D cooperation as well: that is, $\hat{p}^{CC} \lesseqgtr \hat{p}^{BC}$ for $e > 0$, and $\hat{p}^{CC} > \hat{p}^{BC}$ for $e > 0$. Furthermore, putting results (17) and the relationship between p^C and p^B together, the following results are derived:

if $e < 0$,

$$\hat{p}^B < \hat{p}^{BC} < \hat{p}^{CC} < \hat{p}^C \qquad \text{for } b - e/3 > 0.782$$

$$\hat{p}^{BC} < \hat{p}^{CC} < \hat{p}^C \text{ or } \hat{p}^{BC} < \hat{p}^B < \hat{p}^C \qquad \text{for } b - e/3 < 0.782.$$

As long as the cross–price effects are negative, and, moreover, the price elasticity of demand is relatively small, namely $b - e/3 > 0.782$ holds, then the price in the absence of R&D cooperation under Bertrand competition is the lowest among the four modes, and the price in the absence of R&D cooperation under Cournot competition is the highest. Thus consumer's surplus is maximized in case B and is minimized in case C. The results above show that R&D cartelization leads to a rise in price under Bertrand competition and, conversely, to a reduction in it under Cournot competition. In the case of $b - e/3 < 0.782$, which is the less common case in comparison with the other case, the price in the presence of R&D cooperation under Bertrand competition is the lowest among the four modes. Thus consumer's surplus is maximized in case BC. The ranking of $\hat{p}^B$ and $\hat{p}^{BC}$ is reversed according to whether the magnitude of $(b - e/3)$ is less or greater than 0.782. This change is intuitively explained as follows. For example, when the price elasticity of demand gets relatively small, firms have incentives to increase their outputs, so that prices lower. R&D cartelization leads to a reduction in price under Bertrand competition as well as under Cournot competition. When the cross–price effects are positive, there does not exist the perfect correspondence between R&D levels and prices, as shown above.

5.3 Comparison of profits

From the comparison of profits we have

$$\hat{\pi}^{CC} > \hat{\pi}^{BC} \qquad \text{for } e > 0$$
$$\hat{\pi}^{CC} < \hat{\pi}^{BC} \qquad \text{for } e < 0. \tag{18}$$

See the Appendix about the derivation of these results. Whether profits under R&D cooperation are greater in the Cournot–quantity setting model than in the Bertrand–price setting model depends only on the sign of e as in the comparison of the R&D investments: that is, producer's surplus in the former model thus exceeds (falls short of) that in the latter model whenever products are substitutes (complements). In contrast, it is impossible to make a comparison between profits under Cournot and Bertrand competition in the presence of R&D competition, i.e. $\hat{\pi}^C \lesseqgtr \hat{\pi}^B$.

Now, taking account of the previous results concerning price, we obtain the following result: namely, welfare is higher under Cournot competition than under Bertrand competition whenever the cross–price effects are negative and firms cooperatively choose their R&D. Moreover, both consumer's and producer's surpluses are increased by the formation of R&D cartels, and this result does not rely on whether firms engage in Cournot or Bertrand competition in product markets.

We turn to profit comparisons among the four modes. Putting the previous results together, we obtain the following results:

if $e > 0$,

$$\hat{\pi}^{CC} > \hat{\pi}^{BC} > \hat{\pi}^{B} \text{ and } \hat{\pi}^{CC} > \hat{\pi}^{C} \qquad \text{for } \gamma > 6b^2/(2b+e)^2\left[(2b-e)(b-e)+b^2\right]$$

$$\hat{\pi}^{C} > \hat{\pi}^{CC} > \hat{\pi}^{BC} > \hat{\pi}^{B} \qquad \text{for } \gamma < 6b^2/(2b+e)^2\left[(2b-e)(b-e)+b^2\right];$$

and

if $e < 0$,

$$\hat{\pi}^{BC} > \hat{\pi}^{CC} > \hat{\pi}^{C} \text{ and } \hat{\pi}^{BC} > \hat{\pi}^{B}.$$

As mentioned above, when the cross–price effects are positive, the highest profits are attained in the presence of R&D cooperation (competition) under Cournot competition if the curvature, γ, of the R&D expenditure function is comparatively large (small), that is, if the marginal costs of R&D investment increase rapidly (slowly). Then producer's surplus is maximized in the presence of R&D cooperation under Cournot competition as long as its marginal costs rapidly increase, and maximized in the presence of R&D competition under Cournot competition as long as the marginal costs slowly increase. On the other hand, when the effects are negative, the highest profits are attained in the presence of R&D cooperation under Bertrand competition, and then producer's surplus is maximized. On the whole, if firms form an R&D cartel, then this tends to give more profits to them in comparison with the case without it. From the outcomes as to consumer's surplus and producer's surplus we find that welfare in the presence of R&D cooperation under Bertrand competition is the highest among the four modes as long as both the cross–price effects are negative and the price elasticity of demand is great, i.e. $b - e/3 < 0.782$.

6. Summary

We have extended the Poyago–Theotoky (1999) model of three–stage games in two directions: one is to employ more general inverse demand functions more than her model; and the other is to consider the behavior of firms in Bertrand's model of price–setting oligopoly as well as in Cournot's model of quantity–setting oligopoly. These extensions are related only with the final stage of the three–stage game models, and the other two stages are the same as her model. We have derived several results. First, both optimal disclosure strategies of quantity–setting and price–setting firms are the same in the presence of R&D competition, and their strategies are dependent on whether R&D investments are strategic substitutes or strategic complements. For example, the firms withhold (disclose) their information about R&D activities if they are strategic substitutes (complements). We thus find that what determines the disclosure strategies of firms is ultimately dependent on the cross–price effects in inverse demand functions in both Cournot–quantity setting and Bertrand–price setting models. Namely, their strategies deeply relate to the slopes of the R&D reaction curves, not those of the output reaction curves.

Second, when cooperating in investing in R&D, they will make their R&D outcomes public not only under Cournot competition but also under Bertrand competition. It is concluded that the disclosure strategy of the firm in the presence of R&D cooperation and R&D competition depends only on the cross–price effects in inverse demand functions. It is of great interest that both R&D cooperation in the R&D stage and a difference in the type of market competition between firms never influence on their strategies. Firms have the incentives to share their R&D information each other even if products are substitutes under Bertrand competition.

R&D cooperation always leads to RJVs in R&D, i.e. RJV cartelization in terms of Kamien et al. (1992). Moreover, if the cross–price effects are negative, then RJVs are also formed in the presence of R&D competition, irrespective of whether firms engage in Cournot or Bertrand competition. More interestingly, this is obtained even if each of them chooses its R&D expenditure so as to selfishly maximize its own profits. Then this shows that it is not always necessary for governments to support the establishment of RJVs in R&D.

Poyago–Theotoky (1999) makes a comparison between R&D investments, prices and profits in both R&D competition and R&D cooperation under Cournot competition. Her results concerning R&D investment and price hold in more general inverse demand functions as well, however her result concerning profit is invalid. Our results can be, moreover, extended as follows. Even if firms with the intention of disclosing R&D information make a claim for a reward for their disclosure, our results also hold if the level of the reward is not great.

We have compared market performances among the four modes. Generally, prices are lower under Bertrand competition than under Cournot competition when the cross–price effects are negative. Alternatively, if the price elasticity of demand is small, then the price in the presence of R&D competition under Bertrand competition is the lowest among the four modes, while if the elasticity is great, then the price in the presence of R&D cooperation under Bertrand competition is the lowest. This result has some policy implications. For example, in order to raise consumer's surplus the government needs to take policies to deter or promote R&D cartelization according as the elasticity is small or large. This shows that it is not optimal to prohibit firms from forming R&D cartels from the viewpoint of that surplus. When the cross–price effects are positive, prices might be lower under Cournot competition than under Bertrand competition. It is, however, ambiguous whether disclosure of R&D information has advantageous effects on consumers. Consequently, it appears that the effects of disclosure on prices are not typically so great.

When the cross–price effects are positive, the profits in the presence (absence) of R&D cartelization under quantity competition are the largest among the four modes if the marginal costs of R&D investment increase rapidly (slowly). In contrast, when these effects are negative, the largest profits are attained in the presence of R &D cartelization under price competition. Thus the level of producer's surplus totally depends on both the signs of the cross–price effects and rates of increase in the investment costs. These reveal that it is not always profitable for firms to form R&D cartels in the R&D stage. Moreover, the effect of disclosure on firms' profits does not seem to be great. The form of the R&D expenditure function may have important effects on firms' profits rather than disclosure of information.

When the effects are negative and, moreover, the price elasticity of demand is large, welfare under Bertrand competition is raised up to the highest level among the four modes by R&D cartelization. But, on the whole, the formation of them tends to yield larger profits to producers than consumers.

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Appendix

The derivation of (15):

To compare R&D investments we first change parameters, α, δ, ε, in $\hat{x}^B$ into a, b, and c. After calculation it is obtained that

$$\hat{x}^C - \hat{x}^B = \frac{\gamma(4b^2 - e^2)e^3}{\left[\gamma(4b^2 - e^2)(2b + e) - 4b^2\right]\left[\gamma(4b^2 - e^2)(2b - e)(b + e) - 2b(2b^2 - e^2)\right]} \qquad \text{for } e > 0$$

and

$$\hat{x}^{C} - \hat{x}^{B} = \frac{2\gamma e^{3}}{\left[\gamma(2b+e)^{2} - 4b\right]\left[\gamma(2b-e)^{2}(b+e)^{2} - 4b(b^{2}-e^{2})\right]} \qquad \text{for } e < 0.$$

The derivation of (16):

Similarly, we obtain a difference between $\hat{x}^{CC}$ and $\hat{x}^{BC}$:

$$\hat{x}^{CC} - \hat{x}^{BC} = \frac{8b\gamma e^{3}(a-A)}{\left[\gamma(2b+e)^{2} - 8b\right]\left[\gamma(2b-e)^{2}(b+e)^{2} - 8b(b^{2}-e^{2})\right]}.$$

The derivation of (18):

Profits $\hat{\pi}^{BC}$ are rewritten as

$$\hat{\pi}^{BC} = \frac{b\gamma(a-A)^{2}(b-e)}{\gamma(2b-e)^{2}(b+e) - 8b(b-e)}.$$

Then we get a difference between $\hat{\pi}^{CC}$ and $\hat{\pi}^{BC}$:

$$\hat{\pi}^{CC} - \hat{\pi}^{BC} = \frac{2b\gamma e^{3}(a-A)^{2}}{\left[\gamma(2b+e)^{2} - 8b\right]\left[\gamma(2b-e)^{2}(b+e) - 8b(b-e)\right]}.$$

Disclosure Policy, and Competition and Cartelization in R&D: Cournot and Bertrand Competition

Shoji Haruna

This paper considers whether firms have incentives to disclose their R&D information to their rivals in Cournot–quantity setting and Bertrand–price setting models. Furthermore, we compare market performances, e. g. R&D investments, prices and profits, in these models. It is shown that whether they have such incentives depends only on the signs of cross–price effects in demand functions, irrespective of the type of competition, e. g. Cournot or Bertrand competition. When making comparisons of them among four modes, we find that the formation of R&D cartels tends to increase the expenditure of R&D investment and then gains more profits. Alternatively, we point out that quantity–setting firms gain more profits in the presence of R&D cooperation than in the absence of it when products are substitutes in terms of Cournot competition.