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Research Joint Ventures and Cartels in International Product R&D

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Abstract

Purpose – This paper analyzes how Research and Development (R&D) cartelization and Research Joint Ventures (RJV) affect firms that engage in Cournot competition in their product market using a model in which the Home and Foreign firm produce differentiated products and export their total output to a third country's market.
Design/Methodology - In a two-stage game, research expenditures incurred in the first stage improve product quality and are subject to various degrees of spillovers. We consider four different scenarios.
Findings - In a symmetric equilibrium we observe the following: (i) an RJV that cooperates in R&D decision yields the highest R&D expenditure. However, the scenario which yields the lowest expenditure depends on the extent of differentiation between the goods and the degree of spillovers; (ii) RJV cartelization yields the highest product quality, output, and consumer surplus in the third country; however, the lowest is produced by R&D competition if spillovers are strong and by R&D cartelization if spillovers are weak; and (iii) each firm's profit is at its minimum in R&D competition and its maximum in RJV cartelization. Furthermore, if spillovers are strong, the profit of each firm in R&D cartelization is greater than that in RJV competition, and vice versa.
Originality/value - By analyzing product innovation in international markets, we can find similarities and differences between process R&D and product R&D in international markets.

Keywords: Cartel, Cournot Competition, Product R&D, R&D Competition, Research Joint Venture
JEL Classifications: D43, F12, L13

1. Introduction

Since on a stand-alone basis, a firm lacks resources to invest in the development of new technologies, it is common for firms to cooperate in their R&D investments across the industries. This is done through a consortium or the exchange of information between firms. Thus, the R&D investment of one firm causes a spillover for the other firms in the industry. RJV is a form of cooperation which allows for a mutual exchange of information which may help avoid duplication of investment costs. On the other hand, there is a risk that the participating firms free ride on each other and thus weaken competition.

An interesting work by Kamien, Muller and Zang (1992) focuses on process innovation and analyzes the effects of RJV and R&D cartelization on firms that participate in either quantity or price competition in their product market. They found that the effective R&D expenditure is at its minimum in a competitive RJV and at its maximum in RJV cartelization. Thus, technological improvement is minimized in RJV competition and maximized in a RJV cartel. They also show that the equilibrium consumer plus producer surplus under quantity competition is the highest in RJV cartelization.

However, since product R&D is more common than process R&D, it seems that studying the effects of RJV and R&D cartelization in product innovation is more valuable.[1] Moreover, since firms often compete in international markets, it is worth analyzing product innovation

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in international markets. The study aims to check and compare the effects of RJV and cartelization on the equilibrium levels of R&D expenditure, product quality, output, price, consumer surplus, and firm profit in an international duopoly market. For the analysis, we extend previous works by Symeonidis (2003) and construct models which consist of two stages.[2] Here, the firms from different countries produce differentiated products and export their total output to a third country's market. In the first stage, there are four alternative scenarios: the firms compete on product R&D expenditure or form a R&D cartel or form a competitive RJV or form a R&D cartel and an RJV. In the second stage, they compete in a Cournot fashion. In the model, R&D investment of a firm increases the other firm's product quality through a spillover effect as well as its own product quality. Thus, it makes the other firm a tougher competitor.

The principal results are as follows. First, an RJV that cooperates in its R&D decision yields the highest R&D expenditure, but assessing the scenario yielding the lowest expenditure would depend on the extent of differentiation between goods and the degree of spillovers. Second, RJV cartelization yields the highest product quality, output, and consumer surplus in the third country; however, the lowest is produced by R&D competition if spillovers are strong and R&D cartelization if spillovers are weak. Third, the firms' profits are lowest in R&D competition and highest in RJV cartelization. Furthermore, if spillovers are strong, each firm's profit in R&D cartelization is greater than that in RJV competition, and vice versa.

The paper proceeds as follows. In Section Ⅱ, we introduce the basic model and show how R&D expenditures are linked to product quality. In Section Ⅲ, we consider four different scenarios of R&D in the first stage with the same second stage and derive equilibrium levels of R&D expenditure, product quality, output, price, consumer surplus, and firm profit in all cases. In Section Ⅳ, we compare the variables derived in the four cases. Section Ⅴ presents the conclusion.

2. The Basic Model[3]

We consider an international duopoly where both the Home and Foreign firm produce one type of differentiated product which is consumed by a large group of consumers. Firms invest in R&D to improve product quality. A two-stage game is considered. In the first stage, each firm selects a quality, denoted by u, which is represented by either some physical characteristic or a brand image. Investment in product R&D by a firm enhances the product quality which in turn raises the consumers' willingness to pay for the value-added product. However, this comes at a cost. Quantity competition occurs in the second stage.

We assume that S identical consumers reside in a third country.[4] The representative consumer has the following utility function:

$$U(x, y, z) = x + y - \frac{x^2}{u_x^2} - \frac{y^2}{u_y^2} - \gamma \frac{x}{u_x}\frac{y}{u_y} + z \cdot \tag{1}$$

It is a quality-augmented version of the standard quadratic utility function, proposed by

[1] See Scherer and Ross (1990).

[2] Symeonidis (2003) analyzes and compares quantity and price competition in a duopoly model with differentiated products and product R&D. With the degree of product differentiation and R&D spillovers, R&D expenditure (hence, also product quality), output, price, consumer surplus, a firm's profit, and total welfare are examined and compared in two different types of competition.

[3] The notation used in this paper follows the one by Yang Il-Seok (2018).

[4] This type of model is often used in the literature of international trade after Brander and Spencer (1983).

Sutton (1997/1998).[5] Good x is produced by the Home firm in the Home country and good y is produced by the Foreign firm in the Foreign country. The quality of good x and good y are u_x and u_y, respectively, and money spent on outside goods is denoted by $z=M-p_x x-p_y y$. We assume that consumers spend a fraction of their total income on the products such that income effects on the industry are ignored.[6] The parameter $\gamma \in (0,2)$ is a measure of the degree of horizontal differentiation between the goods: in the limit as $\gamma \to 0$ the goods become independent, whereas in the limit as $\gamma \to 2$ they become perfect substitutes when $u_x = u_y$.

p_y and p_x are represented as the prices of good y and good x, respectively. When we maximize the utility subject to $z=M-p_x x-p_y y$, we derive the inverse demand functions of the representative consumer for goods x and y:

$$p_x = 1 - \frac{2x}{u_x^2} - \frac{\gamma}{u_x}\frac{y}{u_y} \tag{2}$$

$$p_y = 1 - \frac{2y}{u_y^2} - \frac{\gamma}{u_y}\frac{x}{u_x}. \tag{3}$$

We can also derive direct demand functions as

$$x = \frac{u_x\left[2u_x(1-p_x) - \gamma u_y(1-p_y)\right]}{(2-\gamma)(2+\gamma)} \tag{4}$$

$$y = \frac{u_y\left[2u_y(1-p_y) - \gamma u_x(1-p_x)\right]}{(2-\gamma)(2+\gamma)}. \tag{5}$$

From the equations (4) and (5), we can see that x is decreasing in p_x and increasing in u_x and y is decreasing in p_y and increasing in u_y. Further, x is increasing in p_y and decreasing in u_y and y is increasing in p_x and decreasing in u_x. Since there are S identical consumers, the Home firm sells quantity Sx and the Foreign firm sells quantity Sy. Each firm has the constant marginal production cost which is equal to $c<1$.[7]

The functions associating quality u_x and u_y with the R&D expenditures R_x and R_y are a modified version of the one suggested by Motta (1992) and are as shown below:

$$u_x = \varepsilon R_x^{\frac{1}{4}} + \varepsilon\rho R_y^{\frac{1}{4}} \tag{6}$$

$$u_y = \varepsilon R_y^{\frac{1}{4}} + \varepsilon\rho R_x^{\frac{1}{4}}, \tag{7}$$

where $\varepsilon > 0$ is a measure of the efficiency of R&D and $\rho \in [0,1]$ denotes all possible degrees of technological R&D spillovers.[8] ε and ρ are industry-specific and exogenously determined by technology. From (6) and (7), we observe decreasing returns to R&D. We need this assumption for the second-order condition of an interior maximum to be satisfied in the R&D stage.

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[5] Symeonidis (1999/2000/2003) also used this function in his paper. Many papers use the standard quadratic utility function. For example, Singh and Vives (1984), Vives (1985) and Qiu (1997).

[6] It ensures an interior solution in maximizing the utility function.

[7] Due to the specific demand system, Symeonidis (2003) tests the robustness of his results with respect to an alternative quadratic utility model, going after Häckner (2000). The results from two models are very similar in the main body of the papers.

[8] Symeonidis (2003) also interprets ε as an index of technological opportunity in the industry or an inverse measure of the cost of R&D.

3. Equilibrium in Four Different Scenarios

In this section, we consider the four scenarios and compute a symmetric subgame-perfect equilibrium which is considered in pure strategies in the two-stage game. In the second stage of our games the Home firm and the Foreign firm are assumed to be in Cournot competition, however, they invest in product R&D in the first stage. Each firm's payoff is composed of the second-stage production profits less its first-stage product R&D expenditure. Research efforts are directed to improving the quality of the goods in the first stage. In our first two models the firms do not share the R&D outcomes, whereas in the other two they fully share the results of the R&D stage to avoid duplication of investment costs.

We now describe the four models. Since Cournot competition occurs in the second stage for all cases given the quality acquired in the first stage, each firm's profit maximization problem in the second stage is given as follows. Along with (2), the Home firm chooses x to maximize

$$\pi_h = S(p_x - c)x - R_x,$$

where the subscript h stands for the Home firm and the quantity and the price are all positive. Solving the Home firm's profit maximization problem yields the best response function for the Home firm as follows:

$$\frac{x}{u_x} = \frac{u_x(1-c)}{4} - \frac{\gamma y}{4u_y}. \tag{8}$$

In a similar way, along with (3), the Foreign firm chooses y to maximize

$$\pi_f = S(p_y - c)y - R_y,$$

where the subscript f represents the Foreign firm and the quantity and the price are all positive. Solving the Foreign firm's profit maximization problem yields the best response function for the Foreign firm as follows:

$$\frac{y}{u_y} = \frac{u_y(1-c)}{4} - \frac{\gamma x}{4u_x}.\text{[9]} \tag{9}$$

We can derive Cournot equilibrium quantity using (8) and (9) as follows:

$$x^e = \frac{u_x(4u_x - \gamma u_y)(1-c)}{(4-\gamma)(4+\gamma)} \tag{10}$$

$$y^e = \frac{u_y(4u_y - \gamma u_x)(1-c)}{(4-\gamma)(4+\gamma)}, \tag{11}$$

where the superscript e denotes equilibrium level in the second stage and x and y are both positive for $\frac{\gamma}{4} < \frac{u_x}{u_y} < \frac{4}{\gamma}$.[10]

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[9] The following second-order conditions for the Home firm and the Foreign firm are satisfied:
$-\frac{4S}{u_x^2} < 0$, $-\frac{4S}{u_y^2} < 0$.

[10] If $\frac{u_x}{u_y} > \frac{4}{\gamma}$, the Home firm would make a monopoly profit, $\pi_h^m = \frac{Su_x^2(1-c)^2}{8}$, and the sales of the

Using (10) and (11), the following prices and profit of each firm are calculated:

$$p_x^e = \frac{u_x\left[8+c(8-\gamma^2)\right]-2\gamma u_y(1-c)}{u_x(4-\gamma)(4+\gamma)} \tag{12}$$

$$p_y^e = \frac{u_y\left[8+c(8-\gamma^2)\right]-2\gamma u_x(1-c)}{u_y(4-\gamma)(4+\gamma)} \tag{13}$$

$$\pi_h^e = \frac{2S(4u_x-\gamma u_y)^2(1-c)^2}{(4-\gamma)^2(4+\gamma)^2} - R_x \tag{14}$$

$$\pi_f^e = \frac{2S(4u_y-\gamma u_x)^2(1-c)^2}{(4-\gamma)^2(4+\gamma)^2} - R_y \,. \tag{15}$$

3.1. R&D Competition (Case N)

In the first case, we consider that each firm chooses its own R&D level given the R&D investment of the other firm in the first stage. In this case, each firm simultaneously decides the level of R&D investment to maximize its own profit. The Home firm maximizes (14) with respect to R_x and the Foreign firm maximizes (15) with respect to R_y, along with (6) and (7). For both the Home and Foreign firm, the first-order conditions are derived by the following equations:

$$\frac{d\pi_h^e}{dR_x} = \frac{\partial \pi_h^e}{\partial u_x}\frac{\partial u_x}{\partial R_x} + \frac{\partial \pi_h^e}{\partial u_y}\frac{\partial u_y}{\partial R_x} - 1 = 0 \tag{16}$$

$$\frac{d\pi_f^e}{dR_y} = \frac{\partial \pi_f^e}{\partial u_y}\frac{\partial u_y}{\partial R_y} + \frac{\partial \pi_f^e}{\partial u_x}\frac{\partial u_x}{\partial R_y} - 1 = 0 \,. \tag{17}$$

Inserting for the expressions for the various partial derivatives into (16) and (17), setting $u_x = \varepsilon R_x^{\frac{1}{4}} + \varepsilon\rho R_y^{\frac{1}{4}}$ and $u_y = \varepsilon R_y^{\frac{1}{4}} + \varepsilon\rho R_x^{\frac{1}{4}}$, to solve for the symmetric equilibrium, we get the following equilibrium level of R&D expenditure and product quality:

$$R_x^N = R_y^N \equiv R^N = \frac{S^2\varepsilon^4(1+\rho)^2(4-\gamma\rho)^2(1-c)^4}{(4-\gamma)^2(4+\gamma)^4} \tag{18}$$

$$u_x^N = u_y^N \equiv u^N = \varepsilon(1+\rho)(R^N)^{\frac{1}{4}} = \frac{S^{\frac{1}{2}}\varepsilon^2(1+\rho)^{\frac{3}{2}}(4-\gamma\rho)^{\frac{1}{2}}(1-c)}{(4-\gamma)^{\frac{1}{2}}(4+\gamma)} \,, \tag{19}$$

where the superscript N stands for equilibrium level in R&D competition.[11]

Foreign firm would be zero; if $\frac{u_x}{u_y} < \frac{\gamma}{4}$, the Foreign firm would make a monopoly profit, $\pi_f^m = \frac{Su_y^2(1-c)^2}{8}$, and the sales of the Home firm would be zero. If $\gamma = 0$, the firms are monopolies in their own market segments, and each firm makes monopoly profit.

[11] The second-order conditions for an interior maximum at the symmetric equilibrium are denoted by $\frac{\partial^2 \pi_h^e}{\partial R_x^2} < 0$ and $\frac{\partial^2 \pi_f^e}{\partial R_y^2} < 0$ when they are evaluated at $u_x = u_y = u^N$. After some calculations, this gives $-\frac{S\varepsilon^2\left[(8-3\gamma)+2\rho(6-\gamma)\right](4-\gamma\rho)(1-c)^2}{4(R^N)^{\frac{3}{2}}(4-\gamma)^2(4+\gamma)^2} < 0$.

To calculate the equilibrium quantity and price, we set $u_x = u_y = u^N$ in (10), (11), (12), and (13). We derive the following equations:

$$x^N = y^N = \frac{(1-c)(u^N)^2}{4+\gamma} \tag{20}$$

$$p_x^N = p_y^N \equiv p^N = c + \frac{2(1-c)}{4+\gamma}. \tag{21}$$

3.2. R&D Cartelization (Case C)

In the second case, both the Home and Foreign firm coordinate their respective R&D decisions to maximize the sum of aggregate profit in the first stage. In other words, they form a R&D cartel. They choose a common level of R&D expenditure R^C to maximize the aggregate profit, which is denoted by $\pi^e = \pi_h^e + \pi_f^e$. The superscript C represents equilibrium level in R&D cartelization. Maximizing π^e with respect to R^C, along with (6) and (7), and solving for the symmetric equilibrium, we get the following equilibrium level of R&D expenditure and the product quality:

$$R_x^C = R_y^C \equiv R^C = \frac{S^2\varepsilon^4(1+\rho)^4(1-c)^4}{(4+\gamma)^4} \tag{22}$$

$$u_x^C = u_y^C \equiv u^C = \varepsilon(1+\rho)(R^C)^{\frac{1}{4}} = \frac{S^{\frac{1}{2}}\varepsilon^2(1+\rho)^2(1-c)}{(4+\gamma)}. \tag{23}$$ [12]

To compute the equilibrium quantity and price, we set $u_x = u_y = u^C$ in (10), (11), (12), and (13). We derive the following equations:

$$x^C = y^C = \frac{(1-c)(u^C)^2}{4+\gamma} \tag{24}$$

$$p_x^C = p_y^C \equiv p^C = c + \frac{2(1-c)}{4+\gamma}. \tag{25}$$

3.3. RJV Competition (Case NJ)

In the third case, each firm chooses its own R&D level given the R&D investment of the other firm, but they divide R&D efforts to avoid duplication of investment costs in the first stage. In other words, the firms form an RJV. Thus, the spillover rate is reached at its maximum level, $\rho = 1$. However, the firms do not coordinate their R&D expenditures and each firm simultaneously decides its R&D investment to maximize its own profit given the R&D expenditure of the other firm. For both the Home and Foreign firm, the first-order conditions are (16) and (17), respectively, with $\rho = 1$. Solving for the symmetric equilibrium yields the following equilibrium levels of R&D expenditure and product quality:

$$R_x^{NJ} = R_y^{NJ} \equiv R^{NJ} = \frac{4S^2\varepsilon^4(1-c)^4}{(4+\gamma)^4} \tag{26}$$

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[12] The second-order condition for an interior maximum at the symmetric equilibrium is denoted by $\frac{\partial^2\pi^e}{\partial(R^C)^2} < 0$ when evaluated at $u_x = u_y = u^C$. After some calculations, this gives $-\frac{S\varepsilon^2(1+\rho)^2(1-c)^2}{(R^C)^{\frac{3}{2}}(4+\gamma)^2} < 0$.

$$u_x^{NJ} = u_y^{NJ} \equiv u^{NJ} = 2\varepsilon(R^{NJ})^{\frac{1}{4}} = \frac{2\sqrt{2}S^{\frac{1}{2}}\varepsilon^2(1-c)}{(4+\gamma)}, \quad (27)$$

where the superscript *NJ* denotes equilibrium level in RJV competition.[13]

To calculate the equilibrium quantity and price, we set $u_x = u_y = u^{NJ}$ in (10), (11), (12), and (13). We derive the following equations:

$$x^{NJ} = y^{NJ} = \frac{(1-c)(u^{NJ})^2}{4+\gamma} \quad (28)$$

$$p_x^{NJ} = p_y^{NJ} \equiv p^{NJ} = c + \frac{2(1-c)}{4+\gamma}. \quad (29)$$

3.4. RJV Cartelization (Case CJ)

In the fourth case, both the Home and Foreign firm coordinate their R&D decisions to maximize the sum of aggregate profit and divide the R&D efforts to avoid duplication of the investment costs in the first stage. In other words, they form a R&D cartel and an RJV. Along with $\rho = 1$, they choose a common level of R&D expenditure R^{CJ} to maximize the aggregate profit, which is denoted by $\pi^e = \pi_h^e + \pi_f^e$. The superscript *CJ* stands for equilibrium level in RJV cartelization. Maximizing π^e with respect to R^{CJ}, along with (6), (7), $\rho = 1$ and solving for the symmetric equilibrium, we get the following equilibrium level of R&D expenditure and the product quality:

$$R_x^{CJ} = R_y^{CJ} \equiv R^{CJ} = \frac{16S^2\varepsilon^4(1-c)^4}{(4+\gamma)^4} \quad (30)$$

$$u_x^{CJ} = u_y^{CJ} \equiv u^{CJ} = 2\varepsilon(R^{CJ})^{\frac{1}{4}} = \frac{4S^{\frac{1}{2}}\varepsilon^2(1-c)}{(4+\gamma)}. \quad (31)$$
[14]

To compute the equilibrium quantity and price, we set $u_x = u_y = u^{CJ}$ in (10), (11), (12), and (13). We derive the following equations:

$$x^{CJ} = y^{CJ} = \frac{(1-c)(u^{CJ})^2}{4+\gamma} \quad (32)$$

$$p_x^{CJ} = p_y^{CJ} \equiv p^{CJ} = c + \frac{2(1-c)}{4+\gamma}. \quad (33)$$

Finally, the equilibrium consumer surplus in the third country and the equilibrium firm

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[13] The second-order conditions for an interior maximum at the symmetric equilibrium are denoted by $\frac{\partial^2 \pi_h^e}{\partial R_x^2} < 0$ and $\frac{\partial^2 \pi_f^e}{\partial R_y^2} < 0$ when $\rho = 1$ and they are evaluated at $u_x = u_y = u^{NJ}$. After some calculations, this gives $-\frac{5S\varepsilon^2(1-c)^2}{4(R^{NJ})^{\frac{3}{2}}(4+\gamma)^2} < 0$.

[14] The second-order condition for an interior maximum at the symmetric equilibrium is denoted by $\frac{\partial^2 \pi^e}{\partial (R^{CJ})^2} < 0$ when evaluated at $u_x = u_y = u^C$. After some calculations, this gives $-\frac{4S\varepsilon^2(1-c)^2}{(R^{CJ})^{\frac{3}{2}}(4+\gamma)^2} < 0$.

profit in the four scenarios are as follows:

$$CS^i = S\left(x^i + y^i - \frac{(x^i)^2}{(u^i)^2} - \frac{(y^i)^2}{(u^i)^2} - \gamma\frac{x^i y^i}{(u^i)^2}\right) - Sp^i x^i - Sp^i y^i,\ i = N, C, NJ, CJ \tag{34}$$

$$\pi_h^i = S(p^i - c)x^i - \frac{(u^i)^4}{\varepsilon^4(1+\rho)^4},\ i = N, C \tag{35}$$

$$\pi_h^i = S(p^i - c)x^i - \frac{(u^i)^4}{16\varepsilon^4},\ i = NJ, CJ \tag{36}$$

$$\pi_f^i = S(p^i - c)y^i - \frac{(u^i)^4}{\varepsilon^4(1+\rho)^4},\ i = N, C \tag{37}$$

$$\pi_f^i = S(p^i - c)y^i - \frac{(u^i)^4}{16\varepsilon^4},\ i = NJ, CJ, \tag{38}$$

where $\pi_h^i = \pi_f^i$, $i = N, C, NJ, CJ$ by symmetry.

4. Comparison of Models

Comparison of R&D expenditures across the four scenarios yields the following proposition:

Proposition 1. (i) The equilibrium R&D expenditures satisfy the following for all ρ: $R^{CJ} > R^i$, $i = N, NJ$, and $R^{CJ} \geq R^C$ (equality holds if and only if $\rho = 1$). (ii) $R^{CJ} \geq R^C > R^{NJ}$ if $\rho > \sqrt{2}-1$ and $R^{CJ} > R^{NJ} > R^C$ if $\rho < \sqrt{2}-1$. (iii) $R^{NJ} \geq R^N$ if γ is sufficiently small (equality holds only if $\rho = 1$) and $R^{NJ} \leq R^N$ if γ and ρ are sufficiently large (equality holds only if $\rho = 1$). (iv) $R^C > R^N$ if ρ is sufficiently large, or γ is quite small except $\rho = 0$ and $R^C < R^N$ if ρ is sufficiently small, or γ is sufficiently large and ρ is quite small.

Proof. (i) Cases CJ and NJ. - $R^{CJ} > R^{NJ}$. (ii) Cases CJ and C. - $R^{CJ} \geq R^C$ (equality holds only if $\rho = 1$). (iii) Cases C and NJ. - $R^C > R^{NJ}$ if $\rho < \sqrt{2}-1$ and $R^C < R^{NJ}$ if $\rho < \sqrt{2}-1$. (iv) Cases NJ and N. - $R^{NJ} - R^N = \dfrac{S^2\varepsilon^4(1-c)^4\left[4(4-\gamma)^2 - (1+\rho)^2(4-\gamma\rho)^2\right]}{(4-\gamma)^2(4+\gamma)^4}$. The sign of the term in the brackets is equal to the sign of this equation. The term, denoted by *A*, can be positive or negative and it's sign depends on the values of γ and ρ for a range of pairs (γ, ρ). On the one hand, we have $A(\rho = 0, \gamma = 0) = 48 > 0$, $A(\rho = 1, \gamma = 0) = 0$, and $A(0 < \rho < 1, \gamma = 0) = 16\left[4 - (1+\rho)^2\right] > 0$. Supposing continuity, if γ is sufficiently small, we have $A \geq 0$ (equality holds only if $\rho = 1$), and hence, $R^{NJ} \geq R^N$. On the other hand, $A(\rho = 0, \gamma = 2) = 0$, $A(\rho = 1, \gamma = 2) = 0$, $A(0 < \rho < 1, \gamma = 2) = 16 - 4(1+\rho)^2(2-\rho)^2 < 0$. Moreover, $\dfrac{\partial A}{\partial \gamma} = -2\left[4(4-\gamma) - \rho(1+\rho)^2(4-\gamma\rho)\right] \leq 0$ for all $\rho \in [0,1]$, $\gamma \in (0,2)$ (equality holds only if $\rho = 1$) and $\dfrac{\partial A}{\partial \rho} = -2(1+\rho)(4-\gamma\rho)\left[4-\gamma(1+2\rho)\right]$;

thus, whenever γ and ρ are sufficiently large, we have $A \leq 0$ (equality holds only if $\rho = 1$), and hence, $R^{NJ} \leq R^{N}$. For example, $A(\rho = 0.7, \gamma = 1.5) = -0.150225 < 0$. (v) Cases CJ and N. - $R^{CJ} > R^{N}$. (vi) Cases C and N. - $R^{C} - R^{N} = \frac{S^2\varepsilon^4(1+\rho)^2(1-c)^4\left[(4-\gamma)^2(1+\rho)^2 - (4-\gamma\rho)^2\right]}{(4-\gamma)^2(4+\gamma)^4}$. The sign of the term in the brackets is equal to the sign of this equation. The term, denoted by *B*, can be positive or negative and it's sign depends on the values of γ and ρ for a range of pairs (γ, ρ). On the one hand, we have $B(\rho = 1, \gamma = 0) = 48 > 0$, $B(\rho = 1, \gamma = 2) = 12 > 0$, and $B(\rho > 0, \gamma = 0) = 16\left[(1+\rho)^2 - 1\right] > 0$. Supposing continuity, if either ρ is close or equal to 1 or γ is close to 0 and $\rho > 0$ or both, we have $B > 0$, and hence, $R^{C} > R^{N}$. On the other hand, $B(\rho = 0, \gamma > 0) = (4-\gamma)^2 - 16 < 0$. Moreover, $\frac{\partial B}{\partial \rho} = 2\left[(4-\gamma)^2(1+\rho) + \gamma(4-\gamma\rho)\right] > 0$ and $\frac{\partial B}{\partial \gamma} = -2\left[(4-\gamma)(1+\rho)^2 - \rho(4-\gamma\rho)\right] < 0$ for all $\rho \in [0,1]$, $\gamma \in (0,2)$; thus, *B* increases in ρ and decreases in γ. Therefore, $R^{C} - R^{N}$ becomes negative for a sufficiently small value of ρ and large value of γ. For example, $B(\rho = 0.2, \gamma = 1.8) = -6.28 < 0$.

The results of cases NJ and N can be explained as follows. When a firm decides its level of R&D investment, it considers the spillover effect it will cause and gain. Thus, it has an incentive to free ride on the other firm's R&D investment. From (18) in R&D competition (case N), we can calculate $\frac{\partial R^{N}}{\partial \rho} = \frac{2S^2\varepsilon^4(1+\rho)(4-\gamma\rho)\left[4-\gamma(1+2\rho)\right](1-c)^4}{(4-\gamma)^2(4+\gamma)^4}$. Here, free-rider effect implies that $\frac{\partial R^{N}}{\partial \rho} < 0$ and thus it exists when $4 - \gamma(1 + 2\rho) < 0$. It does not exist in R&D cartelization (case C) and RJV cartelization (case CJ) since firms coordinate their R&D investments. Therefore, the range of the spillover rate that makes R^{NJ} smaller than R^{N} increases as the two goods are less differentiated (γ is large) in R&D competition (case N).

The results of cases N and C can be explained as follows. As Kamien, Muller and Zang (1992) pointed out, there are two types of externalities caused by R&D activities in the presence of spillovers. They are competitive-advantage externality and combined-profits externality. The first externality means that if a firm spends on R&D some spills over to its competitor, increasing the qualities of their products. This externality prevents a firm's R&D spending. The second externality, which can be positive or negative, is the one influenced by a firm's R&D expenditure on the profits of all the firms. The second externality is ignored in case N but is internalized in case C. Moreover, it is positive if and only if the spillover rate is sufficiently large and vice versa. Therefore, on the one hand, if R&D spillovers are strong, then the two firms' profits increase. This is because total equilibrium profits increase with a rise in product quality and the market share of the firm other than the firm that expends on R&D does not decrease significantly. On the other hand, if R&D spillovers are weak, then two firms' profits decrease. This is because total equilibrium profits decrease with a rise in product quality and the market share of the firm other than the firm that expends on R&D decreases significantly.

The important difference between process R&D and product R&D with respect to R&D expenditure is the following. While Kamien, Muller and Zang (1992) show with process R&D that the effective R&D expenditure is at its minimum in RJV competition and it reaches its maximum in RJV cartelization, the results with product R&D are that RJV cartelization yields the highest R&D expenditure. However, the scenarios which yield the lowest depend on the degree of R&D spillovers and the extent of differentiation between goods.

Similarly, we can compare the product quality in the four scenarios and derive the following proposition.

Proposition 2. (i) For all ρ the equilibrium product quality satisfies $u^{CJ} > u^{i}$, $i = N, C, NJ$. (ii) $u^{CJ} > u^{C} > u^{NJ}$ if $\rho > 2^{\frac{3}{4}} - 1$ and $u^{CJ} > u^{NJ} > u^{C}$ if $\rho < 2^{\frac{3}{4}} - 1$. (iii) $u^{NJ} \geq u^{N}$ (equality holds only if $\rho = 1$). (iv) $u^{C} > u^{N}$ if ρ is sufficiently large, or γ is quite small except $\rho = 0$ and $u^{C} < u^{N}$ if ρ is sufficiently small, or γ is sufficiently large and ρ is quite small.

Proof. (i) Cases CJ and NJ. - $u^{CJ} > u^{NJ}$. (ii) Cases CJ and C. - $u^{CJ} > u^{C}$. (iii) Cases C and NJ. - $u^{C} > u^{NJ}$ if $\rho > 2^{\frac{3}{4}} - 1$ and $u^{C} < u^{NJ}$ if $\rho < 2^{\frac{3}{4}} - 1$. (iv) Cases NJ and N. - $u^{NJ} - u^{N} = \dfrac{S^{\frac{1}{2}} \varepsilon^{2} (1-c) \left[2\sqrt{2} (4-\gamma)^{\frac{1}{2}} - (1+\rho)^{\frac{3}{2}} (4-\gamma\rho)^{\frac{1}{2}} \right]}{(4-\gamma)^{\frac{1}{2}} (4+\gamma)}$. The sign of the term in the brackets is equal to the sign of this equation. The term, denoted by *D*, can be positive or negative and it's sign depends on the values of γ and ρ for a range of pairs (γ, ρ). On the one hand, we have $D(\rho=0, \gamma=0) = 2(2\sqrt{2}-1) > 0$, $D(\rho=1, \gamma=0) = 0$, and $D(0<\rho<1, \gamma=0) = 2\left[2\sqrt{2} - (1+\rho)^{\frac{3}{2}} \right] > 0$. Supposing continuity, if γ is close to 0, we have $D \geq 0$ (equality holds only if $\rho = 1$), and hence, $u^{NJ} \geq u^{N}$. On the other hand, $D(\rho = 0, \gamma = 2) = 2 > 0$, $D(\rho=1, \gamma=2) = 0$, $D(0<\rho<1, \gamma=2) = 4 - (1+\rho)^{\frac{3}{2}} (4-2\rho)^{\frac{1}{2}} > 0$. Moreover, $\dfrac{\partial D}{\partial \rho} = \dfrac{\gamma (1+\rho)^{\frac{3}{2}}}{2(4-\gamma\rho)^{\frac{1}{2}}} - \dfrac{3}{2} (1+\rho)^{\frac{1}{2}} (4-\gamma\rho)^{\frac{1}{2}} < 0$ for all $\rho \in [0,1]$, $\gamma \in (0,2)$ and $\dfrac{\partial D}{\partial \gamma} = \dfrac{\rho (1+\rho)^{\frac{3}{2}}}{2(4-\gamma\rho)^{\frac{1}{2}}} - \dfrac{\sqrt{2}}{(4-\gamma)^{\frac{1}{2}}} \leq 0$ for all $\rho \in [0,1]$, $\gamma \in (0,2)$ (equality holds only if $\rho = 1$); thus, *D* decreases in ρ and γ. Therefore, $u^{NJ} \geq u^{N}$ (equality holds only if $\rho = 1$). (v) Cases CJ and N. - $u^{CJ} > u^{N}$. (vi) Cases C and N. - $u^{C} - u^{N} = \dfrac{S^{\frac{1}{2}} \varepsilon^{2} (1+\rho)^{\frac{3}{2}} (1-c) \left[(4-\gamma)^{\frac{1}{2}} (1+\rho)^{\frac{1}{2}} - (4-\gamma\rho)^{\frac{1}{2}} \right]}{(4-\gamma)^{\frac{1}{2}} (4+\gamma)}$. The sign of the term in the brackets is equal to the sign of this equation. The term, denoted by *E*, can be positive or negative and it's sign depends on the values of γ and ρ for a range of pairs (γ, ρ). On the one hand, we have $E(\rho=1, \gamma=0) = 2(\sqrt{2}-1) > 0$, $E(\rho=1, \gamma=2) = 2-\sqrt{2} > 0$, and $E(\rho>0, \gamma=0) = 2\left[(1+\rho)^{\frac{1}{2}} - 1 \right] > 0$. Supposing continuity, if either ρ is close or equal to 1 or γ is close to 0 and $\rho > 0$ or both, we have $E > 0$, and hence, $u^{C} > u^{N}$. On the other hand, $E(\rho=0, \gamma>0) = (4-\gamma)^{\frac{1}{2}} - 2 < 0$. Moreover, $\dfrac{\partial E}{\partial \rho} = \dfrac{1}{2} \left[\dfrac{(4-\gamma)^{\frac{1}{2}}}{(1+\rho)^{\frac{1}{2}}} + \dfrac{\gamma}{(4-\gamma\rho)^{\frac{1}{2}}} \right] > 0$ and $\dfrac{\partial E}{\partial \gamma} = -\dfrac{1}{2} \left[\dfrac{(1+\rho)^{\frac{1}{2}}}{(4-\gamma)^{\frac{1}{2}}} - \dfrac{\rho}{(4-\gamma\rho)^{\frac{1}{2}}} \right] < 0$ for all $\rho \in [0,1]$, $\gamma \in (0,2)$; thus, *E* increases in ρ and decreases in γ. Therefore, $u^{C} - u^{N}$ becomes negative for a sufficiently small value of ρ and large value of γ. For example, $E(\rho = 0.2, \gamma = 1.8) = -0.283071 < 0$.

If we interpret product quality as technological improvements, the result from product qualities is similar to that from R&D expenditures. While technological improvements are at their minimum in RJV competition and reach a maximum in RJV cartelization in Kamien, Muller and Zang (1992), the results with product R&D are that RJV cartelization yields the highest product quality. However, the scenarios which yield the lowest depend on the degree of R&D spillovers and the extent of differentiation between goods.

Since the quantity increases in product quality, we get the following result characterizing the equilibrium quantities from Proposition 2.

Corollary 1. (i) For all ρ the equilibrium quantity satisfies $x^{CJ} > x^{i}$ and $y^{CJ} > y^{i}$, $i = N, C, NJ$. (ii) $x^{CJ} > x^{C} > x^{NJ}$, $y^{CJ} > y^{C} > y^{NJ}$ if $\rho > 2^{\frac{3}{4}} - 1$ and $x^{CJ} > x^{NJ} > x^{C}$, $y^{CJ} > y^{NJ} > y^{C}$ if $\rho < 2^{\frac{3}{4}} - 1$. (iii) $x^{NJ} \geq x^{N}$ and $y^{NJ} \geq y^{N}$ (equality holds only if $\rho = 1$). (iv) $x^{C} > x^{N}$ and $y^{C} > y^{N}$ if ρ is sufficiently large, or γ is quite small except $\rho = 0$ and $x^{C} < x^{N}$ and $y^{C} < y^{N}$ if ρ is sufficiently small, or γ is sufficiently large and ρ is quite small.

A comparison of consumer surplus in the third country in the four scenarios results in the following:

Proposition 3. (i) The equilibrium consumer surplus in the third country satisfies the following for all ρ : $CS^{CJ} > CS^{i}$, $i = N, NJ$, and $CS^{CJ} \geq CS^{C}$ (equality holds if and only if $\rho = 1$). (ii) $CS^{CJ} \geq CS^{C} > CS^{NJ}$ if $\rho > 2^{\frac{3}{4}} - 1$ and $CS^{CJ} > CS^{NJ} > CS^{C}$ if $\rho < 2^{\frac{3}{4}} - 1$. (iii) $CS^{NJ} \geq CS^{N}$ (equality holds only if $\rho = 1$). (iv) $CS^{C} > CS^{N}$ if ρ is sufficiently large, or γ is quite small except $\rho = 0$ and $CS^{C} < CS^{N}$ if ρ is sufficiently small, or γ is sufficiently large and ρ is quite small.

Proof. (i) Cases CJ and NJ. - $CS^{CJ} > CS^{NJ}$. (ii) Cases CJ and C. - $CS^{CJ} \geq CS^{C}$ (equality holds only if $\rho = 1$). (iii) Cases C and NJ. - $CS^{C} > CS^{NJ}$ if $\rho > 2^{\frac{3}{4}} - 1$ and $CS^{C} < CS^{NJ}$ if $\rho < 2^{\frac{3}{4}} - 1$. (iv) Cases NJ and N. - $CS^{NJ} - CS^{N} = \frac{S^{2}\varepsilon^{4}(2+\gamma)(1-c)^{4}\left[8(4-\gamma)-(1+\rho)^{3}(4-\gamma\rho)\right]}{(4-\gamma)(4+\gamma)^{4}}$. The sign of the term in the brackets is equal to the sign of this equation. The term, denoted by *K*, can be positive or negative and it's sign depends on the values of γ and ρ for a range of pairs (γ, ρ). On the one hand, we have $K(\rho = 0, \gamma = 0) = 28 > 0$, $K(\rho = 1, \gamma = 0) = 0$, and $K(0 < \rho < 1, \gamma = 0) = 32 - 4(1+\rho)^{3} > 0$. Supposing continuity, if γ is close to 0, we have $K \geq 0$ (equality holds only if $\rho = 1$), and hence, $CS^{NJ} \geq CS^{N}$. On the other hand, $K(\rho = 0, \gamma = 2) = 12 > 0$, $K(\rho = 1, \gamma = 2) = 0$, $K(0 < \rho < 1, \gamma = 2) = 16 - 2(2-\rho)(1+\rho)^{3} > 0$. Moreover, $\frac{\partial K}{\partial \rho} = -(1+\rho)^{2}\left[12 - \gamma(1+4\rho)\right] < 0$ for all $\rho \in [0,1]$, $\gamma \in (0,2)$ and $\frac{\partial K}{\partial \gamma} = -8 + \rho(1+\rho)^{3} \leq 0$ for all $\rho \in [0,1]$, $\gamma \in (0,2)$ (equality holds only if $\rho = 1$); thus, *K* decreases in ρ and γ. Therefore, $CS^{NJ} \geq CS^{N}$ (equality holds only if $\rho = 1$). (v) Cases CJ and N. - $CS^{CJ} > CS^{N}$. (vi) Cases C and N. - $CS^{C} - CS^{N} = \frac{S^{2}\varepsilon^{4}(1+\rho)^{3}(2+\gamma)(1-c)^{4}\left[(4-\gamma)(1+\rho)-(4-\gamma\rho)\right]}{(4-\gamma)(4+\gamma)^{4}}$. The sign of the term in the brackets is equal to the sign of this equation. The term, denoted by *L*, can be positive or negative and it's sign depends on the values of γ and ρ for a range of pairs (γ, ρ). On the one hand, we have $L(\rho=1, \gamma=0)=4>0$, $L(\rho=1, \gamma=2)=2>0$, and $L(\rho>0, \gamma=0)=4\rho>0$. Supposing continuity, if either ρ is close or equal to 1 or γ is close to 0 and $\rho > 0$ or both, we have $L>0$, and hence, $CS^C > CS^N$. On the other hand, $L(\rho=0, \gamma>0)=-\gamma<0$. Moreover, $\frac{\partial L}{\partial \rho}=4>0$ and $\frac{\partial L}{\partial \gamma}=-1<0$ for all $\rho \in [0,1]$, $\gamma \in (0,2)$; thus, L increases in ρ and decreases in γ. Therefore, $CS^C - CS^N$ becomes negative for a sufficiently small value of ρ and large value of γ. For example, $L(\rho=0.2, \gamma=1.8)=-1<0$.

In a symmetric equilibrium, the product prices are the same in four scenarios. However, the quantity is the highest in RJV cartelization (case CJ) and thus consumer surplus in the third country is the largest in the case. For the same reason, the critical values of ρ and γ are the same when compared to the other cases.

Finally, we turn to profit comparisons. Comparing the profit of each firm in the four scenarios yields the following result.

Proposition 4. For all ρ the equilibrium profit of each firm satisfies $\pi^{CJ} > \pi^{NJ} \geq \pi^N$ and $\pi^{CJ} \geq \pi^C > \pi^N$. Furthermore, $\pi^{CJ} \geq \pi^C > \pi^{NJ} \geq \pi^N$ if $\rho > 12^{\frac{1}{4}} - 1$ and $\pi^{CJ} > \pi^{NJ} > \pi^C > \pi^N$ if $\rho < 12^{\frac{1}{4}} - 1$.

Proof. (i) Cases CJ and NJ. - $\pi^{CJ} > \pi^{NJ}$. (ii) Cases CJ and C. - $\pi^{CJ} \geq \pi^C$ (equality holds only if $\rho=1$). (iii) Cases C and NJ. - $\pi^C > \pi^{NJ}$ if $\rho > 12^{\frac{1}{4}} - 1$ and $\pi^C < \pi^{NJ}$ if $\rho < 12^{\frac{1}{4}} - 1$. (iv) Cases NJ and N. - $\pi^{NJ} \geq \pi^N$ (equality holds only if $\rho=1$). (v) Cases CJ and N. - $\pi^{CJ} > \pi^N$. (vi) Cases C and N. - $\pi^C - \pi^N = \frac{S^2\varepsilon^4(1+\rho)^2(1-c)^4(\gamma-4\rho)^2}{(4-\gamma)^2(4+\gamma)^4} > 0$.

It implies that the profit of each firm is at its minimum in R&D competition (case N) and it reaches its maximum in RJV cartelization (case CJ). Furthermore, since the sign of $\pi^C - \pi^{NJ}$ depends on the value of ρ, the equilibrium profit of each firm in the four scenarios can be compared to the size of ρ.

The important difference between process R&D and product R&D with respect to firm profit can be explained by the works of Kamien, Muller and Zang (1992). While with process R&D, each firm's profit is at its maximum level in RJV cartelization, the scenario yielding the lowest level cannot be determined. Under product R&D, the RJV cartelization yields the highest profits and R&D competition yields the lowest.

5. Concluding Remarks

In this paper, we analyzed the effects of R&D cartelization and RJVs on firms that participate in quantity competition in an imperfectly competitive international market. There are some similar results between process R&D and product R&D. RJV cartelization yields the highest R&D expenditure and profit for each firm in the cases of process and product R&D. However, some outcomes are different between them. First, the scenario which yields the lowest R&D expenditure depends on the degree of spillovers and the extent of product differentiation in the case of product R&D, whereas RJV competition yields the lowest R&D expenditure in the case of process R&D. Second, the profit of each firm is at its minimum in

R&D competition and the comparative size of its profit in the four scenarios depends on the extent of spillovers in the case of product R&D. However, the profit of a firm is at its minimum in RJV competition or R&D competition in the case of process R&D.[15]

An extension of this paper will be a model of Stackelberg competition instead of Cournot competition in the second stage. It will be interesting to see how the firms' behavior in the product market affects their product R&D decisions in the first stage.[16] Adding a policy stage which precedes the research efforts will be another direction for future research regarding product R&D. The policy analysis that the government in each country chooses in the four scenarios is worth studying.

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[15] See Kamien, Muller and Zang (1992) for the results from process R&D.

[16] Prokop (2014) considers a two-stage game in which firms form an RJV or cartelization of process R&D in the first stage and engage in Stackelberg competition in the second stage.