THE KOREAN ECONOMIC REVIEW
Volume 19, Number 2, Winter 2003

ENDOGENOUS SPILLOVERS AND A COSTLY RESEARCH JOINT VENTURE

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We examine the policy implications of a research joint venture (RJV) while introducing endogenous spillovers and costly RJV. The research joint venture is costly in the sense that the firms incur two kinds of costs when they join in an RJV: RJV formation costs and spillover costs. We derive the condition under which firms do not have an incentive to form an RJV, and identify when firms within an RJV share information completely. Based on the results obtained in this paper we suggest the potential need for active government intervention with respect to RJV formation.

JEL Classification: C7, D6, L1
Keywords: Endogenous spillovers, Research joint venture, Welfare implication

I. INTRODUCTION

Previous studies on R&D, spillovers, and RJV (research joint venture) focus on examining the role of spillovers (information sharing) in comparing outcomes between the R&D non-cooperation and cooperation games (See De Bondt (1996) for a detailed survey). A consistent finding is that the R&D cooperation may result in better outcome especially when spillover parameter has sufficiently high value. These studies usually treat spillovers as exogenous and beyond the control of firms regardless of the RJV (or R&D cooperation) existence. Some papers

Received for publication: Sep. 2, 2003. *Revision accepted:* Nov. 24, 2003.

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This paper is partly based on the author's Ph.D dissertation at Iowa State University, Department of Economics. The author is grateful to the dissertation supervisor, Prof. Harvey E. Lapan. I also thank to two anonymous referees for their valuable comments and suggestions. All remaining errors are mine.

treat spillovers (information sharing) within an RJV as the same as those that occur when there is no RJV, while others assume that maximal spillovers occur within an RJV. For example, in d'Aspremont and Jacquemin (1988), firms face the same spillovers with R&D cooperation as in the R&D non-cooperation game. Meanwhile Kamien et al. (1992) assume that the RJV can achieve complete information sharing.

However, as Katz (1986), Katsoulacos and Ulph (1998), and Poyago-Theotoky (1999) pointed out, it seems unreasonable to assume that spillovers within an RJV are exogenously given when we want to investigate the effect of RJV on economic performance. The above three works consider the R&D cooperation game where the firms choose spillovers (information sharing). Katz (1986) considers only the case of complementary research outcomes. The technology that one firm discovers, therefore, is always beneficial to the rival firm if the rival firm can absorb it through spillovers. Katsoulacos and Ulph (1998) examine a number of factors that need to be considered when the spillovers are treated as endogenous. For example, the amount that firms benefit through spillovers may be restricted, depending on whether firms operate in the same industry or in different industries and whether the research discoveries are technical substitutes or complements.[1] Poyago-Theotoky (1999) extends d'Aspremont and Jacquemin's model (1988) by allowing firms to choose spillovers in both the R&D cooperation and non-cooperation games.

One common result of these works is that firms under RJV choose maximal spillovers in the case where firms compete with a homogenous good in the final market. This result has to be reexamined since it is obtained by ignoring the fact that firms in a real economy face many difficulties and costs when they form an RJV, and when they absorb other firm's information or transfer their knowledge to other firms. The difficulties may be related to the moral hazard problem between the partners of an RJV in the sense that it is very difficult to impose the transfer of technology by contract. Pérez-Castrillo and Sandonis (1996) examine this problem and they show that because of this moral hazard problem, potentially profitable RJVs sometimes do not even start. Meanwhile, Vilasuso and Frascatore (2000) show, by introducing costly RJV, that the interests of firms are not necessarily consistent with social interests. They argue that government should encourage R&D competition rather than the RJV (R&D cooperation) if forming an RJV is very costly.

We extend previous studies mentioned above by simultaneously considering two issues: endogenous spillovers and costly RJV. In this sense, our model is a combination of the Poyago-Theotoky's model (1999) with that of Vilasuso and Frascatore (2000). Poyago-Theotoky introduces endogenous spillovers into d'Aspremont and Jacquemin's model, but she does not consider any cost when

[1] If research discoveries are pure technical substitutes, then neither firm can benefit from the rival firm's knowledge discovery (for more detail, see Katsoulacos and Ulph (1998)).

firms form an RJV or when firms increase information sharing. Vilasuso and Frascatore do not endogenize spillovers even though they consider the case in which firms under RJV face a cost, which depends on the degree of spillovers (see Table 1. The spillover parameter, β, is not a choice variable in their paper).

We examine the policy implications of an RJV on total welfare. There are two specific contributions of this paper. First, we introduce endogenous spillovers within an RJV into d'Aspremont and Jacquemin's model (1988). Few studies have dealt with endogenous spillovers within an RJV. Firms may be different in their ability to absorb or assimilate knowledge spillovers (Cohen and Levinthal (1989)). Also, a number of factors, such as the degree of market competition and the nature of research discoveries, may affect the amount by which the firms benefit through spillovers. The other specific contribution is that we model costly RJV. The potential costs associated with forming an RJV will be large, and may include contracting, monitoring, and management costs (Harrigan (1986)). We assume that both RJV formation and spillovers are costly.

[Table 1] Summary of the literature on 'information sharing' under RJV[2]

	Spillovers (W/O RJV)	Spillovers (With RJV)	Costly RJV	Conclusion
Katz (1986)	Exogenous Symmetric	Endogenous ($\beta=1$)	No	The RJV has socially beneficial effects when there are spillovers in the absence of cooperation
D'Aspremont & Jacquemin (1988)	Exogenous Symmetric	Exogenous No change	No	R&D cooperation results in better outcome than R&D competition for sufficiently high spillovers
Kamien et al. (1992)	Exogenous Symmetric	Exogenous ($\beta=1$)	No	RJV ($\beta=1$)may result in best outcome
Katsoulacos & Ulph (1998)[3]	Endogenous ($\beta=0$)	Endogenous ($\beta=1$, $0<\beta<1$)	No	Under RJV, the firms may choose the maximal or the non-maximal spillovers
Poyago-Theotoky (1999)	Endogenous ($\beta=0$)	Endogenous ($\beta=1$)	No	Under RJV, the firms choose the maximal spillovers. RJV results in better outcome.
Vilasuso & Frascatore (2000)	Exogenous Symmetric	Endogenous ($\beta=1$)	Yes $F=k$ $F=k+\psi\beta$	The interests of firms are not necessarily consistent with social interests if RJV is costly

Assuming Cournot competition with a single homogenous good in the final market, we find that firms under the RJV do not share any information if

[2] $\beta=0$ and $\beta=1$ denote minimal and maximal spillovers, respectively.

[3] For the process innovation and Cournot competition, firms in an RJV choose the maximal spillovers while they choose non-maximal spillovers for the product innovation and Bertrand competition.

spillover costs are sufficiently high. It is also shown that private interests with an RJV are not consistent with public interests for a wide range, which suggests the potential need for active government intervention on RJV. To obtain these results, RJV formation costs, spillover costs, and involuntary spillovers play a crucial role.

This paper is organized as follows. Section II sets up the model and examines possible equilibria. Section III focuses on welfare comparisons, and provides policy implications on RJV. The last section provides concluding remarks.

II. THE MODEL AND EQUILIBRIUM

2.1 The Model

In the final market, two firms sell a homogenous product whose inverse demand is given by $P=A-Q$, where $Q=q_i+q_j$, $i,j=1,2$, $i\neq j$. q_i represent the final output of firm i. Firm i's unit production cost is a function of its own R&D investment (x_i), the rival firm's R&D investment, and spillovers so that it is written by

$$C_i=c-x_i-\sigma_i x_j,\ 0\leq\sigma_i=\theta+\beta_i\leq 1,\ i,j=1,2,\ i\neq j. \tag{1}$$

The spillover parameter, σ, is separated into two terms, industry-wide involuntary spillovers, $\theta\in[0,1]$, and a firm-specific spillover parameter, $\beta\in[0,1-\theta]$. The magnitude of involuntary spillovers may depend on the degree of the intellectual property right (IPR) protection. For example, if IPR protection is perfect, then there may not be involuntary spillovers in the economy, i.e., $\theta=0$. As in Cohen and Levinthal (1989), firm specific spillover, β, may reflect a firm's ability to absorb or assimilate its rival firm's knowledge.[4] We assume that the degree of spillovers from which a firm benefits is determined by this ability as well as involuntary spillovers.[5]

The R&D technology exhibits diminishing returns to scale to R&D investment so that its cost is written by $TC_i(x_i)=rx_i^2/2$ where r denotes R&D efficiency. A higher r implies lower R&D efficiency. The main assumption is that firms face two kinds of costs: RJV formation cost and spillover cost. If firms decide to join in an RJV, then they incur a fixed cost (F) as the fee for

[4] Cohen and Levinthal call this ability absorptive capacity. They take the form of spillover parameter as $\sigma_i=\theta\beta_i$

[5] Contrary to our set-up, in Poyago-Theotoky (1999) spillovers totally depend on the rival firm's voluntary knowledge transmission. Thus, the unit cost function is in the form of $C_i=c-x_i-\sigma_j x_j$. This specification will not qualitatively change any result obtained from this paper.

starting the RJV. Besides this cost, each firm that absorbs the rival firm's knowledge should incur other costs, which depend on the amount of information sharing.[6] We assume that this cost increases with the amount of knowledge absorbed. For example, if each firm wants to absorb more knowledge from the rival firm, then it may have to send more researchers to the research joint venture. We refer to this cost as spillover (or information sharing) cost, which is given by $K_i = k\beta_i,\ i=1,2$.

In the R&D non-cooperation (or competition) game two firms simultaneously choose R&D efforts in the first stage and face Cournot competition in the second stage. We assume that firms cannot choose the spillovers in the R&D non-cooperation game.[7] Thus, the firms under R&D competition face only involuntary spillovers ($\sigma_i = \theta$). In the R&D cooperation game, firms decide whether to join in an RJV or not in the first stage. If they decide to join in an RJV, then they incur a fixed cost (F) as the fee for starting an RJV. Firms also choose both R&D efforts and the degree of information sharing to maximize joint profits in the first stage[8] while they face output competition in the second stage. We assume the decision of joining in an RJV, and choosing both R&D investment and spillovers is taken together in the first stage.[9]

2.2 Equilibrium

The nature of the equilibrium is subgame perfect Nash equilibrium. To find out the equilibrium, we first solve for the Nash equilibrium in the final market and then work backwards, solving for the R&D levels. In the final stage, each firm chooses quantity to maximize its own profits given the previous stage R&D investment. Firm i's final stage profits are as follows: $\pi_i = (A-Q)q_i - C_i q_i$

Solving the problem yields final stage output and profit as a function of

[6] Vilasuso and Frascatore (2000) consider an RJV formation cost that depends on the spillover amount ($K = F + k\beta$), even though they do not make spillovers be endogenous.

[7] Introducing endogenous spillovers into this game leads to the different result than in Poyago-Theotoky, in which the firms choose the minimal spillovers. With our set-up of spillovers, even firms under the R&D non-cooperation game will choose maximal spillovers assuming there is no cost in doing that.

[8] We follow the assumption of joint profit maximation as the standard in the literature in the sense that the literature has uniformly assumed the joint profit maximization under the RJV. However, whether this assumption is appropriate requires further analysis since it is difficult to believe that firms, in reality, can write the contracts to maximize joint profits when they are competitors in a final market. Also, there may be firm's incentive to deviate from joint profit maximization. For example, if firm's profit is a portion of total profits under the RJV and the portion depends on its own R&D spending then it may be more profitable for the firm to deviate by maximizing its own profit choosing own R&D spending. Salant and Shaffer(1998) and Anbarci et al.(2002) briefly mention this issue.

[9] R&D cooperation game may consist of a three-stage game without changing any results obtained here.

R&D investment and spillovers:

$$q_i^* = \frac{A-2C_i+C_j}{3} = \frac{A-c+(2-\sigma_j)x_i+(2\sigma_i-1)x_j}{3},$$
$$\pi_i^* = (q_i^*)^2, \quad i \neq j, \quad i=1,2. \tag{2}$$

2.2.1 Non-cooperative R&D competition

In the first stage, each firm chooses the level of R&D investments to maximize its own profit, which is written by

$$V_i = \pi_i^* - TC_i(x_i) = \frac{\{A-c+(2-\theta)x_i+(2\theta-1)x_j\}^2}{9} - \frac{r}{2}x_i^2 \quad i \neq j, \quad i=1,2 \tag{3}$$

The first and second order conditions are as follows:

$$\frac{\partial V_i}{\partial x_i} = \frac{2\{A-c+(2-\theta)x_i+(2\theta-1)x_j\}(2-\theta)}{9} - rx_i = 0, \quad i \neq j, \quad i=1,2 \tag{4}$$

$$\frac{\partial^2 V}{\partial x_i^2} = \frac{2(2-\theta)^2}{9} - r < 0, \quad i=1,2. \text{ This holds for } \forall\theta \text{ if } r > \frac{8}{9}. \tag{5}$$

From the first order condition, assuming a symmetric solution ($x_i = x_j = x$), we can get the equilibrium R&D investment: $x^N = \frac{2(A-c)(2-\theta)}{9r-2(1+\theta)(2-\theta)}$. We assume $r > 12/9$ such that both the second order and the stability condition holds.[10] Finally, using the equilibrium R&D investment yields the following outcomes, where N denotes the R&D non-cooperation game, and W denotes total welfare.

$$x^N = \frac{2(A-c)(2-\theta)}{9r-2(1+\theta)(2-\theta)}, \quad q^N = \frac{3r(A-c)}{9r-2(1+\theta)(2-\theta)},$$
$$Q^N = \frac{6r(A-c)}{9r-2(1+\theta)(2-\theta)}, \quad V^N = \frac{r(A-c)^2\{9r-2(2-\theta)^2\}}{\{9r-2(1+\theta)(2-\theta)\}^2}$$
$$W^N = \frac{4r(A-c)^2\{9r-2(2-\theta)^2\}}{\{9r-2(1+\theta)(2-\theta)\}^2}$$

[10] As a referee pointed out, it is reasonable to assume stability condition at the outset in the sense that without stability condition weird things can happen in oligopoly (for more detail, see Seade (1980)). As seen in Henriques (1990), without stability condition we may have to consider a corner solution where only one firm invests in R&D under the R&D non-cooperation game, which is not what we want to focus on in this paper.

2.2.2 Cooperative R&D competition (Research Joint Venture)

The final stage profits for each firm are given by equation (2). In the first stage, the firms under RJV maximize their joint profits while choosing the R&D investment and the amount of information sharing (β_i). The firms incur RJV formation cost (F) and spillover cost ($k\beta_i$). The joint profit function can be written by

$$\begin{aligned} V^J = \frac{1}{9}\ & [\{A-c+(2-\sigma_j)x_i+(2\sigma_i-1)x_j\}^2 \\ & + \{A-c+(2-\sigma_i)x_i+(2\sigma_j-1)x_i\}^2\}] \\ & -\{(rx_i^2+rx_j^2)/2\}-\{k\beta_i+k\beta_j\}-2F,\ \ i\neq j,\ \ i=1,2 \end{aligned} \tag{6}$$

where V^j denotes the joint profit under RJV.[11]

The first order conditions for joint profit maximization are

$$\begin{aligned} \frac{\partial V^J}{\partial \beta_i} &= \frac{2}{9}[\{A-c+(2-\sigma_j)x_i+(2\sigma_i-1)x_j\}(2x_j)+ \\ &\qquad \{A-c+(2-\sigma_i)x_j+(2\sigma_j-1)x_i\}(-x_j)]-k=0,\ i\neq j,\ i=1,2 \\ \frac{\partial V^J}{\partial x_i} &= \frac{2}{9}[\{A-c+(2-\sigma_j)x_i+(2\sigma_i-1)x_j\}(2-\sigma_j)+ \\ &\qquad \{A-c+(2-\sigma_i)x_j+(2\sigma_j-1)x_i\}(2\sigma_j-1)]-rx_i=0,\ i\neq j,\ i=1,2 \end{aligned} \tag{7}$$

The second order conditions are: for $i\neq j, i=1,2$,

$$\frac{\partial^2 V^J}{\partial \beta_i^2}=\frac{10}{9}x_j^2>0,\ \ \frac{\partial^2 V_J}{\partial x_i^2}=\frac{2}{9}\{(2-\sigma_j)^2+(2\sigma_j-1)^2\}-r<0\ \text{ for}$$
$$0\leq \sigma_{i,}\ \sigma_j\leq 1\ \text{ if }\ r>\frac{10}{9} \tag{8}$$

Assuming that R&D investment and spillovers are determined together, we can solve the problem. From the second order condition with respect to spillovers, we should consider a corner solution ($\beta_i=\beta_j=\beta=0$ or $\beta_i=\beta_j=\beta=1-\theta$). That is, the firms under RJV will choose the minimal or maximal spillovers. This is confirmed from the fact that Hessian matrix of spillovers is positive definite. That is, $H^{\beta}_{kk}\equiv\partial^2 V/\partial\beta_k^2>0$, $k=i,j$, and $|H^{\beta}|=\frac{4}{9}x_i^2x_j^2>0$ where $H^{\beta}=\begin{bmatrix}\partial^2 V/\partial\beta_i^2, \partial^2 V/\partial\beta_i\partial\beta_j \\ \partial^2 V/\partial\beta_j\partial\beta_i, \partial^2 V/\partial\beta_j^2\end{bmatrix}$. Meanwhile, we can have a symmetric interior solution for R&D investment from (7) and (8).[12]

[11] Thus, the final per firm profit under the RJV is denoted by $V^j/2$

$$x=\frac{2(A-c)(1+\theta)}{9r-2(1+\theta)^2} \text{ if } \beta_i=\beta_j=\beta=0,\ x=\frac{4(A-c)}{9r-8} \text{ if } \beta_i=\beta_j=\beta=1-\theta \tag{9}$$

As pointed out by Salant and Shaffer (1998), we may have to consider the asymmetric outcome of R&D investment. They show that for sufficiently low involuntary spillovers, the symmetric solution may not be optimal under R&D cooperation even though the firms are ex-ante identical. The point of Salant and Shaffer is that the asymmetric R&D investment results in lower aggregate production costs while it yields higher R&D costs compared to the symmetric R&D investment. Thus, asymmetric R&D investment may be optimal if the former effect dominates. However, the result obtained by Salant and Shaffer does not hold in our set-up. This is because we consider the case where the firms under RJV choose the amounts of information sharing, and incur costs in doing so. With the same way as in Salant and Shaffer, we can derive the condition that the asymmetric R&D investment under the R&D cooperation may be optimal as follows:[13]

$$r<\frac{(3-\sigma_j-2\sigma_i)^2+(\sigma_i+2\sigma_j-3)^2}{9}\equiv r^a \tag{10}$$

The condition in Equation (10) should satisfy the second order condition or stability condition[14] we assume in this paper, i.e., $r>12/9$. Recall that we get a corner solution of spillovers, that is, $\beta_k=0$ or $\beta_k=1-\theta,\ k=i,j$. Also, note that asymmetric R&D investment (spillovers) should be excluded for symmetric spillovers (R&D investment) since it does not satisfy the first order condition of the joint profit maximization problem. Therefore, if asymmetric R&D investment could be optimal, one firm under RJV should choose minimal spillovers (e.g., $\beta_i=0$) given that the other firm could choose maximal spillovers (e.g., $\beta_j=1-\theta$). Then, from Equation (10), we get $r^a=5(\theta-1)^2/9$, which is always less than 12/9. This implies that asymmetric R&D investment cannot be optimal under the restriction of R&D efficiency we assume in this paper.[15] In

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[12] Hessian matrix of R&D investment $H^x=\begin{bmatrix} \partial^2 V/\partial\beta_i^2, \partial^2 V/\partial\beta_i\partial\beta_j \\ \partial^2 V/\partial\beta_j\partial\beta_i, \partial^2 V/\partial\beta_j^2 \end{bmatrix}$, is negative definite, i.e., $H^x_{kk}<0$ and $|H^x|=r^2-\frac{4r}{9}\{(2-\sigma)^2+(2\sigma-1)^2\}+4(1-\sigma)^4>0$ for $0\le\sigma\le1$ if $r>\frac{10}{9}$.

[13] The same condition in Salant and Shaffer is $br<2(1-\theta)^2$ where b denotes the substitutability of product. Since $b=1$ in our set-up, the condition is equivalent to $r<2(1-\theta)^2$, which is less than 2 for $\theta\in[0,1]$.

[14] In Salant and Shaffer (1988), there exists a range of R&D efficiency and involuntary spillovers, for which both the condition for asymmetric solutions and the second order (or stability) condition are satisfied. See Fig. 1 on pp197 of their article.

[15] There is one thing to note. It is intuitively obvious that strong diminishing returns to scale

sum, we consider two symmetric solutions of spillovers and R&D investment as the outcomes under RJV. For each case, we get the following outcomes:

Case MAX ($\beta_i=\beta_j=1-\theta$): $x^{MAX}=\dfrac{4(A-c)}{9r-8}$, $q^{MAX}=\dfrac{3(A-c)}{9r-8}$,

$Q^{MAX}=\dfrac{6r(A-c)}{9r-8}$, $V^{MAX}=\dfrac{2r(A-c)^2}{9r-8}-2k(1-\theta)$,

$W^{MAX}=\dfrac{4r(A-c)^2(9r-4)}{(9r-8)^2}-2k(1-\theta)$

Case MIN ($\beta_i=\beta_j=0$): $x^{MIN}=\dfrac{2(A-c)(1+\theta)}{9r-2(1+\theta)^2}$, $q^{MIN}=\dfrac{3r(A-c)}{9r-2(1+\theta)^2}$,

$Q^{MIN}=\dfrac{6r(A-c)}{9r-2(1+\theta)^2}$, $V^{MIN}=\dfrac{2r(A-c)^2}{9r-2(1+\theta)^2}$,

$W^{MIN}=\dfrac{4r(A-c)^2\{9r-(1+\theta)^2\}}{\{9r-2(1+\theta)^2\}^2}$

We can identify when each case can occur as an equilibrium by comparing joint profits between Case MAX and Case MIN: V^{MAX} and V^{MIN}. The profit of firms within an RJV is bigger (smaller) under Case MAX than under Case MIN only if spillover costs are sufficiently low (high), i.e., $V^{MIN} >=< V^{MAX}$ iff $k >=< k^c \equiv \dfrac{2r(A-c)^2\{4-(1+\theta)^2\}}{(9r-8)(1-\theta)\{9r-2(1+\theta)^2\}}$. Thus, the firms under RJV choose minimal spillovers for sufficiently high spillover costs. This is a different result from previous studies where they find that firms always share information completely within an RJV.[16] The intuition is that the firms under RJV always choose maximal spillovers without spillover costs since the increased output by sharing information completely has a dominant effect on profits. However, if spillover costs are sufficiently high the firms under RJV do not have an incentive to share information because spillover costs affect profits negatively.

It is straightforward to show that without RJV formation costs ($F=0$), firms prefer joining in an RJV because profits are always bigger under RJV than under R&D non-cooperation. This result is intuitively obvious in the sense that firms under RJV can choose the outcome under R&D non-cooperation whenever it is a better outcome. Note that neither involuntary spillovers nor spillover costs affec firms' decision as to whether to join in an RJV without RJV formation costs..

to R&D investment may exclude asymmetric solutions as an optimal equilibrium. This is true if R&D efficiency parameter, r, is greater than 2 even when we do not consider endogenous spillovers.

[16] See Katz (1986), Katsoulacos and Ulph (1998), and Poyago-Theotoky (1999). In these studies, the maximal spillovers are obtained, given the assumption of Cournot competition and homogenous good in the final market.

Definition 1: Define the function $\overline{V^J}(k)=\max\{V^{MIN}(k),\ V^{MAX}(k)\}$ where, $\overline{V^J}(k)=V^{MAX}(k)$ for $0<k<k^c$ and $\overline{V^J}(k)=V^{MIN}(k)$ for $k>k^c$.

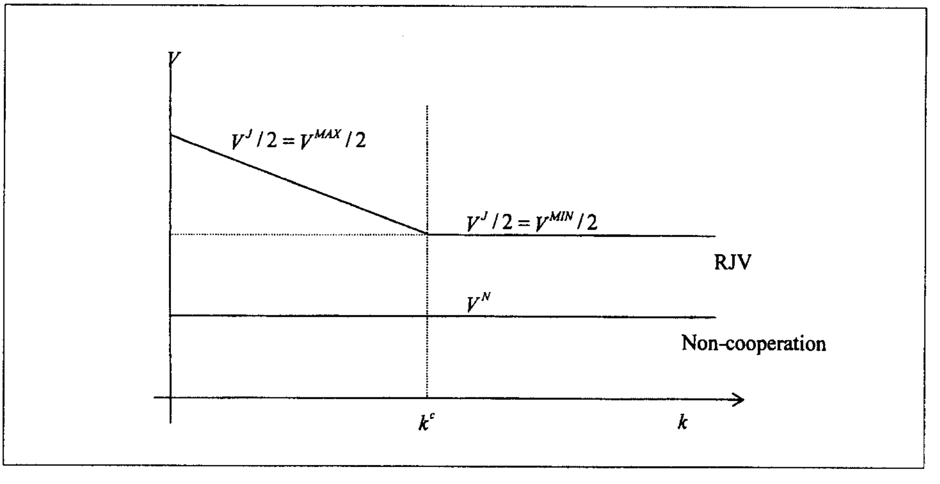
Lemma 1: As long as there is no RJV formation cost ($F=0$), for any $k>0$ firms always prefer joining in a research joint venture.

Proof: $\overline{V^J}(k)=\max\{V^{MIN}(k),\ V^{MAX}(k)\}\geq V^{MIN}>2V^N$

If RJV formation costs exist ($F>0$), spillover costs as well as RJV formation costs affect firms' decision as to whether they will join in an RJV or not. To be more specific, we consider two critical levels of RJV formation costs, F^{vc1} and F^{vc2}, where:

$$F^{vc1}\equiv\frac{V^{MIN}}{2}-V^N=\frac{18r^2(A-c)^2(2\theta-1)^2}{\{9r-2(1+\theta)(2-\theta)\}^2\{9r-2(1+\theta)^2\}}>0$$
$$F^{vc2}\equiv\frac{V^{MIN}}{2}-V^N=\frac{r(A-c)^2D}{\{9r-2(1+\theta)(2-\theta)\}^2\{9r-8\}}-k(1-\theta)>0,\ \text{where}\ k<k^c$$
$$D\equiv\{9r-2(1+\theta)(2-\theta)\}^2-\{9r-2(2-\theta)^2\}(9r-8)$$

[Figure 1] Firms' decision of whether to join in an RJV ($F=0$)



It is straightforward to show $F^{vc1}<F^{vc2}$ because the joint profit under Case MAX is bigger than under Case MIN ($V^{MAX}>V^{MIN}$) for $k<k^c$. As seen in Lemma 2 (also, see Figure 2), there are three cases to analyze, depending on RJV formation costs. If RJV formation costs are very low, $F<F^{vc1}$, then firms always prefer joining in an RJV whatever spillover costs are since RJV, without RJV formation costs, can guarantee at least the gains of F^{vc1} as per

firm profit, compared to R&D non-cooperation. However, firms do not have an incentive to join in an RJV when RJV formation costs are very high, $F>F^{vc2}$. Spillover costs do not affect firms' decision as to whether to join in an RJV because the maximum gains under RJV each firm earns without RJV formation costs are F^{vc2} regardless of spillover costs.

Lemma 2: Suppose that there exist RJV formation costs ($F>0$). Then, a) for $F>F^{vc1}$, firms will always join in an RJV regardless of the magnitude of spillover costs. b) for $F^{vc1}<F<F^{vc2}$, firms will join in an RJV only if $k<k^c$. c) for $F>F^{vc2}$ firms will not join in an RJV whatever spillover costs are.

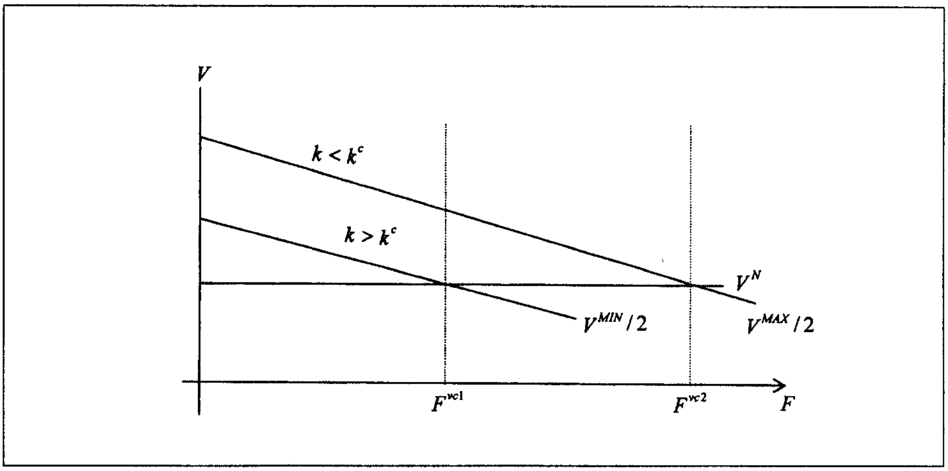
Proof: a) $\overline{V^J}(k, F=0)/2 - V^N = \max\{V^{MIN}(k, F=0)/2,\ V^{MAX}(k, F=0)/2\} - V^N \geq F^{vc1}$

b) $\overline{V^J}(k>k^c, F=0)/2 - V^N = V^{MIN}(F=0)/2 - V^N = F^{vc1}$

$\overline{V^J}(k<k^c, F=0)/2 - V^N = V^{MAX}(k<k^c, F=0)/2 - V^N = F^{vc2} > F^{vc1}$

c) $\overline{V^J}(k, F=0)/2 - V^N = \max\{V^{MIN}(k, F=0)/2,\ V^{MAX}(k, F=0)/2\} - V^N \leq F^{vc1}$

[Figure 2] Firms' decision of whether to join in an RJV ($F>0$)



Meanwhile, for a moderate RJV formation cost ($F^{vc1}<F<F^{vc2}$), firms have to consider spillover costs as a key determinant as to whether they will join in an RJV or not. If spillover costs are sufficiently high ($k>k^c$), then firms will not join in an RJV because the firms under RJV will choose minimal spillovers, but the profit is smaller with RJV formation costs $F\in(F^{vc1}, F^{vc2})$ than under R&D non-cooperation. If spillover costs are relatively low ($k<k^c$), however, firms will join in an RJV because they will choose maximal spillovers under

the RJV, and it will guarantee the gains of F^{vc2}, compared to R&D non-cooperation. The intuition from Lemma 2 gives an explanation of why a potentially profitable RJV sometimes does not start in a real economy.[17] By our analysis, the RJV will not be formed if RJV formation costs are very high or if RJV formation costs are moderate but spillover costs are sufficiently high.

Ⅲ. WELFARE IMPLICATIONS

In the previous section, we have examined when firms prefer joining in an RJV and when they choose minimal or maximal spillovers under the RJV. The key determinants are RJV formation and spillover costs while the amount of involuntary spillovers does not affect firm's decision as to whether to join in an RJV. In this section, we compare outcomes between R&D non-cooperation and R&D cooperation (RJV) in terms of total welfare, which is the sum of the profits and the consumer surplus (CS), and suggest some policy implications.

The firms' incentive to invest in R&D is the highest under Case MAX because they can completely internalize externality due to spillovers ($x^{MAX} \geq x^{MIN}$, and $x^{MAX} \geq x^{N}$). The final output increases with R&D investment. Thus, aggregate output is the largest while market price is the lowest under Case MAX ($P^{MAX} \leq P^{MIN}$, $P^{MAX} \leq P^{N}$), which implies that the consumer surplus is the biggest when the firms under the RJV choose maximal spillovers ($CS^{MAX} \geq CS^{MIN}$, $CS^{MAX} \geq CS^{N}$). Meanwhile, the degree of involuntary spillovers plays a key role in comparing outcomes between Case MIN and Case N. Note that Case MIN takes place as the equilibrium under RJV if spillover costs are sufficiently high. If the degree of involuntary spillovers is sufficiently high ($\theta > 1/2$), R&D investment is greater under Case MIN than under case N while the opposite is true for sufficiently low involuntary spillovers ($\theta < 1/2$), i.e., $x^{N} >=< x^{MIN} \Leftrightarrow \theta <=> 1/2$. Intuitively, for sufficiently high involuntary spillovers the firm under R&D non-cooperation fears that its R&D investment intensifies cost advantage of the rival firm through spillovers, which decreases the incentive of each firm to invest in R&D. However, if the degree of involuntary spillovers is low the effect of R&D investment on cost reduction of the other firm is small. The cost advantage is bigger for the firm that invests in more R&D, which increases the incentive to invest in R&D. On the other hand, the firms under RJV consider the effect of R&D investment on joint profits. Obviously, we get the opposite result from R&D non-cooperation since R&D investment of each firm increases (decreases) profits of the other firm for sufficiently high (low) involuntary spillovers. It is straightforward to show that aggregate output and consumer surplus are larger (smaller) under Case MIN than under Case N for sufficiently high (low) involuntary spillovers, i.e., $Q^{N} >=< Q^{MIN} \Leftrightarrow$

[17] For an example see Pérez-Castrillo and Sandonís (1996). They explain this fact with moral hazard problem regarding information disclosure between partners.

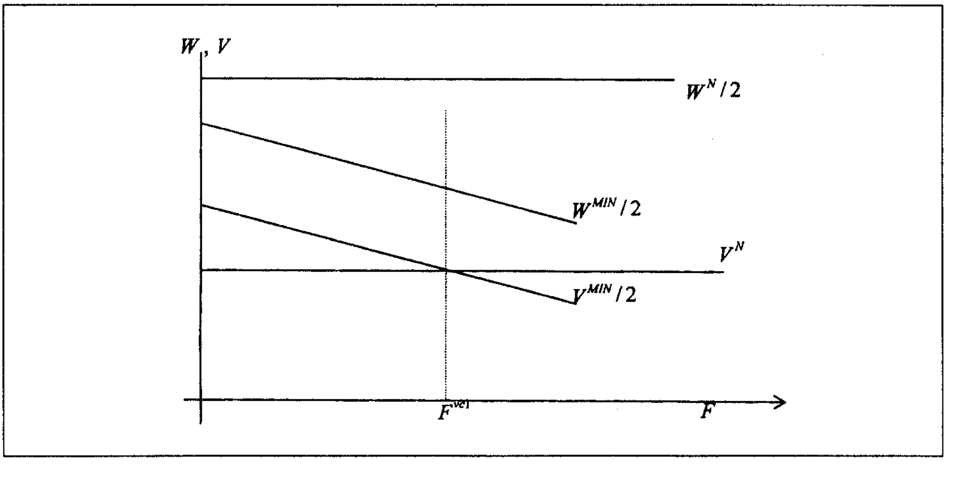
$\theta <=> 1/2$ and $CS^N >=< CS^{MIN} \Leftrightarrow \theta <=> 1/2$.

For the comparison of total welfare between R&D non-cooperation and RJV, we have to consider three factors: involuntary spillovers (information leakages), spillover costs, and RJV formation costs. First, suppose that spillover costs are sufficiently high, $k > k^c$. The firms under RJV choose minimal spillovers (Case MIN). If the degree of involuntary spillovers is sufficiently low, $\theta < 1/2$, total welfare under RJV is less than under R&D non-cooperation regardless of RJV formation costs ($W^C < W^N$). This is because consumers' loss due to reduced R&D investment under case MIN dominates firms' gains, that is, $CS^{MIN} \leq CS^N$, $|CS^{MIN} - CS^N| > 2F^{vc1} \equiv V^{MIN}(F=0) - 2V^N$. Recall that firms join in an RJV only if RJV formation costs are relatively low, $F < F^{vc1}$, while they do not for relatively high RJV formation costs, $F > F^{vc1}$. Thus, if RJV formation costs are relatively high ($F > F^{vc1}$), government intervention is unnecessary since firms do not join in an RJV and total welfare is bigger under R&D non-cooperation than under RJV (see Figure 3). However, for relatively low RJV formation costs ($F < F^{vc1}$) government should discourage firms from joining in an RJV since firms' decision of joining in an RJV is not desirable in terms of total welfare. A possible policy may be a tax on RJV.

Lemma 3: Suppose that spillover costs are sufficiently high ($k > k^c$), but involuntary spillovers are sufficiently low ($\theta < 1/2$). Then, government should discourage firms from joining in an RJV for $F < F^{vc1}$ while it needs not implement any policy for $F > F^{vc1}$.

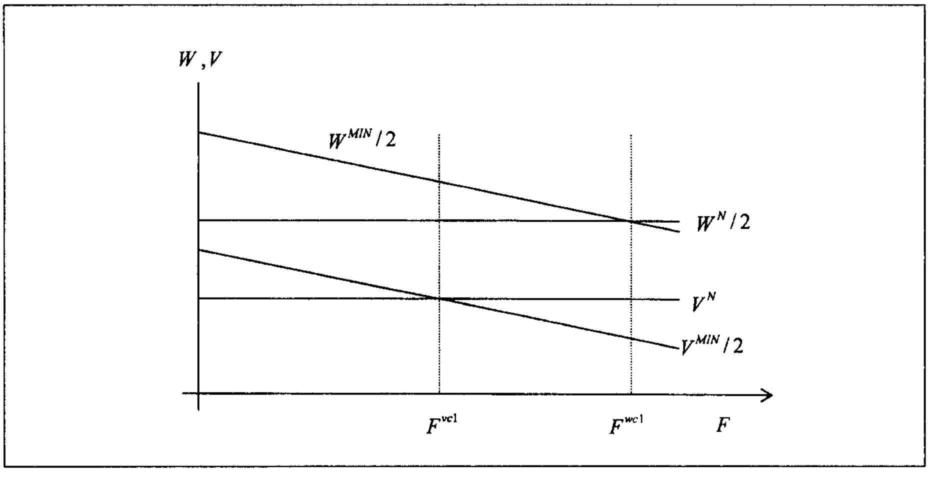
Proof: It is a straightforward result from Lemma 2 and $W^{MIN} < W^N$ for $\theta < 1/2$

[Figure 3] Welfare comparison and policy implication ($k > k^c$, $\theta < 1/2$)



However, if involuntary spillovers are sufficiently large ($\theta>1/2$), we have different policy implications. Consumers gain under RJV since aggregate output (market price) is greater (lower) than under R&D non-cooperation. The profit of firm is also bigger under RJV if RJV formation costs are relatively low, $F<F^{vcl}$. Therefore, with RJV formation costs, $F<F^{vcl}$, no government intervention is necessary since private and public interests are consistent in the sense that firms prefer joining in an RJV while total welfare is bigger under RJV than under R&D non-cooperation. Government intervention is unnecessary even when RJV formation costs are very high[18] ($F>F^{wcl}$, where $F^{wcl}\equiv\frac{W^{MIN}(F=0)-W^{N}}{2}=\frac{72r^2(A-c)^2(1-2\theta)\Phi(\theta,r)}{\{9r-2(1+\theta)^2\}^2\{9r-2(1+\theta)(2-\theta)\}^2}$, and $\Phi(\theta,r)\equiv(1+\theta)^3-9r(1+\theta)+6.75r$). But the reason is different from the previous case. Unlike in the previous case, RJV formation is not desirable in terms of both firms' profits and total welfare. Meanwhile, for moderate value of RJV formation costs ($F^{vcl}<F<F^{wcl}$), firms will not join in an RJV but total welfare is higher under RJV than under R&D non-cooperation. Therefore, government should encourage firms to join in an RJV. Subsidy on RJV may be a possible policy.

[Figure 4] Welfare comparison and Policy implication ($k>k^c$, $\theta>1/2$)



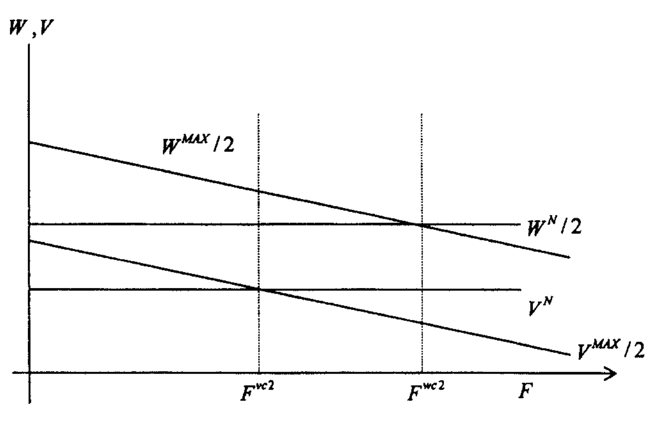
Lemma 4: Suppose both spillover costs and involuntary spillovers are sufficiently high, i.e., $k>k^c$ and $\theta>1/2$. a) Government does not have to implement any policy for very low or very high RJV formation costs, i.e., $F<F^{vcl}$ or $F>F^{wcl}$. b) Government should encourage firms to join in an RJV for moderate value of RJV formation costs ($F^{vcl}<F<F^{wcl}$).

[18] $W^{MIN}>=<W^{N}\Leftrightarrow F<=>F^{wcl}$ and $F^{vcl}<F^{wcl}$ for $\theta<=>1/2$.

Proof: $W^{MIN} >=< W^N \Leftrightarrow F <=> F^{wc1}$, where $F^{vc1} < F^{wc1}$ for $\theta > 1/2$. Also, see Lemma 2.

Now, suppose that spillover costs are sufficiently low, $k < k^c$. Then, firms will completely share their information if they join in an RJV (Case MAX). Without RJV formation costs, total welfare is maximized under case MAX ($CS^{MAX} \geq CS^{MIN}$, CS^N and $V^{MAX} \geq V^{MIN}$, V^N). With RJV formation costs, total welfare under case MAX is greater than under case MIN, but the comparison of total welfare between case MAX and case N is determined by RJV formation costs. Even if the firms within an RJV share their information completely, RJV formation is not beneficial for very high RJV formation costs ($W^{MAX} < W^N$ if, $F > F^{wc2}$, $F^{wc2} \equiv \frac{W^{MIN}(F=0) - W^N}{2} = \frac{4r(A-c)^2 \Omega(\theta, r)}{\{9r - 2(1+\theta)^2\}^2 (9r-8)^2} - 2k(-\theta)$ where, $k > k^c$ and $\Omega(\theta, r) \equiv (9r-4)\{9r - 2(1+\theta)(2-\theta)\}^2 - \{9r - (2-\theta)^2\}(9r-8)^2$). Since the firms will not join in an RJV, government does not have to implement any policy when RJV formation costs are very high ($F > F^{wc2}$). Recall that the firms will not join in an RJV for sufficiently high RJV formation costs ($F > F^{vc2}$ where $F^{vc2} < F^{wc2}$). If RJV formation costs are sufficiently low ($F < F^{vc2}$), the government intervention is also unnecessary because the firms will join in an RJV and total welfare is higher under RJV than under R&D non-cooperation. However, if RJV formation costs lie in a median range ($F^{vc2} < F < F^{wc2}$), government should implement a policy to encourage firms to join in an RJV because total welfare is high under RJV while firms do not prefer joining in an RJV. A possible policy may be subsidy on RJV.

[Figure 5] Welfare comparison and Policy implication ($k < k^c$)



Lemma 5: Suppose spillover costs are sufficiently low, $k<k^c$. Then, a) government does not have to implement any policy for very low or high RJV formation cost ($F<F^{vc2}$ or $F>F^{wc2}$), b) government should encourage firms to join in a RJV for a moderate value of RJV formation cost ($F^{vc2}<F<F^{wc2}$).

Proof: It is a straightforward result from Lemma 2 and $W^{MAX}<=>W^N \Leftrightarrow F>=<F^{wc2}$.

[Table 2] Summary of policy implication

$k>k^c$	A. $\theta<1/2$ $F<F^{vc1}$: Intervention (Discourage (tax) RJV) $F<F^{vc1}$: No intervention (Private and public interests are consistent) B. $\theta>1/2$ $F<F^{vc1}$: No intervention (Private and public interests are consistent) $F<{}^{vc1}F<F^{wc1}$: Intervention (Encourage (subsidy) RJV) $F>F^{wc1}$: No intervention (Private and public interests are consistent)
$k<k^c$	$F<F^{vc2}$: No intervention (Private and public interests are consistent) $F<{}^{vc2}F<F^{wc2}$: Intervention (Encourage (subsidy) RJV) $F>F^{wc2}$: No intervention (Private and public interests are consistent)

The policy implications on RJV (or R&D cooperation) are summarized at Table 2. First, if spillover cost is above the threshold level ($k>k^c$), then the information sharing under RJV (or R&D cooperation) is the same as the degree of involuntary spillovers. In d'Aspremont and Jacquemin's (1988) model the critical value of involuntary spillovers is 1/2 in determining as to whether R&D cooperation increases R&D investments or not, compared to R&D non-cooperation. It is well known that R&D investment creates positive externalities on consumers because it decreases unit production costs and hence decreases market price. Now, suppose that involuntary spillovers are sufficiently high ($\theta>1/2$). Then RJV creates positive externalities on consumers because it results in bigger R&D investment and hence lower market price, compared to R&D non-cooperation. Therefore, policy authorities should encourage firms to form an RJV especially when the firms do not find private interests on RJV formation because of high fixed RJV formation costs. Meanwhile, RJV formation creates negative externalities on consumers if involuntary spillovers are sufficiently low ($\theta<1/2$), because it results in lower R&D investment and higher market price compared to R&D non-cooperation. Thus, policy authorities should discourage firms from forming an RJV when the firms find their private interests on RJV formation.

Second, if spillover cost is below the threshold level ($k<k^c$), then the firms under RJV choose maximal spillovers. This is equivalent to the result obtained

by Katz(1986) and Poyago-Theotoky (1999). Both show that the firms under RJV will choose maximal spillovers without spillover costs. Kamien, Muller, and Zang (1992) show that the efficiency gains, which are based on complete information sharing under RJV, are so big that consumers gain. As we showed above, however, firms do not have incentives to form an RJV if the fixed RJV formation costs are sufficiently high ($F>F^{vc2}$). The policy implication is that government may need to encourage firms to form an RJV through subsidy when firms do not find private interests on RJV formation.

Ⅳ. CONCLUSION

This paper considers the problem of R&D competition in the presence of spillovers. Unlike most previous studies where spillovers are treated as exogenous, we allow spillovers to be determined endogenously. The other important feature in our model is to introduce costly RJV formation, which is more reasonable in a real economy as suggested by Vilasuso and Frascatore. Two main questions we have asked in this paper are whether firms under RJV (or R&D cooperation) will choose to share their information completely, and whether private interests are consistent with public interests in terms of total welfare.

Regarding the first question, we showed that firms under RJV would achieve complete information sharing only if spillover costs are sufficiently low. Meanwhile firms under RJV do not share any information if spillover costs are very high. This result is novel in the sense that it was never found in previous studies where a homogenous good and Cournot competition in the final market are assumed. Unlike the previous studies where private interests on RJV are consistent with public interests, we also found that private interests with an RJV are not consistent with public interests for a wide range of parameter values. Thus, we suggest the potential need for active government intervention on RJV formation. As seen in the previous sections, RJV formation costs, spillover costs, and involuntary spillovers are key determinants of which policy government should consider when it decides whether to intervene or not.

The main policy implications are as follows. First, if spillover costs and the degree of involuntary spillover are sufficiently high and low, respectively, then government should discourage firms from joining in an RJV for relatively low RJV formation costs while no government intervention is necessary for relatively high RJV formation costs. Second, if both spillover costs and the degree of involuntary spillover are sufficiently high, then government does not have to implement any policy for very low or high RJV formation costs, while government should encourage firms to join in an RJV for a moderate level of RJV formation costs. Finally, if spillover costs are sufficiently low, the same results as in the second case are obtained, but it is shown that the critical value of RJV formation costs is different.

There are a few possible extensions of this paper. As mentioned earlier, the assumption of 'joint profit maximization' under RJV may be inappropriate, especially when the two firms are rivals in the final market. Thus, it is worthwhile to investigate the relevancy of the 'joint profit maximization' assumption under RJV. A second possible extension is to consider a case in which firms face Bertrand competition with differentiated products in the final market. This may help examine the robustness of the results obtained in this paper. A third extension is to introduce initially asymmetric firms. Then, probably we may find asymmetric outcomes as equilibrium, and thus we may obtain a more practical policy implication. The last extension is to introduce a research design step and consider different research outcomes. This is obviously more realistic and it may help understand the role of information sharing.

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