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R&D Spillovers and Optimal Anti-Trust Enforcement

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Using a three-stage game model, this paper analyzes the optimal level of anti-trust enforcement against joint production in relation to the degree of R&D spillovers. It shows that the optimal level of anti-trust enforcement is negatively related to the magnitude of R&D spillovers. In particular, the government should show some tolerance of joint production cartels only when R&D spillovers are sufficient for firms to cooperate voluntarily in their R&D activities. When R&D spillovers are so weak that firms do not cooperate voluntarily in the R&D stage, the government should intensify anti-trust enforcement against joint production to a prohibitive level.

Keywords : R&D, Spillovers, Cooperation, Anti-trust, Social Welfare.
JEL Classifications : L0, L1, L4, L5

I. Introduction

This paper investigates the level of anti-trust enforcement against joint production that is called for in industries where R&D activities and their spillover effects are significant. One motivation for examining this situation is disputes over the revision of anti-trust law in the United States in the early 1990s.

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Jorde and Teece (1990) have suggested that the protection of cooperative R&D must be extended to the collusive use of such R&D results in order to encourage investments in R&D by high-tech firms. By contrast, Shapiro and Willig (1990) and Brodley (1990) have opposed this relaxed anti-trust policy against joint production on the grounds that it would result in much greater social costs due to the increased market power of joint producers. The major controversy over the relaxation of anti-trust enforcement relates to whether the social benefits produced by enhanced R&D incentives are outweighed by the social costs caused by producers' increased market power. Despite these disputes, few studies have attempted to use economic analysis to shed light on this controversy and to provide guidelines for policy makers. This paper will attempt to provide an economic model formally addressing this issue. To this end, it deals with situations where the competitive structure of the product market is endogenously determined by the intensity of anti-trust enforcement against joint production.

Many studies[1)] have examined the economic implications of cooperative R&D investment in relation to the competitive structure of product markets. However, these studies are not relevant for analyzing the current issue because they analyze firms' incentives to invest and cooperate in R&D only within the predetermined competitive structures of the product markets. For instance, the seminal work of d'Aspremont and Jacquemin (1988) analyzes firms' incentives to invest and cooperate in R&D under the assumption that the competitive structure of a product market is determined exogenously as either joint production or duopoly competition. Likewise, previous studies have overlooked the fact that the structure of market competition may be affected by the degree to which governments enforce anti-trust measures in their efforts to maximize social welfare.

In this paper, the competitive structure of the product market is affected by the degree of anti-trust enforcement against joint production, which is determined by the government maximizing social welfare. Firms try to maximize

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1) See, for example, d'Aspremont and Jacquemin (1988), Suzumura (1992), Kamien et al. (1992) Ziss (1994) Yi (1996) and Leahy and Neary (1997)

their profits by adjusting their levels of R&D and production in accordance with the intensity of anti-trust enforcement determined by the government. Using a simple three-stage game model, we will analyze the effects that a change in anti-trust enforcement against joint production has on the level of R&D, cooperation in R&D, and social welfare. In particular, these effects are examined in relation to the degree of R&D spillovers. It is well known that strong R&D spillovers are likely to cause insufficient R&D incentives from a social welfare standpoint. Strong R&D spillovers may therefore provide a justification for relaxing anti-trust enforcement which would enhance R&D incentives. In this regard, we would like to provide some guidelines for anti-trust authorities and legislatures for setting optimal anti-trust enforcement against joint production in innovating industries where incentives to invest and cooperate in R&D are of great importance. For this, the level of anti-trust enforcement maximizing social welfare will be investigated in relation to the degree of R&D spillovers.

The plan of this paper is as follows. Chapter 1 introduces the three-stage game model where the competitive structure of the product market is decided endogenously by the government that chooses the intensity of anti-trust enforcement maximizing social welfare. Chapter 2 shows free market outcomes for a given intensity of anti-trust enforcement. Chapter 3 provides the full description of the model by solving for the intensity of anti-trust enforcement needed to maximize social welfare. Chapter 4 concludes with a summary of the results.

Ⅱ. The Model

In this chapter, we construct a simple model to reflect the idea that the competitive structure of a product market is determined by the intensity of anti-trust enforcement against joint production.

1. Demand and cost structure[2)]

Assume that there are two identical firms, *1* and *2,* each with a quadratic cost function for R&D and a unit production cost function that is independent of the level of production. Given a linear demand, each firm maximizes its profits. Each firm's level of R&D is denoted by x_1 and x_2 respectively, and each firm's unit production cost, reflecting the spillover effect of R&D, is written as :

$$c_i = c_0 - (x_i + \eta x_j)\ ;\ i,j = 1,2,\ \ c_o > 0,\ \ 0 \leq \eta \leq 1 \tag{1}$$

where η can be interpreted as the degree of spillover effects. Products are assumed to be homogeneous. The linear demand and the quadratic R&D cost function are given as :

$$p = a - bQ,\ a,b > 0,\ \ a,b > 0, \tag{2}$$

$$C(x) = \gamma \frac{x^2}{2},\ \gamma > 0, \tag{3}$$

where x is the level of R&D investment.

2. Game structure

The model is based on a three-stage game. In addition to the two firms, the game also includes the government as a player, which, in the first stage of the game, decides upon and commits to a specific level of anti-trust enforcement against joint production to maximize social welfare. This government decision can be regarded as being irreversible for a certain period of time, as it involves complicated legislative and administrative procedures. Assume that this level of anti-trust enforcement against joint production is specifically

2) We have adopted the basic components of the model, such as the demand and cost functions, from d'Aspremont & Jacquemin (1988) to take advantage of the simplicity of their model.

represented by the probability of a successful joint production. Let P denote this probability.[3] It is natural to assume that firms know this probability or the level of anti-trust enforcement committed by the government when they engage in their R&D activities and production. Therefore, given P, firms choose the levels of R&D and production to maximize their profits. Since R&D investment and production have a natural temporal sequence, the level of R&D is chosen in the second stage and the level of output in the third stage.

In the production stage, assume that firms face a choice between forming a joint production cartel and competing in the Cournot manner. For the sake of simplicity, once firms agree on the joint production cartel, we assume that it is not possible to deviate from the cartel without such behavior being noticed and that the agreed penalty for such noticed deviations is sufficiently severe and instantaneous to ensure that such deviations are unprofitable. That is, firms have no incentive to deviate from their agreement on the joint production cartel and thus the joint production cartel is stable once it is established.

In the absence of government intervention against the joint production cartel, it is obvious that under our simplifying assumptions, the formation of the joint production cartel is a strongly dominant strategy compared to simply engaging in Cournot competition. Thus, in this case we have $P=1$ or $1-P=0$. That is, the level of anti-trust enforcement against joint production is at its minimum.

With government intervention against joint production, we have$0<1-P\leq 1$. That is, the probability of the government discovering the joint production cartel is given by $1-P$. In this case, the government randomly monitors joint production of firms entering the production stage. For the simplicity, we assume that the government monitors firms only at the moment they enter the production stage and that once their joint production is not disclosed by this monitoring, they can produce jointly. On the contrary, when firms engaging in joint production are detected by the government, they are forced to compete

3) This underlies the assumption that the intensity of anti-trust enforcement against joint production does not vary according to whether firms to cooperate in R&D or not.

in the Cournot manner by the credible threat of a government-imposed financial penalty that is sufficiently large to ensure that firms do not attempt to reestablish the joint production cartel. To avoid unnecessary complications and maintain the focus on the main subjects, we also assume that the government does not impose any financial penalty on a joint production cartel the first time it is detected. Considering the fact that the government could adjust the amount of financial penalty as well as the intensity of monitoring to control the joint production, this simplifying assumption enables us to confine the control variables of the government regarding the anti-trust enforcement against joint production to the intensity of monitoring only.

In the case of a prohibitive level of anti-trust enforcement, we have $P=0$ or $1-P=1$. That is, the level of anti-trust enforcement against joint production is at its maximum. In this case, every attempt to form a joint production cartel by firms is detected before they successfully produce jointly and therefore, firms always compete in the Cournot manner in the production stage.

Ⅲ. Equilibrium With a Given Intensity of Anti-trust Enforcement

We will figure out the subgame perfect equilibrium in this game using backward induction. To begin with we will solve the equilibrium for the last two stages given an intensity of anti-trust enforcement determined by the government in the first stage. For simplicity, we consider only the symmetric equilibrium where both firms invest the same amount in R&D.[4)]

At the third stage, each firm determines its level of output by taking into consideration the level of R&D resulting from the second stage and the in-

4) This is a common assumption, but it may be open to discussion. As Salant and Shaffer (1998)noted, there may be asymmetric strategies that may create larger industry profits than the symmetric strategy. In order to avoid unnecessary complexity and maintain the focus on the main subjects, we do not consider such situations.

tensity of the anti-trust enforcement decided by the government in the first stage. This decision depends on whether the competitive structure realized in the product market is based on a joint production cartel or Cournot competition. When two firms succeed in forming a joint production cartel, they will decide upon the level of output so as to maximize industry profits. The two firms will produce the same amount of output since they will have identical unit production costs in this symmetric equilibrium. In this case, the level of industry output can be solved in terms of the level of R&D using the following maximization problem :

$$\max_{Q} \Pi_S \equiv Q\left[\left(a-bQ\right)-\frac{1}{2}c_1-\frac{1}{2}c_2\right]. \tag{4}$$[5]

From (4), we obtain the following relationships in the symmetric equilibrium:

$$Q_S=\frac{\left(A+\theta x\right)}{2b},\ \ q_S=\frac{\left(A+\theta x\right)}{4b} \tag{5}$$

$$\Pi_S=\frac{\left(A+\theta x\right)^2}{4b},\ \ \pi_S=\frac{\left(A+\theta x\right)^2}{8b}, \tag{6}$$

where $A=a-c_0$ and $\theta=1+\eta$. The term θ can be interpreted as the efficiency of the R&D investment. The small letters represent the levels for individual firms.

When the two firms fail to form a joint production cartel and instead face Cournot competition, both the industry's and the firms' level of output and profits are given as :

$$Q_F=\frac{2\left(A+\theta x\right)}{3b},\ \ q_F=\frac{\left(A+\theta x\right)}{3b} \tag{7}$$[6]

$$\Pi_F=\frac{2\left(A+\theta x\right)^2}{9b},\ \ \pi_F=\frac{\left(A+\theta x\right)^2}{9b} \tag{8}$$

5) Subscript S stands for success in the formation of the joint production cartel.
6) Subscript F stands for failure in the formation of the joint production cartel.

At the second stage, each firm selects its level of R&D, given the behavior of each firm in the third stage, which is represented by (6) and (8). In the case of R&D cooperation,[7] each firm decides upon its level of R&D to maximize industry profits, whereas in the case of R&D competition, each firm chooses its level of R&D to maximize its own profits.

1. Equilibrium with R&D cooperation

When two firms cooperate in R&D, the maximization problem facing each firm is given as :

$$\max_{x_i} E\Pi = P\Pi_S + (1-P)(\pi_F^A + \pi_F^B) - \gamma \frac{x_1^2 + x_2^2}{2} \;;\; i,\, j = 1,\, 2. \tag{9}$$

Using (6), (8) and the first order conditions for (9), we can obtain the level of cooperative R&D investment in the symmetric equilibrium as follows :

$$x^C = \frac{A\theta\psi^C}{b\gamma - \theta^2\psi^C}, \tag{10}$$

where $\psi^C \equiv \psi^C(P) = \frac{1}{4}P + \frac{2}{9}(1-P)$. The second order condition for (9) is given by $b\gamma - \theta^2\psi^C > 0$ and is assumed to be satisfied for arbitrary values of η and P to exclude any corner solutions. Note that the necessary and sufficient condition for this is given by $b\gamma > 1$, as we have $\max_{\eta,P} \theta^2\psi^C = 1$. Henceforth, we assume $b\gamma > 1$. Once the level of R&D investment is determined from (10), the expected level of output and profits for each firm can be derived as :

$$Eq^C = \frac{A\gamma\psi^q}{b\gamma - \theta^2\psi^C}, \quad \psi^q \equiv \frac{1}{4}P + \frac{1}{3}(1-P) \tag{11}$$

$$E\pi^C = \frac{b\psi^C}{2}\left[\frac{A\gamma}{b\gamma - \theta^2\psi^C}\right]^2 \tag{12}$$

7) Cooperative R&D or R&D cooperation can be defined in several ways. Following d'Aspremont and Jacquemin (1988), we define it as a mode of R&D where cooperating firms maximize the sum of their profits.

2. Equilibrium with R&D competition

When the two firms compete in R&D, the maximization problem facing each firm is given as :

$$\max_{x_i} E\pi^i = P\frac{1}{2}\Pi_S + (1-P)(\pi_F^i) - \gamma\frac{x_i^2}{2}, \; i = A, \; B. \tag{13}$$

Using (6), (8) and the first order conditions for (13), we obtain the level of competitive R&D investment in the symmetric equilibrium as follows :

$$x^N = \frac{A\theta\psi^N}{b\gamma - \theta^2\psi^N}, \tag{14}$$

where $\psi^N \equiv \psi^N(P, \eta) = \frac{1}{8}P + \frac{2}{9}(1-P)\frac{2-\eta}{1+\eta}$. Note that the second order condition for (13) is satisfied for arbitrary values of η and P under the assumption of $b\gamma > 1$ as we have $\max_{\eta,P}\theta^2\psi^N = 1/2$. Once the level of the R&D investment is chosen from (14), the expected level of output and profits for each firm can be derived as :

$$Eq^N = \frac{A\gamma\psi^q}{b\gamma - \theta^2\psi^N}, \tag{15}$$

$$E\pi^N = \frac{b\psi^C}{2}\left[\frac{A\gamma}{b\gamma - \theta^2\psi^N}\right]^2 \tag{16}$$

3. Comparison between two equilibria

Let us compare two equilibria that are characterized by (10) and (14), respectively. From these equations, it is simple to show the following :

$$x^C \gtrless x^N \Leftrightarrow \eta \gtrless \chi(P) \equiv \frac{16-25P}{32-23P}, \; 0 \le \eta, \; P \le 1. \tag{17}$$[8]

This implies that the cooperative level of R&D is higher than the competitive level when either the degree of R&D spillover effects is sufficiently high or the anti-trust enforcement is very loose. In particular, when $P > \frac{16}{25}$ or $\eta > \frac{1}{2}$, the cooperative level of R&D always dominates the competitive level of R&D. Regarding this result, it is notable that the cooperative level of R&D always dominates the competitive level irrespective of the degree of spillovers when the anti-trust enforcement is tight enough. Intuitively, when firms compete in R&D, additional investment by one firm is more profitable in the case of Cournot competition than in the case of a joint production cartel due to the business stealing effect. Therefore, loosened anti-trust enforcement or the decreased chance of Cournot competition will reduce the investment incentives under competitive R&D. In other words, a increase in P, *ceteris paribus*, will decrease R&D investment in this case. On the other hand, this business stealing effect does not exist when firms cooperate in R&D, since it is only industry profit that matters. In the case of cooperative R&D, loosened anti-trust enforcement or the increased chance of joint production encourages R&D investment due to the increased expected profits.

In addition, from (11) and (15), we have the following :

$$x^C \gtreqless x^N \Leftrightarrow Eq^C \gtreqless Eq^N. \tag{18}$$

That is, the expected level of production is higher in the case of cooperative R&D when the cooperative R&D creates more incentives for R&D investment. When the cooperative R&D is better motivated than the competitive R&D, the marginal cost of production becomes lower and consequently the profit maximizing level of production becomes larger with the cooperative R&D.

When individual firms make choices between R&D cooperation and competition, they will compare expected profits in both cases. That is, they will choose

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8) In fact, the results of d'Aspremont and Jacquemin (1988) can be derived as special cases of equation (17) where P = 0 or P = 1, that is, the product market structures are exogenously predetermined as Cournot competition or joint production respectively.

to cooperate (compete) in R&D when cooperation (competition) in R&D yields higher expected profits. Because the expected profits of individual firms are identical in the symmetric equilibrium, we can investigate the natural choices of firms by comparing the industry profits. The following proposition sums up the result :

Proposition 1. $E\Pi^{C} \gtrless E\Pi^{N} \Leftrightarrow x^{C} \gtrless x^{N}$, where Π^{C} and Π^{N} are industry profits from cooperative R&D and competitive R&D respectively.

Proof. By using (12) and (16), we have $\frac{E\Pi^{C}}{E\Pi^{N}} = \frac{E\pi^{C}}{E\pi^{N}} = \left[\frac{b\gamma - \theta^{2}\psi^{N}}{b\gamma - \theta^{2}\psi^{C}}\right]^{2}$. Since $\psi^{C} \gtrless \psi^{N} \Leftrightarrow x^{C} \gtrless x^{N}$, we can conclude that $E\Pi^{C} \gtrless E\Pi^{N} \Leftrightarrow \psi^{C} \gtrless \psi^{N}$ $\Leftrightarrow x^{C} \gtrless x^{N}$. **Q.E.D.**

Therefore, firms will cooperate voluntarily in their R&D efforts to pursue higher expected profits when cooperation creates higher R&D incentives. Intuitively, in case the cooperative R&D is better motivated than the competitive R&D, the cost of unit production becomes lower with the cooperative R&D regardless of product market structure as is indicated by the equation (1). With given demand and cost functions, this reduction of unit cost outweighs the decrease of average revenue caused by the increased production so that the profits will be higher with the cooperative R&D than with the competitive R&D. This can be easily confirmed from the equations (6) and equations(8) that describe the maximized profits as increasing functions of the level of R&D investment.

Note that this result would be maintained under the underlying assumption that coordination cost would not be incurred or would be negligible in the course of cooperation in R&D. If substantial cost would be inevitable in the coordination of R&D efforts between firms, then it would be possible for firms not to cooperate voluntarily in their R&D efforts despite such cooperation could create higher R&D incentives.

Ⅳ. Welfare Implications

The full description of the equilibrium, including the government-determined level of anti-trust enforcement will be presented in this chapter. The welfare implications of the model will also be explored.

1. Evaluation of two equilibria in terms of social welfare

The market choice driven by private incentives can be evaluated from a social welfare standpoint. Social welfare is measured by the sum of consumers' surplus and firms' profits. When each firm invests x in R&D, the expected level of social welfare from the investment can be expressed as :

$$E(W) \equiv P\int_0^{Q_s} b[2Q_s - Q]\,dQ + (1-P)\int_0^{Q_F} b\left[\frac{3}{2}Q_F - Q\right]dQ - \gamma x^2 \tag{18}$$

By using (5) and (7), (18) can be reduced to :

$$E(W) = \frac{(A+\theta x^2)}{b}\psi^W - \gamma x^2, \tag{19}$$

where $\psi^W \equiv \psi^W(P) = \frac{3}{8}P + \frac{4}{9}(1-P)$. Let EW^C and EW^N denote the expected levels of social welfare when firms engage in cooperative and competitive R&D respectively. Note that $E(W) = EW^C$ if $x = x^C$ and $E(W) = EW^N$ if $x = x^N$. The next proposition shows that private incentives coincide with social incentives :

Proposition 2. $EW^C \gtreqless EW^N \Leftrightarrow x^C \gtreqless x^N$.

Proof. See Appendix 1.

This proposition implies that the order of magnitude of the expected levels of welfare coincides with the order of magnitude of the levels of R&D investment. In fact, D'Aspremont and Jacquemin (1988) and Leahy and Neary (1997) provide similar results on which they base their claim that government intervention to promote R&D cooperation is unnecessary. Together with Proposition 1, this result suggests that firms will naturally make a socially desirable choice between R&D cooperation or competition in accordance with government decisions on the intensity of anti-trust enforcement.

Note that, like proposition 1, this result would not be maintained if coordination cost would be substantial in the course of R&D cooperation.

Note also that this social welfare function does not take into account the cost that is likely to be incurred in the course of monitoring against joint production. However, it is straightforward to see that the consideration of monitoring cost does not affect the proposition 2 as long as the amount of monitoring cost is independent of whether firms cooperate or not in their R&D efforts.

2. Optimal anti-trust enforcement

In the first stage of the game, the government determines what intensity of anti-trust enforcement against joint production, or $1-P$, will maximize social welfare, given the strategies that will be adopted by the two firms in the R&D and production stages. Using notation from (17), we define N and C as $N \equiv \{(\eta, P) | \eta < \chi(P)\}$ and $C \equiv \{(\eta, P) | \eta \geq \chi(P)\}$ respectively. Note that firms will voluntarily choose to cooperate in R&D when $(\eta, P) \in C$ and to compete in R&D when $(\eta, P) \in N$. From (10), (14) and (17), the following can be easily verified :

$$\frac{\partial x^C}{\partial P} > 0 \text{ if } (\eta, P) \in C, \tag{20}$$

$$\frac{\partial x^N}{\partial P} < 0 \text{ if } (\eta, P) \in N. \tag{21}$$

When firms compete in R&D, additional investment by one firm is more profitable in the case of Cournot competition than in the case of a joint production cartel due to the business stealing effect. Therefore, as shown in (21), intensified anti-trust enforcement or the increased chance of Cournot competition will improve the investment incentives under competitive R&D. On the other hand, this business stealing effect does not exist when firms cooperate in R&D, since it is only industry profit that matters. In the case of cooperative R&D, intensified anti-trust enforcement or the decreased chance of joint production discourages R&D investment due to the decreased expected profits, as indicated in (20).

From this, we can predict that when firms choose to compete in R&D, intensified anti-trust enforcement is likely to raise social welfare because it will increase the level of R&D as well as the level of expected output given the level of R&D. In this case, it would be appropriate for the government to maximize its anti-trust monitoring. When by contrast, firms choose to cooperate in R&D, intensified anti-trust enforcement decreases the level of R&D, and this negative effect may outweigh the positive effect caused by producers' decreased market power. In this case, it may thus be preferable to ease anti-trust enforcement to some extent, depending on the market situation.

This intuitive argument provides a clue as to how the level of anti-trust enforcement should be determined in order to raise social welfare. Nevertheless, it is not a straightforward task for the government to do this. The following major proposition supports the preceding intuitive argument and provides guidelines for the government's decision.

Proposition 3. Let $b\gamma \equiv \lambda$ for notational simplicity. For a given $\eta \in [0, 1]$, we have :

$$\arg\max_P \left(E(W)\right) = \arg\max_P \left(EW^C\right) = 1, \qquad \text{if } \frac{20}{7}\lambda \le (1+\eta)^2$$

$$\arg\max_P \left(E(W)\right) = \arg\max_P \left(EW^C\right) = 8 - 20 \cdot \frac{\lambda}{(1+\eta)^2}, \qquad \text{if } \frac{20}{8}\lambda < (1+\eta)^2 < \frac{20}{7}\lambda$$

$$\arg\max_P \left(E(W)\right) = \arg\max_P \left(EW^C\right) = 0, \qquad \text{if } \frac{9}{4} \le (1+\eta)^2 \le \frac{20}{8}\lambda$$

$$\arg\max_P \left(E(W)\right) = \arg\max_P \left(EW^N\right) = 0, \qquad \text{if } 1 \le (1+\eta)^2 < \frac{9}{4}$$

Proof. See Appendix 2.

Many implications can be drawn from this. First, this proposition implies that the intensity of anti-trust enforcement maximizing social welfare can be greater than zero, depending on the degree of R&D spillovers. In fact, given the value of λ, the optimal intensity of anti-trust enforcement, say, $1-\hat{P}$, is a non-increasing function with respect to the degree of R&D spillovers, namely η. Therefore, the more R&D activities of related firms are characterized by stronger spillover effects, the more anti-trust enforcement against the joint production cartel should be relaxed. In the case of sufficiently strong spillover effects in the R&D activities of related firms, the anti-trust authority may even fully allow the joint production cartel.

Secondly, optimal anti-trust enforcement against the joint production cartel should allow some degree of joint production only if the R&D spillovers are sufficient for related firms to cooperate voluntarily in their R&D activities. In other words, $1-\hat{P}<1$ only if $E\Pi^{C}>E\Pi^{N}$. Therefore, the anti-trust policy can accommodate the joint production cartel to some extent only when the R&D spillovers are so strong that related firms would voluntarily cooperate in their R&D activities without any government intervention.

Thirdly, when R&D spillovers are weak enough that firms do not cooperate voluntarily in their R&D activities, the optimal anti-trust enforcement should be prohibitively severe. That is, we have $1-\hat{P}=1$ if $E\Pi^{C}<E\Pi^{N}$. Note that this prohibitive anti-trust enforcement can also be optimal even when firms cooperate voluntarily. As is shown in the proposition above, we have $1-\hat{P}=1$, with a relatively low degree of R&D spillovers, or $(1+\eta)^2 \leq \frac{20}{8}\lambda$.

Finally, the above proposition suggests that joint exploitation of R&D results should be generously allowed when the slope of the demand (b) is gentle and the curvature of the R&D cost curve (γ) is mild relative to the degree of R&D spillovers. Intuitively, the cost of additional R&D investment in this case is small relative to its effect on the increase in output, and the positive effect of joint production on R&D incentives is thus more likely to outweigh its negative effect on the output level.

V. Conclusion

This paper has analyzed the optimal intensity of anti-trust enforcement against joint production in relation to the degree of R&D spillovers. For this purpose, a simple three-stage game was constructed where the government sets the intensity of antitrust enforcement against joint production to maximize social welfare in the first stage.

Using this model, we showed that the intensity of anti-trust enforcement maximizing social welfare could allow some degree of joint production. In fact, we showed that the optimal intensity of anti-trust enforcement is negatively related to the magnitude of R&D spillovers. In particular, anti-trust enforcement may be relaxed only when the R&D spillovers are sufficient for firms to cooperate voluntarily in their R&D activities. When firms do not cooperate voluntarily in the R&D stage due to weak R&D spillovers, we showed that to maximize social welfare, there needs to be a prohibitively high level of anti-trust enforcement.

We can provide some guidelines for anti-trust authorities and legislatures in setting optimal anti-trust enforcement against joint production for innovating industries where incentives to invest and cooperate in R&D activities are of great importance.

First, in industries where R&D activities are characterized by stronger spillover effects, the government should show greater tolerance for joint production cartels. Secondly, the government should show some tolerance of joint production cartels only when the R&D spillovers are sufficient for related firms to voluntarily cooperate in their R&D activities. Third, when R&D spillovers are so weak that firms do not cooperate voluntarily in their R&D activities, the government should intensify anti-trust enforcement to a prohibitive level. Finally, to obtain a more detailed anti-trust policy, the government should investigate the demand and cost structure of the industry as well as the degree of R&D spillovers and the presence of voluntary R&D cooperation.

Note that these results may have limited implications due to the simple structure of the model. It is worth to check in future research whether these results and implications continue to be valid with general forms of demand and cost functions. Besides the simplistic demand and cost functions, we ignore the monitoring cost that is likely to increase with the efforts of monitoring against joint production and the coordination cost that is likely to be substantial in the R&D cooperation of the real world. Although we briefly argued the effects of considerations of such costs on the results, it would be interesting to investigate further the implications of monitoring cost and coordination cost in future research. For example, if the monitoring cost is incurred by the lump sum, then the main results of this paper would remain unchanged. However, if the monitoring cost is increasing with the monitoring intensity, then the optimal monitoring intensity that maximizes the expected level of social welfare would be lowered. If the coordination cost is substantial in the R&D cooperation, then it will have a considerable effect on the main results because it is possible for firms not to cooperate voluntarily despite the cooperation is socially desirable.

In addition, we may extend the model by including the amount of financial penalty as an additional policy instrument against joint production. In this case, we could examine the optimal choice of the government between the amount of financial penalty and the intensity of monitoring against joint production. Finally, in this paper, the government does not differentiate its monitoring intensity between firms with cooperative R&D and with competitive R&D. Regarding this, we could consider the situations where the monitoring intensity is stronger or weaker against firms with cooperative R&D than against firms with competitive R&D in a further complicated model.

Appendix 1. Proof of Proposition 2

By making use of (10) or (14), (19) can be written as :

$$E(W)=\frac{A^2\gamma(b\gamma\psi^W-\theta^2\psi^2)}{(b\gamma-\theta^2\gamma)^2} \tag{A1}$$

Note that $E(W)=EW^C$ if $\psi=\psi^C$ and $E(W)=EW^N$ if $\psi=\psi^N$. At the point $P=0$, $\eta=0$, we have $\psi^W=\psi^N>\psi^C$ and, in this case, we have the following :

$$\frac{EW^N}{EW^C}=\frac{(b\gamma-\theta^2\psi^C)}{(b\gamma-\theta^2\psi^N)}\frac{(b\gamma-\theta^2\psi^C)}{(b\gamma-\theta^2\psi^C\bullet\frac{\psi^C}{\psi^N})}$$

$$=\frac{(b\gamma)^2+(\theta^2\psi^C)^2-2b\gamma\,\theta^2\psi^C}{(b\gamma)^2+(\theta^2\psi^C)^2-b\gamma\theta^2\psi^N\big((\psi^N)^2+(\psi^C)^2\big)}>1 \tag{A2}$$

The last inequality is derived from the following :

$$-2b\gamma\,\theta^2\psi^C+b\gamma\,\theta^2\,\frac{1}{\psi^N}\big((\psi^C)^2+(\psi^C)^2\big)=b\gamma\,\theta^2\,\frac{1}{\psi^N}\,(\psi^N-\psi^C)^2>0 \tag{A3}$$

Differentiating (A1) with respect to ψ yields :

$$\frac{\partial E(W)}{\partial\psi}=\frac{2bA^2\theta^2\gamma^2\,(\psi^W-\psi)}{(b\gamma-\theta^2\psi)^3} \tag{A4}$$

As $\psi^W>\max(\psi^N,\psi^C)$, for all (P,η) except at the point $P=0$, $\eta=0$, we have $\frac{\partial E(W)}{\partial\psi}>0$ for all (P,η) except at the point $P=0$, $\eta=0$. With (A2), this proves $EW^C\gtrless EW^N\Leftrightarrow\psi^C\gtrless\psi^N$ for all (P,η) since $E(W)$ is continuous with respect to ψ. We have $\psi^C\gtrless\psi^N\Leftrightarrow\chi^C\gtrless\chi^N$ from (10) and (14) and the result follows.

Q.E.D.

Appendix 2. Proof of Proposition 3

Let $\frac{b\gamma}{\theta^2} \equiv \phi$ for notational simplicity. Note that $E(W) = EW^C$ if $\psi = \psi^C$ and that $E(W) = EW^N$ if $\psi = \psi^N$. From (A1) we have the following :

$$\frac{\partial EW^C}{\partial P} = \frac{\partial EW^C}{\partial \psi^C}\psi_P^C + \frac{\partial EW^C}{\partial \psi^W}\psi_P^W = 0$$

$$\Rightarrow \hat{P} = \frac{\psi_P^W k^C - 2\psi_P^C k^W + 2\psi_P^C k^C}{\psi_P^C \psi_P^W - 2(\psi_P^C)^2} - \frac{\psi_P^W}{\psi_P^C \psi_P^W - 2(\psi_P^C)^2} \cdot \phi = 8 - 20 \cdot \phi, \tag{A5}$$

where $\psi^i \equiv \psi_P^i \cdot P + k^i$, $i = W, C$. For the second order condition we have :

$$\mathrm{sgn}\left[\frac{\partial^2 EW^C}{\partial P^2}\right] = \mathrm{sgn}\left[\frac{\partial^2 EW^C}{\partial (\psi^C)^2}(\psi_P^C)^2 + 2 \cdot \frac{\partial^2 EW^C}{\partial \psi^C \psi^W}\psi_P^C \psi_P^W\right]$$

$$= -\mathrm{sgn}\left[b\gamma - \left(\psi^C - \frac{3\psi_P^C}{2\psi_P^W - \psi_P^C}(\psi^W - \psi^C)\right)\theta^2\right] = -\mathrm{sgn}\left[b\gamma - \left(-\frac{1}{48}P + \frac{1}{3}\right)\theta^2\right] \tag{A6}$$

From (A5) and (A6) we have :

$$\mathrm{sgn}\left[\left.\frac{\partial^2 EW^C}{\partial P^2}\right|_{P=\hat{P}}\right] = -\mathrm{sgn}\left[\phi - \frac{2}{7}\right] \tag{A7}$$

As we should have $0 \le P \le 1$, we should consider three cases. First, when we have $0 \le 8 - 20 \cdot \phi \le 1$, it is easy to see that the second order condition is satisfied and that therefore EW^C reaches its maximum at $P = 8 - 20 \cdot \phi$. Second, when we have $8 - 20 \cdot \phi < 0$, we should then compare the values of EW^C evaluated at $P = 0$ and $P = 1$. From (A1), it can be verified after some algebra that when $8 - 20 \cdot \phi < 0$, the value of EW^C is greater at $P = 0$ than at $P = 1$. Therefore, EW^C reaches its maximum at $P = 0$ in this case. Note that $\phi > \frac{1}{4}$ from the assumption of $b\gamma > 1$ and $0 \le \eta \le 1$. Finally, when we have $8 - 20 \cdot \phi > 0$ and $\phi > \frac{1}{4}$, namely, $\frac{1}{4} < \phi < \frac{7}{20}$, we can also verify from (A1) that the value of EW^C is greater at $P = 1$ than at $P = 0$. Therefore, EW^C reaches its maximum at $P=1$ in this case.

Therefore, we have the following results from (A5), given η :

$$\arg\max_{P}\left(EW^{C}\right)=1 \text{ if } \phi \leq \frac{7}{20} \tag{A8}$$

$$\arg\max_{P}\left(EW^{C}\right)=\hat{P}=8-20\cdot\phi \text{ if } \frac{7}{20}\leq\phi\leq\frac{8}{20} \tag{A9}$$

$$\arg\max_{P}\left(EW^{C}\right)=0 \text{ if } \frac{8}{20}<\phi \tag{A10}$$

Now, we want to show that $\frac{\partial EW^{N}}{\partial P}<0$ in $(\eta, P)\in N$, which means that $\arg\max_{P}\left(EW^{N}\right)=0$ in $(\eta, P)\in N$. Differentiating (19) with respect to P gives the following expression :

$$\frac{\partial EW^{N}}{\partial P}=\frac{\partial EW^{N}}{\partial\psi^{W}}\frac{\partial\psi^{W}}{\partial P}+\frac{\partial EW^{N}}{\partial x^{N}}\frac{\partial x^{N}}{\partial P} \tag{A11}$$

The first term of (A11) is negative because $\frac{\partial EW^{N}}{\partial\psi^{W}}=\frac{(A+\theta x^{N})^{2}}{b}>0$ and $\frac{\partial\psi^{W}}{\partial P}=-\frac{5}{72}<0$. As for the sign of $\frac{\partial EW^{N}}{\partial x}$, note that $\left.\frac{\partial E(W)}{\partial x}\right|_{x=x^{N}}\geq 0$ because $\left.\frac{\partial E(W)}{\partial x}\right|_{x=\arg max(EW)}=0$, $\frac{\partial^{2}E(W)}{\partial x^{2}}<0$ from the first and the second order conditions for maximization of (19) with respect to x and $\max(x^{C}, x^{N})\leq\arg\max(E(W))$. Note also that $\frac{\partial x^{N}}{\partial P}<0$ in $(\eta, P)\in N$ from (21). Therefore, we can conclude that $\frac{\partial EW^{N}}{\partial P}<0$ in $(\eta, P)\in N$, which proves that $\arg\max_{P}\left(EW^{N}\right)=0$ in $(\eta, P)\in N$.

Last, we derive $\arg\max_{P}\left(E(W)\right)$. Given $\eta\in[0, 1]$, note that $EW^{C}\leq EW^{N}$ in $(\eta, P)\in N$ and $EW^{N}\leq EW^{C}$ in $(\eta, P)\in C$ from Proposition 2. Therefore, we have $\arg\max_{P}(E(W))=\arg\max_{P}\left(EW^{N}\right)$ when $\left(\eta, \arg\max_{P}\left(EW^{N}\right)\right)\in N$ and $\arg\max_{P}(E(W))=$

$\arg\max_P(EW^C)$ when $\left(\eta, \arg\max_P(EW^C)\right) \in C$. Let η_0 denote η satisfying $\hat{P} = 8 - 20 \cdot \phi = 0$. That is $(1+\eta_0)^2 = \frac{20}{8} b\gamma$. The assumption of $b\gamma > 1$ implies $\eta_0 > \frac{1}{2}$. Therefore, from (17) we have $\left(\eta, \arg\max_P(EW^C)\right) \in C$ iff $\eta \geq \frac{1}{2}$ and $\left(\eta, \arg\max_P(EW^N)\right) \in N$ iff $\eta < \frac{1}{2}$. Finally we have the following results :

$$\arg\max_P(E(W)) = \arg\max_P(EW^C) = 1 \text{ if } \phi \leq \frac{7}{20} \text{ or } \frac{20}{7}\lambda \leq (1+\eta)^2 \qquad \text{(A11)}$$

$$\arg\max_P(E(W)) = \arg\max_P(EW^C) = \hat{P} = 8 - 20 \cdot \phi$$
$$\text{if } \frac{7}{20} < \phi < \frac{8}{20} \text{ or } \frac{20}{8}\lambda < (1+\eta)^2 < \frac{20}{7}\lambda \qquad \text{(A12)}$$

$$\arg\max_P(E(W)) = \arg\max_P(EW^C) = 0$$
$$\text{if } \frac{8}{20} \leq \phi \text{ , } \eta \geq \frac{1}{2} \text{ or } \frac{9}{4} \leq (1+\eta)^2 \leq \frac{20}{8}\lambda \qquad \text{(A13)}$$

$$\arg\max_P(E(W)) = \arg\max_P(EW^N) = 0 \text{ if } 1 \leq (1+\eta)^2 < \frac{9}{4} \qquad \text{(A14)}$$

Q.E.D.

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〔Abstract〕

연구개발 파급과 최적 반독점 정책 강도

이 광 훈

삼단계 게임 모형을 이용하여, 연구개발투자의 파급 수준에 따른 공동생산에 대한 반독점 정책 강도의 최적 수준을 분석하였다. 그 결과 공동생산에 대한 최적의 반독점 정책 강도는 연구개발 파급의 크기가 클수록 완화되는 것으로 나타났다. 특히 연구개발 파급의 정도가 기업들이 자발적으로 연구개발 과정에서 협조할 만큼 충분히 큰 경우에 한해, 공동생산에 대한 부분적 용인이 가능함을 보였다. 반면에 연구개발 파급의 크기가 기업들의 자발적 공동연구개발을 유인할 만큼 충분하지 않을 경우, 공동생산을 허용하지 않는 수준으로 반독점 정책을 강화하는 것이 최적인 것으로 나타났다.

핵심용어 : 연구개발, 파급, 협조, 반독점, 후생