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International R&D Contest with IPR Coordination and Cost Externality*

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Abstract

Purpose – This paper examines the international R&D contest in which the extent of intellectual property right (IPR) affects both the size of prize for the winning firm and the extent of positive spillover through cost of firms. Recognizing the possibility of incomplete protection of IPR, the present paper analyzes the effect of changes in the extent of IPR on payoffs to firms and social welfare.
Design/methodology – This paper examines coordination of IPRs by countries in economic integration. The paper then develops a general model of international R&D contest with incomplete protection of IPR. An increase in the extent of IPR augments the share of the prize the winning firm can appropriate, while decreasing the positive cost externality. To derive sharper results, the paper considers the cases of linear and fixed spillovers.
Findings – Under plausible assumptions, an increase in the IPR augments the payoff to each firm and the aggregate payoffs as well. The paper also shows that the number of firms participating in the R&D contest can be endogenously determined in the two-stage R&D contest. The higher the extent of cost spillover, and the larger the effective prize, the more firms participate in the international R&D contest.
Originality/value – Existing studies assume that firms winning the R&D contest enjoy perfect IPR to the output of their R&D activities. This is a very restrictive assumption in that other firms can copy the new products or processes. By allowing for the incompleteness of the IPR, the present paper develops a more realistic model of R&D contest. The novelty of the present paper is to allow for the possibility that the higher extent of IPR increases the prize and decreases positive cost externality at the same time. The findings of the present paper can serve as a basis for government policy toward R&D activities of firms and protection of IPRs.

Keywords: Coordination of IPRs, Cost Externality, Effective Prize, Intellectual Property Right (IPR), R&D Contest
JEL Classifications: D21, D72, F13

1. Introduction

Economic growth can be achieved by putting more production factors such as labor, capital and natural resources into production process. Another source of economic growth is technological progress such as the creation of new products or the development of new technologies. Examples are the invention of internal combustion engines or semiconductors. Romer (1986/1990) considers the technological progress as an endogenous process

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determined by the input of capital and labor whereas the neoclassical theory considered it as an exogenous one. Furthermore, technological progress is achieved by cumulative research and development (R&D, hereafter) activities of firms.

If technological progress is achieved, economic growth can be sustained in the long run with the same amount of labor or capital put into the production process. Thus, investment in R&D is essential to long-run growth. While substantial amount of resources must be invested in inventing or creating new products and processes, it is less costly and time-consuming to copy or imitate them. Therefore, insufficient protection of the intellectual property tends to result in under-investment on R&D activities.

Since the late 1970s, most countries have tried to stimulate R&D activities by protecting the output of firms' R&D activities, i.e., by bestowing intellectual property right (IPR, hereafter) for new products and processes on firms winning the R&D contest. Since the creation of knowledge, technological innovation and inventions are actively carried out with guarantee of sufficient benefits for the creators, the extent of protection of the creator's rights is higher in the knowledge-based society. The fundamental basis for the international discussion of IPRs is the TRIPs[1] which provides minimum protection standards for international markets in the multilateral dimension as well as in economic integration through bilateral or regional agreements.[2]

Firms compete in an integrated international market in goods and services markets, and in R&D markets as well. The international R&D competition can be viewed as a contest in which firms expend resources to develop new products or processes. In such R&D contests winners enjoy lucrative profits while losers pay costs without reaping any return from their activities. Since the seminal work of Spencer and Brander (1983), much attention has been paid on the role of government subsidies on R&D activity of domestic firms in competition with foreign firms, especially in the literature on strategic trade policy.

Most papers on international R&D rivalry are based on the implicit assumption that firms winning the R&D contest enjoy perfect IPRs to the output of their R&D activities. However, as noted by Kang Moon-Sung (2006), this is a very restrictive assumption. Other firms may copy the new products via so-called 'reverse engineering.' The knowledge on cost-reducing processes may leak into other firms through various channels as well. Moreover, protection of IPR incurs costs, i.e., enforcing IPR is costly. Thus, it may not be optimal to fully protect the IPR from the social point of view. Kang Moon-Sung (2006) shows that it is optimal for a government to adopt a sufficiently low level of IPR and to subsidize R&D activity of home firms in competition with foreign firms. In the model of Kang Moon-Sung (2006), exporting countries might wish to agree to provide no protection on IPRs. As noted by Kang Moon-Sung (2006), this is in direct conflict with the Agreement on Trade-Related Aspects of Intellectual Property Rights, also known as Trade-Related Intellectual Property Rights (TRIPs) Agreement, of WTO that seeks strong enforcement of IPRs.

The purpose of this paper is to examine the international R&D contest in which the extent of coordinated IPR affects both the size of prize for the winning firm and the extent of positive spillover in costs in an integrated international market. Following Kang Moon-Sung (2006), this paper recognizes the possibility that the protection of IPRs is incomplete. That is, the firm winning the R&D contest cannot appropriate the prize to its full extent, as other firms can

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[1] The Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPs) is an international agreement between the member nations of the World Trade Organization (WTO).

[2] In the TRIPs-Plus agreement, the standard of protection for IPRs is scaled up than required in the TRIPs, and it contains specifications regarding data exclusivity, compulsory licensing, and patent term extension.

copy the products or cost-reducing processes, i.e., free-ride on the firm's R&D activities. Moreover, the extent of IPR can be different across countries. This leads to the need for international coordination of IPRs in the multilateral trading system and in the negotiation for economic integration such as FTA as well.

Enforceable rules regarding IPR were introduced into the multilateral trading system under the TRIPs Agreement of the WTO.[3] Such coordination of IPRs also leads to changes in the size of the effective prize the winning firm of the international R&D contest can appropriate, thereby affecting the R&D activities of firms. This offers policy implications for IPR negotiation in the process of economic integration: For the coordinated IPR to increase the real size of the R&D prize, it turns out, the coordinated IPR should be at least as high as the market size-weighted average of IPRs. This paper also recognizes the possibility of spillover of R&D activities through costs, as in Lee Sang-Hack and Kang Jae-Hyeong (1998) and Lee Sang-Hack (2007).

Building on the theory of contest, this paper develops a model of international R&D contest in which the extent of IPR affects both the prize and cost of firms. Contests are a resource-allocating mechanism in which prizes are awarded to a small number of players by a pre-specified rule.[4] As noted by Park Sung-Hoon and Lee Sang-Hack (2019), many economic, political, and social interactions can be regarded as a contest in which players expend resources to win prizes. Elections, R&D contests, and rent-seeking contests belong to a set of examples of contests. In such contests, winners enjoy a prize in excess of their expended resources, while losers simply expend resources without reaping any return for their expenditures. R&D competition among firms can also be viewed as a contest. Winning firms enjoy prizes while losing firms simply expend resources. The higher extent of IPR increases the prize to the winner of the R&D contest. On the other hand, the higher extent of IPR reduces positive spillover in the cost side as higher IPR makes it difficult for firms to copy cost-reducing process of succeeding firms. The model of the present paper analyzes two opposing effects of the IPR on the prize and costs.

The remainder of the paper is organized as follows. Section 2 first examines coordination of IPRs by countries in multilateral negotiations or in the process of economic integration. We find the condition under which the coordinated IPR generates larger effective prize for the winner than before. The criterion turns out to be the market size-weighted average of IPRs. Section 2 then proceeds to set up a general model of international R&D contest. To derive sharper results, Section 2 considers the case of linear spillover in cost. Section 3 then considers the case of fixed spillovers in cost. The final section concludes.

2. International R&D Contest

Different countries have different levels of IPR. Countries can coordinate the extent of IPR through multilateral or bilateral negotiation. This section first considers coordination of IPRs by countries in the process of economic integration. We find the condition under which the coordinated IPR generates larger effective prize for the winner than before. The criterion turns out to be the market size-weighted average of IPRs. Section 2 then sets up a general model of international R&D contest with coordinated IPR and with spillovers in cost.

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[3] Some of developed countries even want to move to the so-called "TRIPS-Plus" which provides stronger protection of IPR than the TRIPs Agreement, since the protection level of IPR in the TRIPs Agreement is lower than the level the countries want.

[4] Konrad (2009) offers a succinct summary of main contributions in the theory of contest.

2.1. Coordination of IPRs

Suppose that there are two countries, labelled 1 and 2, respectively, in the world. There are n symmetric firms in the world. They engage in the international R&D contest. The firm winning the R&D contest takes all the markets in the world. The (nominal) market size of country i for the winner of the international R&D contest is given as S_i, for $i = 1, 2$. However, due to incomplete IPR, the winning firm cannot fully appropriate S_i, for $i = 1, 2$. The extent of IPR in country i is denoted as r_i, $0 < r_i \leq 1$, for $i = 1, 2$. The effective market size of country i for the winner of international R&D contest is assumed to be given as r_iS_i, for $i = 1, 2$. That is, the winning firm can appropriate the proportion of the nominal market size given by the extent of the IPR.

The governments of the two countries can coordinate the extent of IPRs. In fact, most FTAs contain sections regarding the IPRs. For example, Korea-US FTA contains sections on IPR in several areas. Going through the process of IPR coordination, the two countries can set the common extent of the IPRs. Let us denote the common extent of the IPRs by r. The aggregate effective market for the winner in international R&D contest is then given as $r(S_1 + S_2)$. Coordination of the IPRs increases the size of effective markets if

$$r(S_1 + S_2) \geq (r_1S_1 + r_2S_2). \tag{1}$$

Without loss of generality, we assume that $S_1 \leq S_2$. That is, the market size of country 1 is not greater than that of country 2. We denote the market size of country 1 relative to country 2's by k ($\equiv S_1/S_2$). Then it follows that $0 < k \leq 1$. Utilizing the definition of k, the inequality (1) can be written as

$$r \geq (r_1k + r_2)/(k + 1). \tag{2}$$

The inequality (2) is easy to interpret. The right-hand side of (2) is the market size-weighted average IPR of the two countries. Thus, if the coordinated extent of IPR is greater than the market size-weighted average IPR, then the coordination of the IPRs increases the effective market size. This result offers important policy implication for IPR coordination: For economic integration or multilateral negotiation on IPR to increase the size of effective market, the coordinated IPR should be greater than the market size-weighted average IPR.

The coordination of IPRs was one of hot issues in the Korea-US FTA negotiation.[5] The USA has a higher level of IPR than Korea. Moreover, the market size of the USA is much greater than that of Korea. The IPR in the Korea-US FTA is set higher than the initial extent of IPR in Korea. This seems to reflect the higher level of IPR of the USA and asymmetry in market size between Korea and the USA. The coordinated IPR in the Korea-US FTA would satisfy the inequality (2).

Fig. 1 displays the case when $r_1 \leq r_2$. If the coordinated IPR is located in the shaded area in Fig. 1, the coordinated IPR increases the effective prize for the winning firm of the R&D contest. Fig. 2 displays the other case when $r_1 \geq r_2$. Again, the coordinated IPR increases the effective prize for the winning firm in the R&D contest, if it is located in the shaded area in Fig. 2.

[5] The proliferation of bilateral FTA is one of important policy issues in the 21st century. Cheong Sun-Tae (2013) explains the recent trend, and feature of such bilateral FTAs in East Asia.

Fig. 1. The Case when $r_1 \leq r_2$

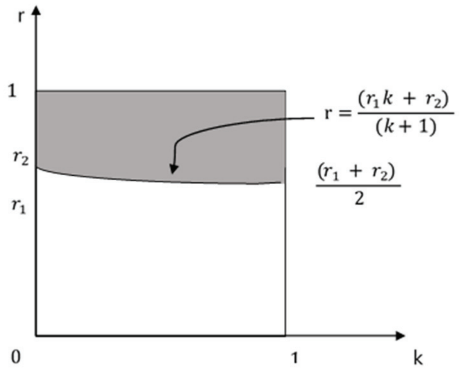
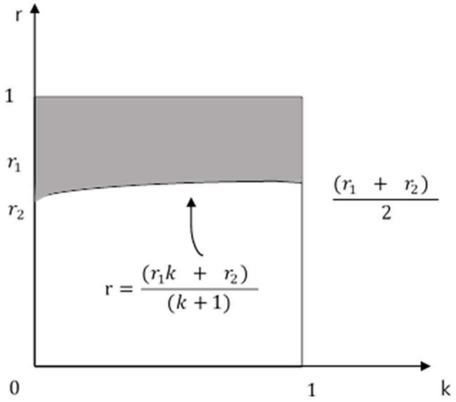


Fig. 2. The Case when $r_1 \geq r_2$



2.2. General Model of International R&D Contest

We now examine the international R&D contest in the integrated economy, i.e., R&D contest in the integrated international market. There are n symmetric firms worldwide participating in the international R&D contest. The firms compete to win the prize worth S. We assume that the winning firm cannot fully appropriate the whole prize as the IPR regarding the new product or process cannot be fully protected in the real world. The winning firm of the R&D contest is assumed to appropriate r proportion of the prize S, rS, where $0 < r \leq 1$. The parameter r represents the extent of IPR. The more the IPR protected, the higher and closer to 1 the value of r.

To win the prize, firm i expends x_i ($i = 1, 2, \ldots, n$). As in Tullock (1980), the probability of firm i's winning the R&D contest, or the share of the prize, P_i, is given by firm i's expenditure on R&D relative to total expenditures:

$$P_i = x_i/X \text{ if } X > 0, \text{ and } \\ = 1/n \text{ if } X = 0, \qquad (3)$$

where X ($= \sum_i x_i$) denotes the total expenditures on R&D contest.

Following Lee and Kang (1998) and Lee (2007), we assume that the R&D contest is associated with externality in costs in that each firm's real cost of expenditure is affected by the aggregate expenditures on R&D, i.e., by R&D activities of other firms. An increase in the extent of the IPR increases the proportion of the prize the winning firm can appropriate. On the other hand, the augmented IPR decreases the positive spillover effect through cost. The novelty of the present paper is to allow for the possibility that the higher extent of IPR increases the prize and decreases cost externality at the same time. Specifically, the real cost of R&D for firm i is assumed to be given by $x_i - f(r)X$, where $f(r)$ is a small positive number and $df(r)/dr \leq 0$.[6] That is, as the extent of IPR increases, the extent of externality in cost decreases or remains the same. This is in accordance with Kang Moon-Sung (2006) that argues that an increase in foreign R&D activities reduces the domestic firm's marginal cost if the home country enforces IPR protection loosely. This is also in line with the work of D'Aspremont and Jacquemin (1988) that deal with R&D spillover via costs among competing firms.

Risk-neutral firm i maximizes the expected payoff of R&D contest, v_i, for $i = 1, 2, \ldots, n$,

$$\begin{aligned} \text{Max. } v_i &= (P_i)[rS - x_i + f(r)X] + [1 - P_i][-x_i + f(r)X] \\ &= (x_i/X)[rS - x_i + f(r)X] + [1-(x_i/X)][-x_i + f(r)X] \qquad (4) \\ &= rS(x_i/X) - x_i + f(r)X. \end{aligned}$$

Each firm participating in the R&D contest receives $f(r)X$ amount of positive externality effect through cost, regardless of whether the firm is a winner or a loser in the R&D contest. The sum of real costs of firms must be positive, i.e., $\sum (x_i - f(r)X) = X - nf(r)X > 0$. It thus follows that $f(r) < 1/n$.

The first-order condition for (4) is given as

$$\partial v_i/\partial x_i = rS(X - x_i)/(X)^2 - 1 + f(r) = 0 \qquad (5)$$

The equilibrium R&D expenditure of each firm and the aggregate expenditures can be obtained by solving (5). Utilizing symmetry, we denote the individual firm's outlay and the aggregate outlays by x_* and X_*, respectively. Solving (5), we obtain x_* and X_* as follows:

$$\begin{aligned} x_* &= (n - 1)\, rS/(n)^2(1 - f(r)), \text{ and} \qquad (6) \\ X_* &= (n - 1)\, rS/n(1 - f(r)). \end{aligned}$$

It is easy to find that $\partial x_*/\partial r > 0$ and $\partial X_*/\partial r > 0$ if $1/f(r) > [1- (df(r)/dr)(r/f(r))\ ]$. To see this condition more clearly, we denote the elasticity of $f(r)$ with respect to r by e_r, i.e., $e_r \equiv (df(r)/dr)(r/f(r))$. The elasticity e_r measures the sensitivity of spillover through cost, $f(r)$, to a change in the IPR, r. Utilizing the definition of e_r, it follows that $\partial x_*/\partial r > 0$ and $\partial X_*/\partial r > 0$ if $e_r > 1-1/f(r)$. Since $f(r)$ is a very small positive number, $1/f(r)$ is a very large positive number.[7]

Unless e_r has a very large negative value, it is likely that an increase in the extent of IPR increases the individual firm's outlay and the aggregate outlays. This result can resolve the "puzzle" proposed by Kang Moon-Sung (2006) that exporting countries might wish to agree

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[6] It is also possible that $f(r)$has a negative value. In such a case, the firms are affected negatively by the collective R&D activities of firms. This is the case if R&D activity of firms increases the prices of inputs to the R&D contest. The present paper does not consider this possibility, however.

[7] Note that $1/f(r) > n$.

to provide no protection on IPR, while TRIPs Agreement of WTO seeks strong enforcement of IPRs. In the model of Kang Moon-Sung (2006) the extent of IPR affects only the extent of spillover through cost. In the present model, on the other hand, higher IPR works to increase the prize to the winner as well as to reduce the extent of positive spillovers. The present paper has shown that under plausible assumptions, higher IPR increases R&D expenditures when IPR affects both prize and cost. This result can be viewed as the rationale underlying TRIPs Agreement of WTO that seeks strong enforcement of IPRs.

As noted above, in the model of this section, the strengthened IPR works in two opposite directions. It increases the prize of the R&D contest (prize effect), while decreasing the extent of positive spillovers through costs (cost effect). If $e_r > 1\text{-}1/f(r)$, the prize effect dominates the cost effect, thereby intensifying the R&D contest. However, it is also possible, at least *a priori*, that an increase in the extent of IPR decreases the individual firm's outlay and the aggregate outlays on R&D contest. This case occurs when the reduction in cost externality with strengthened IPR, i.e., cost effect, dominates positive prize effect through an increase in the effective prize. This occurs when e_r has a sufficiently large negative value.

Inserting x_* and X_* into v_i in Eq. (4), we obtain

$$\begin{aligned} v_* &= rS(x_*/X_*) - x_* + f(r)X_* \qquad (7) \\ &= rS\,[f(r)(n)^2 - 2f(r)n + 1]/(n)^2(1- f(r)) \text{ and} \\ V_* &= \textstyle\sum v_* = rS\,[f(r)(n)^2 - 2f(r)n + 1]/n(1- f(r)). \end{aligned}$$

From (7) we find that $\partial v_*/\partial n < 0$. $\partial V_*/\partial n$ is negative when $f(r) < 1/(n)^2$. However, $\partial V_*/\partial n$ has a positive value when $1/(n)^2 < f(r) < 1/n$. It is difficult to determine the effect of a change in IPR on the individual and the aggregate payoffs as r affects both the effective prize and cost externality at the same time. This will be examined with a specific functional form of $f(r)$ in the following subsection.

2.3. The Case of Linear Spillover (Case 1)

We have shown that the increase in the extent of IPR works in opposite directions. In one way an increase in the extent of IPR augments the share of the prize the winning firm appropriates. On the other hand it reduces the cost externality as the IPR is strengthened, as in Kang (2006). To show these effects in a tractable way, we consider a linear externality function given as $f(r) = 1/Ar$, where A is a very large positive number. As the extent of IPR increases, the positive externality through cost decreases. Given the specific functional form for $f(r)$, we are now able to derive more specific results.

Risk-neutral firm i solves the following maximization problem, for $i = 1, 2, \ldots, n$.

$$\begin{aligned} \text{Max. } v_{1i} &= (P_i)[rS - x_{1i} + (1/Ar)X_1] + [1- P_i][-x_{1i} + (1/Ar)X_1] \\ &= rS\,(x_{1i}/X_1) - x_{1i} + (1/Ar)X_1 \text{ with respect to } x_{1i}. \qquad (4)\text{-}1 \end{aligned}$$

The subscript 1 in variables indicates Case 1. The upper bound on $(1/Ar)$ can be derived from the condition that $\sum_i (x_{1i} - (1/Ar)X_1) = X_1 - (1/Ar)nX_1 > 0$. That is, the sum of real costs must be positive. From this condition we derive the condition that $Ar > n$. This condition is satisfied if A is sufficiently large, as $0 < r \leq 1$.

Each firm decides the level of own expenditure on R&D contest, taking all the other firms' outlays as given. The first-order conditions for maximization of v_{1i} are given by, for $i = 1, 2, \ldots, n$:

$$\partial v_{1i}/\partial x_{1i} = rS(X_1 - x_{1i})/(X_1)^2 - 1 + 1/Ar = 0. \tag{5-1}$$

The second-order conditions for maximization are satisfied. Utilizing symmetry, we denote the equilibrium R&D expenditure of each firm by x_{1^*} and total expenditure by X_{1^*}. Solving Eq. (5)-1, we obtain the following results:

$$x_{1^*} = [(n - 1)/(n)^2][A(r)^2S/(Ar - 1)], \text{ and} \tag{6-1}$$
$$X_{1^*} = [(n - 1)/n][A(r)^2S/(Ar - 1)].$$

Comparative statics effects can be easily found from Eq. (6)-1: $\partial x_{1^*}/\partial n < 0$, $\partial x_{1^*}/\partial r > 0$, $\partial X_{1^*}/\partial n > 0$, and $\partial X_{1^*}/\partial r > 0$. An increase in the extent of IPR increases the aggregate outlays on R&D even though it reduces the cost externality via strengthened IPR.

Inserting x_{1^*} and X_{1^*} into v_{1i} we find

$$v_{1^*} = [(1/n)A(r)^2 + (n - 2)r]S/n(Ar - 1) \text{ and} \tag{7-1}$$
$$V_{1^*} = \textstyle\sum v_{1^*} = [(1/n)A(r)^2 + (n - 2)r]S/(Ar - 1).$$

Comparative statics effects can be found from Eq. (7)-1: $\partial v_{1^*}/\partial r > 0$ and $\partial V_{1^*}/\partial r > 0$. An increase in the extent of IPR increases the share of the prize the winning firm can appropriate, while decreasing the positive cost externality. The overall effect of the increase in the extent of IPR is to increase the individual payoff and the aggregate payoffs as well.

3. The Case of Fixed Spillovers (Case 2)

In this section we consider another specific functional form of $f(r)$ to derive sharper results. As in Lee and Kang (1998), the real cost of R&D for firm i is assumed to be given by $x_i - \beta X$, where β is a small positive number.[8] There are externalities in costs. However, as in Lee Sang-Hack and Kang Jae-Hyeong (1998), the externality parameter β is exogenously given and fixed. In such a case, IPR coordination affects the extent of IPR, but does not affect the extent of spillovers through costs. We will also examine the role of fixed cost to allow for endogenous determination of the number of firms at the end of this section.

Risk-neutral firm i solves the following maximization problem, for $i = 1, 2, \ldots, n$,

$$\begin{aligned}\text{Max. } v_{2i} &= (P_i)[rS - x_{2i} + \beta X_2] + [1 - P_i][-x_{2i} + \beta X_2] \\ &= (x_{2i}/X_2)[rS - x_{2i} + \beta X_2] + [1-(x_{2i}/X_2)][-x_{2i} + \beta X_2] \\ &= r\,S\,(x_{2i}/X_2) - x_{2i} + \beta X_2,\end{aligned} \tag{4-2}$$

where v_{2i} denotes firm i's expected payoff and $\beta < 1/n$. The subscript 2 in variables indicates Case 2. The upper bound on β is derived from the condition that $\sum_i (x_{2i} - \beta X_2) = X_2 - \beta n X_2 > 0$. That is, the sum of real costs must be positive. Each firm decides the level of own expenditure on R&D, taking all the other firms' outlays as given. The first-order condition for (4)-2 is given as

$$\partial v_{2i}/\partial x_{2i} = rS(X_2 - x_{2i})/(X_2)^2 - 1 + \beta = 0 \tag{5-2}$$

The second-order conditions for maximization are satisfied. Individual firm's equilibrium

[8] As noted in the previous footnote, it is also possible that β has a negative value. In such a case, the firms are affected negatively by the R&D activities of other firms.

R&D expenditure and the aggregate expenditures can be obtained by solving (5)-2. Utilizing symmetry, we denote the individual firm's outlay and the aggregate outlays by x_{2^*} and X_{2^*}, respectively. x_{2^*} and X_{2^*} are given as follows:

$$x_{2^*} = (n - 1)\, rS/(n)^2(1 - \beta) \text{ and} \qquad (6)\text{-}2$$
$$X_{2^*} = (n - 1)\, rS/n(1 - \beta).$$

It is easy to find the comparative statics results from Eq. (6)-2: $\partial x_{2^*}/\partial n < 0$, $\partial x_{2^*}/\partial r > 0$, $\partial x_{2^*}/\partial \beta > 0$, $\partial X_{2^*}/\partial n > 0$, $\partial X_{2^*}/\partial r > 0$, and $\partial X_{2^*}/\partial \beta > 0$. As the number of firms increases, the individual firm's outlay decreases while the aggregate outlays increase. An increase in the size of the prize, S, in the extent of IPR, r, or cost externality, β, augments both the individual and the aggregate outlays on R&D contest.

Inserting x_{2^*} and X_{2^*} into v_{2i} in Eq. (4)-2, we obtain

$$v_{2^*} = rS(x_{2^*}/X_{2^*}) - x_{2^*} + \beta X_{2^*} \qquad (7)\text{-}2$$
$$= rS\,[\beta(n)^2 - 2\beta n + 1]/(n)^2(1-\beta) \text{ and}$$
$$V_{2^*} = \sum v_{2^*} = rS\,[\beta(n)^2 - 2\beta n + 1]/n(1-\beta).$$

Comparative statics effects can be found from Eq. (7)-2: $\partial v_{2^*}/\partial n < 0$, $\partial v_{2^*}/\partial r > 0$, $\partial v_{2^*}/\partial \beta > 0$, $\partial V_{2^*}/\partial r > 0$, and $\partial V_{2^*}/\partial \beta > 0$. $\partial V_{2^*}/\partial n$ is negative when $\beta < 1/(n)^2$. However, $\partial V_{2^*}/\partial n$ has a positive value when $1/(n)^2 < \beta < 1/n$. The individual payoff always decreases as more firms participate in the R&D contest. The aggregate payoffs exhibit a different response to an increase in the number of firms. As more firms participate in the R&D contest, the aggregate payoffs may initially decrease. However, if the number of firms increases sufficiently, the aggregate externality in cost outweighs the increase in R&D expenditures, thereby increasing the aggregate payoffs.

3.1. Endogenous Number of Firms in the R&D Contest

The number of firms participating in the R&D contest is so far assumed to be exogenously given. We now consider the possibility of endogenous determination of the number of firms. The number of firms participating in the R&D contest can be determined in several ways. One possibility is that the number of firms is exogenously given. In some circumstances only firms with certain level of technology can participate in the R&D contest. For example, only firms possessing a fairly high level of bio-technology can participate in the race to develop a new medicine for avian flu. In such a case the number of firms is given exogenously. That is, the number is exogenously given as there are prerequisites to enter the R&D contest. This case does not require any analysis, however.

An interesting possibility is that the R&D contest takes place in two stages as in Lee and Nam (2018). In the first stage, firms expend fixed costs that might be related to the size of the prize. That is, firms expend a kind of fixed costs, or entrance costs, to participate in the R&D contest. For example, firms may have to build laboratories necessary for the experiments in the second stage. In the second stage, firms expend on R&D contest. In this situation, the number of firms can be endogenously determined. Firms may participate in the R&D contest up to the point where the expected variable profit given in Eq. (7)-2 is just enough to cover the fixed cost. We will examine this possibility.

For concise exposition, let us denote the effective market size by R: $R \equiv rS$. The fixed cost is likely to be related to the effective prize. The fixed cost can also be constant regardless of the size of the effective prize. Let $g(R)$ denote the fixed cost each firm has to pay to participate in the R&D contest. As in Lee Sang-Hak and Nam Bo-Ra (2018), the fixed cost function $g(R)$ satisfies the following assumption:

Assumption 1. (1) $g(R) > 0$. (2) $0 \leq dg(R)/dR < g(R)/R$.

The fixed cost $g(R)$ is a non-decreasing function of R. Moreover, $[dg(R)/dR][R/g(R)] < 1$. As the effective prize increases, the fixed cost tends to increase. However, the increasing rate of the fixed cost is smaller than the increasing rate of the effective prize. That is, the elasticity of the fixed cost to the effective prize is assumed to be less than 1.

In the limit, firms enter into the R&D contest up to the point where the fixed cost is equal to the expected variable profit given in (7)-2:

$$rS\,[\beta(n)^2 - 2\beta n + 1]/(n)^2(1-\beta) = g(R) \tag{8}$$

Utilizing the definition of R, (8) can be rewritten as an implicit function of R, β and n.

$$H(R, \beta, n) \equiv [\beta(n)^2 - 2\beta n + 1]/(n)^2(1-\beta) - g(R)/R = 0. \tag{9}$$

$H(R, \beta, n)$ is continuously differentiable with respect to R, β and n. Moreover, $\partial H(R, \beta, n)/\partial n < 0$. Thus the sufficient condition for the implicit function theorem, i.e., $\partial H(R, \beta, n)/\partial n \neq 0$, is satisfied. Then, applying the implicit function theorem to (9), we find the following results:

Remark: $\partial n^*/\partial R > 0$ and $\partial n^*/\partial \beta > 0$.

An increase in the extent of IPR, r, or the size of prize, S, results in an increase in R, thereby augmenting the number of firms participating in the international R&D contest. An increase in the extent of cost externality β also induces more firms to participate in the international R&D contest. In deriving these results, the firms are assumed to be risk-neutral. Risk-aversion of firms would reduce the number of firms participating in the international R&D contest.

4. Concluding Remarks

Building on the theory of contest, this paper has developed a model of international R&D contest in which the extent of IPR affects both the prize and cost of firms. The higher extent of IPR is assumed to increase the prize for the winner of the R&D contest, while reducing spillover in the cost side. The present paper has found conditions under which the coordinated IPR in the economic integration generates larger effective prize for the winner than before, which turns out to be the market size-weighted average of IPRs.

This paper has set up a general model of international R&D contest with spillovers both in prize and cost. This paper has then considered the case of fixed spillovers in cost. The number of firms participating in the R&D contest is shown to be determined endogenously. The higher the extent of cost spillover, and the larger the effective prize, the more firms participate in the R&D contest.

The analysis in this paper is focused on theoretical aspects of IPR. It would be interesting to examine the real world case of IPR coordination and its effect on R&D activities. For example, one may examine the IPR coordination in the negotiation of Korea-US FTA (KORUS) and its effect on R&D activities of firms in some strategic industries, such as medicines and pharmaceutical industries. Another interesting extension would be to allow for asymmetry of firms. Firms in international markets are different in their size and R&D ability. The asymmetry of firms would naturally affect the effect of IPR coordination. We leave these topics for future research.

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