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Abstract

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Key Words:completely complementary technologies, a cross-licensing system, duopoly and R&D investments

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1. INTRODUCTION

Technological innovations are supported by the technological inventions, which have the following two features. First, technological inventions have the characteristic of public goods. Since they are a kind of information, the discoverer of such an invention cannot exclude other persons from using it. Also many people can use it simultaneously. These features of technological inventions induce non-discoverers' (non-inventors') imitation of them, and discourage researchers or inventors from creating them. Secondly, technological inventions are associated with other technologies. When the discoverers or inventors of plural distinct technological inventions differ, how does the coordination make among the discoverers affect the interest of each discoverer or inventor, and also affect their R&D incentives of them.

Over the past decade of the last century, a number of studies have been discussed on the effects of the relations among technological inventions upon the R&D activities, the licensing or the patent systems.

The technological inventions of the type of cumulative relations in which one (some) of them is (are) developed or worked out on the basis of other preceding one(s). Under such cumulative technological innovations, Green and Scotcher(1995), Chang(1995) show(s) that the externality due to the lack of the coordination among the discoverers of plural distinct technological inventions decreases their incentives to create or develop them.

Another feature of the relations among the technological inventions is the complementary relation among them. As we typically have seen in the IT (Information Technologies) industries, technological innovations occur on the basis of plural distinct technological inventions invented (developed) in different systems of technologies. In this environment, distinct technologies are technologically complementary for the product produced by making use of them. Of course, in such a complementary technological innovation, the externality problem due to the lack of the coordination among the discoverers of plural complementary technologies does occur. Heller and Eisenberg(1998) point out that the existence of such externality brings the result known as "the tragedy of anti-commons:" When the property rights of plural distinct technologies are authorized to different agents (firms), the externality brings excessive exercises of the exclusive rights, and under-utilization of these technologies, and discourages incentives for R&D activities of agents(firms).

In the case where a product is produced by utilizing such complementary inventions, a (cross-) licensing for them has strategic importance. If two different firms have one of the two distinct technological inventions with a perfect complementarity, then they cannot produce a product at all without a (cross-) licensing for them. In practice, as the positive analyses in the appliance and IC industries conducted by Grindley and Teece(1997) and Hall and Ziedonis(2001) show us, the conditions of the firms' (cross-) licensing for the product have a great effect on their incentives for R&D activities in such industries where perfectly complementary technological inventions are indispensable for producing the product . In economic literatures, however, there have been made few theoretical studies on how the conditions of the firms' (cross-) licensing for the product affect firms' incentives for R&D activities. Fershtman and Kamien(1992) does analyze how a cross-licensing affect firms' incentives for R&D activities in their seminar study in such a context. But they consider four stage model in order to focus on a dynamic prospect of technological innovation. That is, in their model, the first stage involves initial research in which the firms start to develop the two complementary technologies. Once they have succeed in developing at least one of the two technologies the firm can decide to licence—stage 2— or to go to stage 3 and to continue the innovation race. When at least one of the firms possesses both technologies, either through licensing or through their own development, the game is in the stage 4 and they produce their goods and interact in the market. However, in practice, the pace of innovation race of the complementary technologies is very high and the life of each technologies in that it has economic values is very short especially in the IT industries. So their model setting in which has two research stages is not suitable for our analysis.

Hence, in this paper, we make a analysis on how a cross-licensing affects firms' incentives for R&D activities in a Cournot duoply model in which there are one of the innovation race stage, one of decision on licensing and one production competition stage. When one of the firms succeeds in developing both technologies, the market becomes a monopolistic one since the firm has no incentive to licence unilaterally its technologies to its rival. So note that the only licensing that may occur is a cross-licensing when each firm succeeds in only one of distinct technology of the two. Therefore, in our analysis, we focus on the case where each duopolistic firm can invest on R&D for the two distinct technological inventions with strong complementarity with each other. But we conduct our analysis by a static model with respect to each firm's R&D investment since we does not treat dynamic aspects of technological innovations.

In section 2, we describe our model, and analyze the problem of R&D in Cournot duopoly with perfectly complementary technological innovations without licensing as a benchmark in section 3. In section 4, at first, we examine the conditions under which (cross-) licensing occur. Then, extending our analysis to the case with a (cross-) licensing, we examine how the existence of a (cross-)licensing system firms' incentives for R&D activities in a Cournot duoply. In the final section, we present our concluding remarks.

2. MODEL

Let us consider a duopolistic market in which a homogeneous product is produced and sold by two firms: Firm x and Firm y. At the first stage, each firm invests in R&D for the two distinct but perfectly complementary technologies, A and B simultaneously. By "the perfectly complementary technologies", we mean that each firm cannot produce the goods without both of the two technologies. Denote by x_A, $x_B(\geq 0)$ and $y_A, x\ y_B(\geq 0)$, the investment levels for the technologies A, B of firm x and the investment levels for the technologies A, B of firm y, respectively. When each firm succeeds in the development of both of these two technologies or when by licensing , it become available to use both of technologies, it can produce its product. Assume that each firm has constant returns to scale production technology, so it ha a linear cost function,

$$C_i(q_i) = cq_i \tag{1}$$

,where c is a marginal cost of production and without loss of generality, we can assume that $c = 0$. At the end of the first stage, "nature" chooses whether each firm succeeds in the development of the technologies or not. Suppose that each firm succeeds in the development of the technology j with probability

$$p(x_j) = 1 - e^{-x_j}, \qquad p(y_j) = 1 - e^{-y_j}, j = A, B. \tag{2}$$

This probability function $p(\cdot)$ is well defined since we have, $p'(\cdot) > 0$, $p''(\cdot) < 0$, $\lim_{x \to 0} p'(x) = \infty$.[1]

We also assume that are identically and independently distributed. And we may assume that $k_j = 1$ each firm's marginal cost of the development of the technology $j = A, B$ without loss of generality.

The inverse market demand function of the product is given by,

$$p = D(Q) \tag{3}$$

where p is the market price and Q is the aggregate output of production in the market, that is $Q = q_x + q_y$. We assume that $D'(\cdot) < 0$, $D''(\cdot) < 0$ and this assumption guarantees the inner solutions of the monopoly and the duopoly equilibria. At the beginning of the second stage, each firm knows all successes or failures of the both firms' developments of the technologies.

[1] In this paper, we assume the effect of the R&D activity on a process innovation as a static one. These properties of the success probability function are similar ones for the dynamic "memoryless" or "Poisson" patent race model associated with Reiganum(1982). In her model, the research technology is characterized by the assumption that a firm's probability of making a discovery and obtaining a patent at a point of time depends only on this firm's current R&D investment level and not on its past R&D experience. For Introductory illustration to the dynamic patent race model, see section 10.2 of Chap.10 in Tirole(1989).

At the second stage, if a (cross-) licensing system is available, then each firm bargains to its rival and agrees a (cross-) licensing contract, and they divide the total profit due to the licensing according to the Nash bargaining solution. If the (cross-) licensing system is not available, then the game proceeds to the third stage. At the third stage, whether the market becomes a monopoly or a duopoly determines, and each firm chooses its quantity of output according to the market structure. That is, if the market succeeds in the developments of the two technologies, both of technologies are available to only one of the two firms, say firm x, the market becomes a monopoly at the beginning of the second stage. From the assumption presented before, the inner optimal solution output exists. Denote by q_x^M, this output. Then the maximal profit $\pi_x^M(q_x^M)$ is given by

$$\pi_x^M(q_x^M) = D(q_x^M) \cdot q_x^M \equiv \pi^M. \tag{4}$$

However, if both technologies are available to all the two firms, then the market considered becomes a duopoly at the beginning of the second stage. Assume that they compete in Cournot way in the duopolistic market. From the assumption presented before, the inner optimal solution outputs q_i^C and q_j^C exist. Denote by $\pi_i^D(q_i^C, q_j^C)$, Firm i' s profit, then it is given by

$$\pi_i^D(q_i^C, q_j^C) = D(q_i^C + q_j^C) \cdot q_i^C \equiv \pi^D, \; j \neq i, i, j = x, y. \tag{5}$$

Here we assume that[2]

$$\pi^M > 2\pi^D. \tag{6}$$

In the next section, we analyze the problem of R&D in duopoly with perfectly complementary technological innovation without licensing as a benchmark.

3. R&D INVESTMENT WITHOUT (CROSS) LICENSING——A BENCHMARK——

In this section, we consider the case when the two firms cannot any (cross) licensing as a benchmark. After each firm invests in R&D of the two technologies at the first stage, nature chooses the outcome of each firm's development of these technologies. Denote the t th outcome by

[2]When an inversed demand function is linear, then we can easily show that this assumption satisfied.

$$\theta_t = [X_t^A, X_t^B, Y_t^A, Y_t^B] \in \Theta,$$

where $X_t^j, Y_t^j \in \{0,1\}, j = A, B$ and $X_t^j = 1, Y_t^j = 0$ implies that Firm x succeed in the development of technology j,and that Firm y fails to the development of technology j, respectively. Then all possible θ_t s are $\theta_1 = [1,1,1,0]$, $\theta_2 = [1,1,0,1]$, $\theta_3 = [1,1,0,0], \theta_4 = [1,1,1,1]$, $\theta_5 = [1,0,1,1]$, $\theta_6 = [0,1,1,1]$.

The cases when Firm x can produce its goods are three cases of monopoly by Firm x

$$\theta_1 = [1,1,1,0],\ \theta_2 = [1,1,0,1],\ \theta_3 = [1,1,0,0]$$

and the case of duopoly,

$$\theta_4 = [1,1,1,1].$$

In the other four cases, Firm x cannot produce the product at all from perfectly complementary technologies assumption.

The expected profit of Firm x, $\pi_x(x_A, x_B, y_A, y_B)$ is given by

$$\begin{aligned}\pi_x(x_A, x_B, y_A, y_B) &= (1-e^{-x_A})(1-e^{-x_B})(1-e^{-y_A})(1-e^{-y_B})\pi^D \\ &+(1-e^{-x_A})(1-e^{-x_B})\{(1-e^{-y_A})e^{-y_B} + \\ &(1-e^{-y_B})e^{-y_A} + e^{-y_A}\cdot e^{-y_B}\}\pi^M - x_A - x_B\end{aligned} \tag{7}$$

Firm x solves the following maximization problem:

$$Max\ \pi_x(x_A, x_B, y_A, y_B),\ \text{given}\ y_A, y_B$$

.The first order condition w.r.t. x_A is give by

$$\begin{aligned}\frac{\partial \pi_x}{\partial x_A} &= e^{-x_A}(1-e^{-x_B})(1-e^{-y_A})(1-e^{-y_B})\pi^D \\ &+e^{-x_A}(1-e^{-x_B})\{(1-e^{-y_A})e^{-y_B} \\ &+\ (1-e^{-y_B})e^{-y_A} + e^{-y_A}\cdot e^{-y_B}\}\pi^M - 1 = 0 \qquad (8).\end{aligned}$$

Since all the probability functions $p(\cdot)$'s are identical, we focus our analysis on symmetric Nash equilibrium. Let $s = e^{-x_A} = e^{-x_B} = e^{-y_A} = e^{-y_B} = e^{-x}$. Then, the first order condition (8) is rewritten to

$$s(1-s)^3\pi^D + s^2(1-s)(2-s)\pi^M - 1$$

$$= s(1-s)\{(1-s)^2\pi^D + s(2-s)\pi^M\} - 1 = 0 \qquad (9).$$

So s that satisfies with the equation (9) may constitute symmetric Nash equilibrium if it satisfies with the second order condition. We have

$$\frac{\partial^2 \pi_x}{\partial x_A^2} = -e^{-x_A}(1-e^{-x_B})(1-e^{-y_A})(1-e^{-y_B})\pi^D$$

$$-e^{-x_A}(1-e^{-x_B})\{(1-e^{-y_A})e^{-y_B} + (1-e^{-y_B})e^{-y_A} + e^{-y_A}\cdot e^{-y_B}\}\pi^M, \qquad (10)$$

and

$$\frac{\partial^2 \pi_x}{\partial x_B \partial x_A} = e^{-x_A}e^{-x_B}(1-e^{-y_A})(1-e^{-y_B})\pi^D$$

$$+e^{-x_A}e^{-x_B}\{(1-e^{-y_A})e^{-y_B} + (1-e^{-y_B})e^{-y_A} + e^{-y_A}\cdot e^{-y_B}\}\pi^M \qquad (11).$$

Let s^* that satisfies with the equation (9). Then

$$\left|\frac{\partial^2 \pi_x}{\partial x_A^2}\right|_{s=s^*} = -s^*(1-s^*)\{(1-s^*)^2\pi^D + s^*(2-s*)\pi^M\} = -1 \qquad (12),$$

and

$$\left|\frac{\partial^2 \pi_x}{\partial x_B \partial x_A}\right|_{s=s^*} = (s^*)^2\{(1-s^*)^2\pi^D + s^*(2-s^*)\pi^M\}$$

$$= \frac{(s^*)^2}{s^*(1-s^*)} = \frac{s^*}{1-s^*}$$

(13), where the last equality holds since s^* satisfies the equation (9).

Then, the second order condition is given by

$$\left|\frac{\partial^2 \pi_x}{\partial x_A^2}\right|_{s=s^*} = -1 < 0,$$

and $$\left\| \begin{matrix} \frac{\partial^2 \pi_x}{\partial x_A^2} & \frac{\partial^2 \pi_x}{\partial x_B \partial x_A} \\ \frac{\partial^2 \pi_x}{\partial x_B \partial x_A} & \frac{\partial^2 \pi_x}{\partial x_A^2} \end{matrix} \right\|_{s=s^*} = \left| \begin{matrix} -1 & \frac{s^*}{1-s^*} \\ \frac{s^*}{1-s^*} & -1 \end{matrix} \right| = 1 - \left(\frac{s^*}{1-s^*}\right)^2 > 0$$

(13) . Since $s = e^{-x}$ is the probability that Firm x fails the development of the technology when it chooses its investment level x, we see that $0 \leq s^* \leq 1$. From the fact described above, we can present the following proposition.

PROPOSITION 3.1. *Suppose that* $\pi^D + 3\pi^M > 16$. *Then, there exists a symmetric Nash equilibrium investment level*

$$x^* = -\ln s_L^* > -\ln(\tfrac{1}{2})$$

in our R&D investment competition in completely complementary technologies without licensing system.

Proof. Let the left hand side of the equation(9) $\phi(s)$, then $\phi(s)$ can be

rewritten by $\phi(s) = [\pi^M - \pi^D]s^4 - 3[\pi^M - \pi^D]s^3 + [2\pi^M - 3\pi^D]s^2 + \pi^D s - 1$ (14)

From the assumption, $\pi^M - \pi^D > \pi^M - 2\pi^D > 0$. So we have
$\lim_{s \to +\infty} \phi(s) = \lim_{s \to -\infty} \phi(s) = \infty$ (15).

Furthermore, from (14) and the assumption of this proposition, we see that

$$\phi(0) = \phi(1) = -1 < 0 \text{ and } \phi(1/2) = \tfrac{\pi^D + 3\pi^M}{16} - 1 > 0$$

(16).

Also we have $\phi'(s) = (1-s)^2(1-4s)\pi^D + s(4s^2 - 9s + 4)\pi^M$, so

$$\phi'(0) = \pi^D > 0 \text{ and } \phi'(1) = -\pi^M < 0$$

(17).

From (17) and the intermediate value theorem, there exists at least one $s \in [0,1]$ such that $\phi'(s) = 0$.

Now, let λ_1, λ_2 and λ_3 be the three roots of the equation $\phi'(s) = 0$. We have

$(s-\lambda_1)(s-\lambda_2)(s-\lambda_3) = s^3 - (\lambda_1 + \lambda_2 + \lambda_3)s^2 + (\lambda_1\lambda_2 + \lambda_2\lambda_3 + \lambda_3\lambda_1)s - \lambda_1\lambda_2\lambda_3 = 0$ (18)

Deviding $\phi(s) = 4[\pi^M - \pi^D]s^3 - 9[\pi^M - \pi^D]s^2 + 2[2\pi^M - 3\pi^D]s + \pi^D = 0$ by $4[\pi^M - \pi^D]$,

we get

$$s^3 - \frac{9}{4}s^2 + \frac{2\pi^M - 3\pi^D}{2[\pi^M - \pi^D]}s + \frac{\pi^D}{4[\pi^M - \pi^D]} = 0$$

(19).

By comparing (18) and (19), we obtain

$$\lambda_1 + \lambda_2 + \lambda_3 = \frac{9}{4} > 0$$

(20),

$$\lambda_1\lambda_2 + \lambda_2\lambda_3 + \lambda_3\lambda_1 = \frac{2\pi^M - 3\pi^D}{2[\pi^M - \pi^D]} \tag{21}$$

and

$$\lambda_1\lambda_2\lambda_3 = -\frac{\pi^D}{4[\pi^M - \pi^D]} < 0 \tag{22}$$

From (22), we can see that any of the following three cases holds:
(i)all roots are negative , (ii)two roots are positive and one root is negative and (iii)two roots are imaginary roots
and one root is negative. However, from (15), (16), (17), we see that the cases (i) and (iii) never occur. So we can
the case (ii) occurs. Here suppose that $0 < \lambda_1, \lambda_2 < 1$ and $\lambda_3 < 0$. Then, $\lambda_1 + \lambda_2 + \lambda_3 < \lambda_1 + \lambda_2 < 2$ holds,
but then this and (20) contradict each other. So we have one negative root, one positive root in $\{s : 0 < s < 1\}$
and one positive root in $\{s : s > 1\}$. In addition to this argument and the fact that $\phi(s)$,
the biquadratic function of s has at most three extreme points, we can conclude that $\phi(s)$ is unimodal in $s \in [0, 1]$
so it has a maximum point as shown by Figure 1.
So we have two $s^* \in (0, 1)$, say s^*_L and s^*_H such that $0 < s^*_L < \frac{1}{2} < s^*_H < 1$. However, we see that only s^*_L $(< \frac{1}{2})$
does satisfy with the seconsd order condition (13), and the result follows.
∎

[Insert Figure 1 here]

4. R&D INVESTMENT(CROSS) LICENSING

In this section, we consider the case when firms(firm) can license each other its technologies if they(it) succeed(s) in the development of the technology(technologies). We assume that they determine their licensing fee by Nash bargaining if they agree with their licensing contract.

We can see the following two type of possible cases in which licensing may occur. We consider here the cases in which Firm x can licence its technology that it succeeds in the development by the symmetry of the two firms. In $\theta_3 = [1,1,0,0]$, the market becomes the monopoly of Firm x , so it has no incentive to licence its technologies to his rival.

(Case 1)$\theta_1 = [1,1,1,0]$ or $\theta_2 = [1,1,0,1]$

In this case, a unilateral licensing of one technology may occur from Firm x to Firm y. Consequently, the market becomes a duopoly. Denote by N_1

the licence fee, the Nash Bargaining function B_1 is given by

$$B_1 = [\pi^D + N_1 - \pi^M][\pi^D - N_1]$$

Then we have

$$\frac{\partial B_1}{\partial N_1} = \pi^D - N_1 - (\pi^D + N_1 - \pi^M) = \pi^M - 2N_1 = 0$$

or equivalently

$$N_1 = \frac{\pi^M}{2}$$

. The profits of Firm x and Firm y after side payment are

$$\pi^D + \frac{\pi^M}{2}, \pi^D - \frac{\pi^M}{2}$$

respectively. Since the threat points of Firm x and Firm y are $\pi^M, 0$, respectly and they are greater than the profits of Firm x and Firm y after side payment. So any licensing may not occur in this case.

(Case 2)$\theta_7 = [1,0,0,1]$ or $\theta_2 = [0,1,1,0]$

In this case, cross-licensing between Firm x and Firm y occurs. Consequently, the market becomes a duopoly. Denote by N_2 the licence fee, the Nash Bargaining function B_2 is given by

$$B_2 = [\pi^D + N_2][\pi^D - N_2]$$

Then we have

$$\frac{\partial B_1}{\partial N_1} = \pi^D - N_2 - (\pi^D + N_2) = -2N_2 = 0$$

or equivalently

$$N_2 = 0$$

. The profits of Firm x and Firm y after side payment are identical

π^D

. From the above observation, The expected profit of Firm x with (cross-)licensing, $\widetilde{\pi_x}(x_A, x_B, y_A, y_B)$ is given by

$$\begin{aligned}\widetilde{\pi_x}(x_A, x_B, y_A, y_B) &= \pi_x(x_A, x_B, y_A, y_B) \\ &+(1-e^{-x_A})e^{-x_B} \cdot e^{-y_A}(1-e^{-y_B})\pi^D \\ &+e^{-x_A}(1-e^{-x_B})(1-e^{-y_A})e^{-y_B}\pi^D\end{aligned} \quad (23).$$

Note that the second term in the right hand side of (23) is the realized profit of Firm x in the case when Firm x succeeds in the development of the technology A and Firm y does in that of the tehnology B. Similarly, the third term in the right hand side of (23) is the realized profit of Firm x in the case when Firm x succeeds in the development of the technology B and Firm y does in that of the tehnology A. By using the symmetry, the first order condition w.r.t.x_A can be written as

$$\begin{aligned}\frac{\partial \widetilde{\pi_x}}{\partial x_A} &= \frac{\partial \pi_x}{\partial x_A} + e^{-x_A}e^{-x_B}e^{-y_A}(1-e^{-y_B})\pi^D \\ &\quad -e^{-x_A}(1-e^{-x_B})(1-e^{-y_A})e^{-y_B}\pi^D \\ &= \phi(s) + s^2(1-s)(2s-1)\pi^D = 0\end{aligned} \quad (24).$$

Define $\psi(s) \equiv \phi(s) + s^2(1-s)(2s-1)\pi^D = \phi(s) + (-2s^4 + 3s^3 - s^2)\pi^D$ (25).
Then, we have $\psi(0) = \phi(0) = \psi(1) = \phi(1) = -1$ (26).
Since $\psi'(s) = \phi'(s) + s(-8s^2 + 9s - 2)\pi^D$ (27),
we also have $\psi'(0) = \phi'(0) = \pi^D > 0$ (28)
and $\psi'(1) = \phi'(1) - \pi^D = -\pi^M - \pi^D < \phi'(1) = -\pi^M < 0$ (29).
Rearranging $\psi(s)$ w.r.t. s yeilds
$\psi(s) = [\pi^M - 3\pi^D]s^4 - 3[\pi^M - 2\pi^D]s^3 + 2[\pi^M - 2\pi^D]s^2 + \pi^D s - 1$ (30).
Then we obtain the following lemma on the extreme points of $\psi(s)$.

LEMMA 4.1. *$\psi(s)$ has a unique maximum in* $[0, 1]$.

Proof. *In order to examine the extreme points of* $\psi(s)$*,the first order condition is* $\psi'(s) = 4[\pi^M - 3\pi^D]s^3 - 9[\pi^M - 2\pi^D]s^2 + 4[\pi^M - 2\pi^D]s + \pi^D = 0$ *(31). Suppose that* $\pi^M - 3\pi^D \neq 0$*. Then, deviding both sides of (31) by* $4[\pi^M - 3\pi^D]$ *yeilds*

$$s^3 - \frac{9[\pi^M - 2\pi^D]}{4[\pi^M - 3\pi^D]}s^2 + \frac{[\pi^M - 2\pi^D]}{[\pi^M - 3\pi^D]}s + \frac{\pi^D}{4[\pi^M - 3\pi^D]} = 0$$

(32). Using the relation between the roots of the cubic equation and coefficients, we have

$$\lambda_1 + \lambda_2 + \lambda_3 = \frac{9[\pi^M - 2\pi^D]}{4[\pi^M - 3\pi^D]}$$

(33),

$$\lambda_1\lambda_2\lambda_3 = -\frac{\pi^D}{4[\pi^M - 3\pi^D]}$$

(34). If $\pi^M - 3\pi^D < 0$*, then we see that the right hand sides of (33) and (34) are negative and positive, respectively. So if all the three roots of (31) are real roots, then two of them are negative and one of them is positive. If (31) has one real root and two imaginary roots, then the real root must be positive since (34) has positive sign. In both cases, (31) has a unique positive real root. Taking this fact and (28), (29) into consideration, we can see that there exists the maximum in* $[0,1]$*. Next suppose that* $\pi^M - 3\pi^D > 0$*. Then, in tyhis case, we see that the right hand sides of (33) and (34) are positive and negative, respectively. Since the sign of (34) is negative, as we see on* $\phi(s)$ *in the proof of the proposition 3.1, we can see that any of the following three cases holds:(i)all roots are negative , (ii)two roots are positive and one root is negative and (iii)two roots are imaginary roots and one root is negative. However, from the signs of (33)and (34), we see that the cases (i) and (iii) never occur. So we can the case (ii) occurs. Here suppose that* $0 < \lambda_1, \lambda_2 < 1$ *and* $\lambda_3 < 0$*. Then,* $\lambda_1 + \lambda_2 + \lambda_3 < \lambda_1 + \lambda_2 < 2 < \frac{9}{4} < \frac{9[\pi^M - 2\pi^D]}{4[\pi^M - 3\pi^D]}$ *holds, since* $\pi^M - 3\pi^D > 0$*. But then this and the fact that the sign of (33) is positive contradict each other. So (31) has one negative root, one positive root in* $\{s : 0 < s < 1\}$ *and one positive root in* $\{s : s > 1\}$*. So from this fact and (28), (29), we can see that there exists the maximum in* $[0,1]$*. Finally suppose that* $\pi^M - 3\pi^D = 0$*. Then, form (30) we have* $\psi(s) = -3[\pi^M - 2\pi^D]s^3 + 2[\pi^M - 2\pi^D]s^2 + \pi^D s - 1 = -3\pi^D s^3 + 2\pi^D s^2 + \pi^D s - 1$*. So we also have* $\psi'(s) = -9\pi^D s^2 + 4\pi^D s + \pi^D = 0$*. Deviding both sides of this by* $\pi^D (\neq 0)$ *yeilds:* $-9s^2 + 4s + 1 = 0$*. Solving this w.r.t. s, we get*

$$s^* = \frac{2 \pm \sqrt{13}}{9}$$

. *So $\psi(s)$ has a unique maximaum $s^* = \frac{2+\sqrt{13}}{9}$ in $[0,1]$. So it has a maximum point as shown by Figure 2 and the lemma holds.* ∎

[Insert Figure 2 here]

From (25), we can easily show that $\psi(s) \lesseqgtr \phi(s) \Leftrightarrow s \lesseqgtr \frac{1}{2}$ (35). From (26), (27), (28), (29) and Lemma 4.1, we can present our main result without proof.

PROPOSITION 4.1. *Suppose that $\pi^D + 3\pi^M > 16$. Then, there exists a symmetric Nash equilibrium investment level $\widetilde{x^*}$*

$$x^* = -\ln s_L^* > \widetilde{x^*} = -\ln \widetilde{s_L^*} > -\ln(\tfrac{1}{2})$$

in our R&D investment competition in completely complementary technologies with licensing system. That is, the existence of licwnsing system discourages R&D investment in completely complementary technologies.

From the proposition above, we see that the existence of a cross-licensing system discourages firm's R&D investments, when the duopolistic firms can produce goods by using the two completely complementary technologies, where any unilateral licensing cannot occur since firms needs both of the two technologies for their production of a product. An economic intuition of our result is that the existence of a cross-licensing system decreases firms' incentives for R&D through the chance of the exchanges of their technologies.

5. CONCLUDING REMARKS

In this paper, we explored the incentives for R&D investments of the duopolistic firms facing technological innovations in completely complementary technologies by analyzing a simple static innovation model. At first, as a benchmark we derive symmetric Nash equilibrium investment levels in our R&D investment competition in completely complementary technologies without licensing system. Then we examine the conditions under which (cross-) licensing occur. Then, by deriving symmetric Nash equilibrium investment levels in our R&D investment competition in completely complementary technologies with licensing system, we examine how the existence of a (cross-)licensing system affects firms' incentives for R&D activities in a Cournot duoply. And we show that the existence of a cross-licensing system discourages firm's R&D investments, when the duopolistic firms can produce goods by using the two completely complementary technologies, where any unilateral licensing cannot occur since firms needs both of the two technologies for their production of a product. An economic intuition of our result is that the existence of a cross-licensing system decreases firms' incentives for R&D through the chance of the exchanges of their technologies.

There remain many problems for future researches. First, in this paper, we focus on the symmetric equilibrium in order to make our analysis easy. In practice, however, firms cannot be symmetric in the industries where the complementary technologies are indispensable for the production of goods. In addition, the role of R&D ventures who do not produce products but concentrate on R&D, increases its importance in such industries. Secondly, in this paper, since we concentrate on the effect on the incentives for R&D, we did not examine the effects on the social welfare at the equilibrium. If we clarify how governments should plan and exercise the policy for technologies under complementary technological innovations, it is important for us to explore the implications on the economic welfare at the equilibrium in our model.

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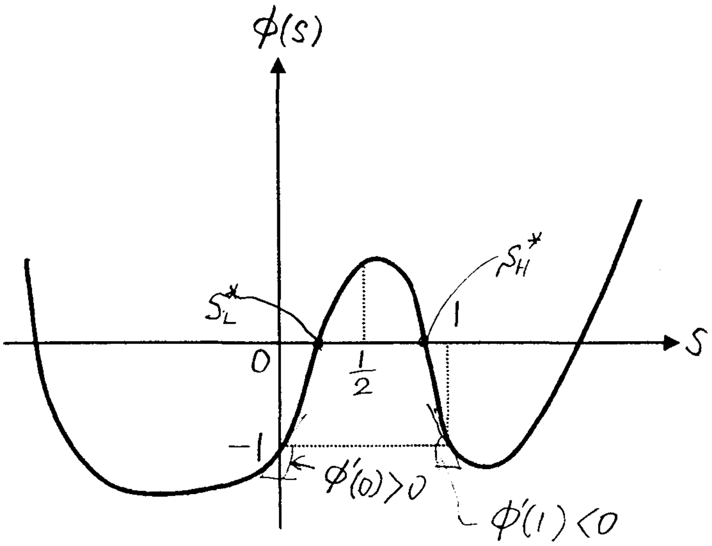

Figure 1

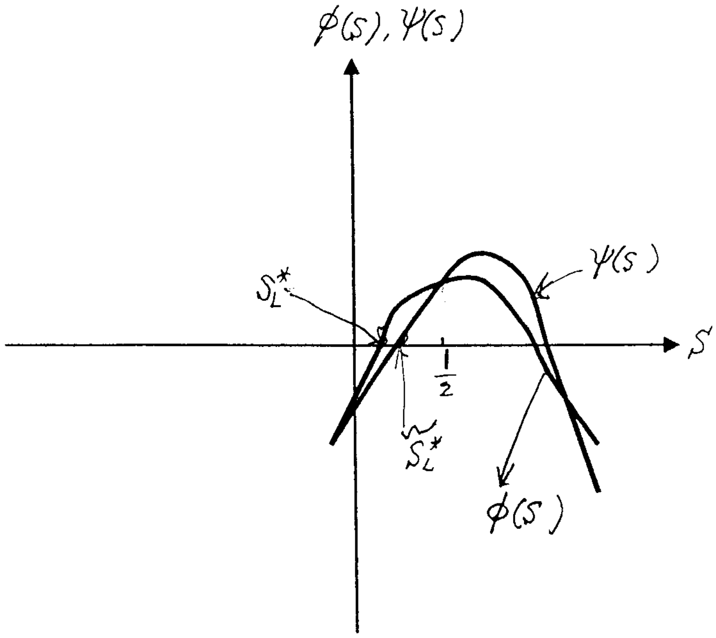

Figure 2