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Innovation, Licensing and Welfare

by

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Abstract This paper examines how the option for licensing affects research and development (R&D) and social welfare. We find that if cost reduction from R&D is sufficiently small and there is an option of licensing, firms will do non-cooperative R&D. In absence of licensing, firms will do cooperative R&D for sufficiently small cost reduction from R&D. Whether the option for licensing increases social welfare is ambiguous. If the possibility of licensing increases probability of success in R&D significantly then welfare is higher in presence of licensing.

Keywords Cooperative R&D, Licensing, Welfare

J.E.L. Class D43, L13, O34

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1 Introduction

Two important ways of improving the technological level of an economy are research and development (R&D) and technology licensing. As technology licensing is usually less expensive way of improving technological quality compared to indigenous R&D, many countries are encouraging their firms to engage in technology licensing and improving their technological quality.

However, it has been found that, in case of process innovation[1], technology licensing may reduce social welfare. Kabiraj and Marjit (1992) and Lin (1996) have argued that licensing can reduce welfare if cost reduction of a firm induces some firms to exit the market or if licensing facilitates collusion. Therefore, technology licensing can reduce social welfare by increasing market concentration.

In this paper we provide another reason for lower social welfare under technology licensing. More specifically, we argue that the possibility of licensing may reduce social welfare by discouraging firm to do cooperative R&D. Thus, we show that the presence of technology licensing can reduce social welfare even if licensing does not induce exit of firms or does not facilitate collusion but changes R&D organization.

Researchers have already paid large amount of attention to discuss several issues on R&D. One important area of research is to explain the rationale for doing cooperative R&D and its effect on R&D investment and social welfare (see, e.g., d'Aspremont and Jacquemin, 1988, Suzumura, 1992, Choi, 1993 and Hinloopen, 1997).[2] However, previous works on R&D generally ignored the possibility of other business strategies such as technology licensing. [3] Previous papers assumed that a firm could share its knowledge with another firm if they do R&D together but did not allow a firm to sell its knowledge to another firm. This assumption is reasonable in those industries where technology licensing is very difficult or costly. Hence, the assumption of the previous papers might be suitable in industries with tacit knowledge but might not be relevant where knowledge sharing is not difficult.

We show that if we allow firms to increase their strategic options by making licensing as a feasible option along with cooperative and non-cooperative R&D then the incentive for knowledge sharing through cooperative R&D would be reduced. We find that firms would prefer to do non-cooperative R&D keeping the option for licensing open. Whether the possibility of licensing increases social welfare is, however, ambiguous. Thus, the present paper is a step to examine the impact of licensing on R&D organization and social welfare.

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[1] In case of process innovation, better quality of the technology implies lower cost of production for the corresponding firm.

[2] For papers on patent race one may refer to Loury (1979) and Lee and Wilde (1980).

[3] Two exceptions are Gallini and Winter (1985) and Katz and Shapiro (1985). In totally different context, these papers focus on the effect of licensing on R&D. While Gallini and Winter (1985) identify the conditions for licensing in a search-theoretic model of R&D, Katz and Shapiro (1985) focus on the incentives to develop a process when patent holder has the option for licensing its technology to the competitor.

Hence, this paper serves two purposes. Firstly, it shows the effect of licensing on R&D. Secondly, it shows that licensing may reduce welfare when the firms have the option for R&D before licensing.

In what follows, section 2 considers a model of R&D competition between Cournot duopolists with homogeneous goods, where success in R&D is uncertain. We examine R&D organization and social welfare with and without the option for licensing. We show that, in absence of licensing, firms will do cooperative R&D when cost reduction from R&D is sufficiently low. While cooperation in R&D stage will increase the probability of using a better technology by both firms, knowledge sharing through R&D cooperation will also increase competition in the product market. If cost reduction from R&D is sufficiently small then the former effect will dominate the latter effect and will make cooperative R&D profitable compared to non-cooperative R&D.

However, the possibility of unilateral success in R&D can create the possibility of technology licensing. In this situation, the successful firm will always prefer to license its technology against pre-unit output royalty. Thus, licensing will help the licenser to raise its profit from royalty income and also to reduce competition from the licensee, as optimal output royalty will not change the effective marginal cost of production of the licensee compared to a situation with no licensing. The possibility of licensing will always encourage the firms to do non-cooperative R&D keeping the option for licensing open.

If cost reduction from R&D is sufficiently large then firms will do non-cooperative R&D irrespective of the availability of licensing. In case of unilateral success in R&D, licensing does not change the effective marginal cost of production of the unsuccessful firm compared to a situation with no licensing. But, licensing increases profit of the successful firm through royalty income. Hence, presence of licensing increases social welfare when cost reduction from R&D is sufficiently large.

If cost reduction from R&D is sufficiently small and licensing is an option then firms will do non-cooperative R&D. Firms will do cooperative R&D without the possibility of licensing. Since licensing does not change the effective marginal cost of the licensee compared to a situation with no licensing, licensing does not affect consumer surplus. But, in absence of licensing, cooperative R&D will help to reduce the marginal cost of production of the unsuccessful firm under unilateral success in R&D. Therefore, in case of unilateral success in R&D, cooperative R&D will increase consumer surplus compared to 'non-cooperative R&D and licensing afterwards'. Hence, presence of licensing reduces social welfare when cost reduction from R&D is sufficiently small. However, as we will show, if possibility of licensing increases probability of success in R&D significantly then, even if cost reduction from R&D is sufficiently small, social welfare can be higher in presence of licensing. Thus, we show that the effect of licensing on social welfare depends on the degree of cost reduction from R&D and the effect of R&D investment on probability of success in R&D.

At this point it is worth mentioning a related result of the literature on licensing. Previous works on licensing argue that firms would prefer licensing with output royalty than fixed fee licensing (see, e.g., Gallini and Winter, 1985 and Rockett, 1990). In the following analysis, we will show that the cooperative R&D of this paper is similar to a licensing contract with fixed fee only. Hence, if licensing is not a feasible option then cooperative R&D helps the firms to replicate a situation similar to a licensing contract with fixed fee. But cooperative R&D does not help the firms to replicate a licensing contract with output royalty. Thus, if licensing is not allowed then it reduces the option to the firms and increases social welfare.

The rest of the paper is organized as follows. The next section provides a model with non-cooperative and cooperative R&D without the possibility of licensing. We extend this model in section 3 by incorporating licensing. Section 4 looks at the welfare implications. In section 5, we discuss the implications of endogenous R&D costs on social welfare. Section 6 concludes the paper.

2 The basic model

Consider an economy with two firms, called firm 1 and firm 2. Assume that these firms can produce a homogeneous product with a technology corresponding to constant marginal cost of production $\bar{c}$. Both firms do R&D and each of them can reduce the cost of production to c. However, success in R&D is uncertain. Assume that p and $(1-p)$ show the respective unconditional probability of success and failure in R&D. We assume that both firms face same probability of success in R&D. Further we assume that there are no other costs related to production or R&D.

The assumption of no costs of doing R&D will implies that both firms always find it profitable to do R&D compared to non-R&D. If there were costs of doing R&D, firms might not find it profitable to do R&D when the probability of success in R&D was sufficiently low. Since our purpose is to examine the impact of licensing on R&D organization, i.e., non-cooperative and cooperative R&D, and social welfare, we abstract the possibility of non-R&D by assuming no cost of doing R&D.

Finally, assume that the inverse market demand function is given by

$$P = a - q, \tag{1}$$

where, P shows the price of the product, q stands for the industry output and $a > \bar{c}$. Further, throughout the analysis, we assume that $c > 2\bar{c} - a$. This assumption implies that if one firm has a technology corresponding to marginal cost of production c and another firm has a technology corresponding to marginal cost of production $\bar{c}$, the output of the both firms will be positive.

In this section we will assume that these firms do not have the option for licensing. Therefore, here we consider the following game. In stage 1, these firms decide

whether to do non-cooperative R&D or cooperative R&D. Then, in stage 2, they compete like Cournot duopolists in the product market. We solve the game through backward induction.

Let us first consider non-cooperative R&D. Profit of the ith firm from R&D is

$$V_i(NC) = p^2\pi_i(c,c) + p(1-p)\pi_i(c,\bar{c}) + (1-p)p\pi_i(\bar{c},c) + (1-p)^2\pi_i(\bar{c},\bar{c}), \qquad (2)$$

where, $i = 1,2$ and the first (second) argument in the π function represents the marginal cost of production of firm 1 (firm 2).

Now we examine the possibility of cooperative R&D by these firms. Following Choi (1993), we assume that, under cooperative R&D, both firms operate their own R&D lab but these firms will use the innovated technology if at least one of them succeeds in R&D.[4] Therefore, in case of cooperative R&D, profit of the ith firm, $i = 1,2$, is

$$V_i(C) = p^2\pi_i(c,c) + p(1-p)\pi_i(c,c) + (1-p)p\pi_i(c,c) + (1-p)^2\pi_i(\bar{c},\bar{c}). \qquad (3)$$

However, these firms will prefer to do cooperative R&D compared to non-cooperative R&D provided neither of them is worse-off under cooperative R&D compared to non-cooperative R&D. So, these firms will do cooperative R&D instead of non-cooperative R&D provided

$$V_i(C) > V_i(NC) \qquad \text{or} \qquad 2\pi_i(c,c) > \pi_i(c,\bar{c}) + \pi_i(\bar{c},c). \qquad (4)$$

Condition (4) shows that if industry profit in case of unilateral success in R&D increases under cooperative R&D compared to non-cooperative R&D then firms will prefer cooperative R&D compared to non-cooperative R&D. Since, industry profit remains same in case of both-success and no-success in R&D, the determinant for cooperative or non-cooperative R&D becomes the industry profit under unilateral success in R&D. Hence, if condition (4) does not hold then firms will prefer to do non-cooperative R&D compared to cooperative R&D.

With the demand and cost specification we find that (4) holds if and only if

$$c > \frac{(5\bar{c} - 2a)}{3}. \qquad (5)$$

Therefore, following proposition is immediate from the above discussion.

[4] Given our assumptions on R&D, it is always optimal for the firms to operate two research labs under cooperative R&D.

Proposition 1: *Firms will prefer to do cooperative R&D compared to non-cooperative R&D when cost reduction from R&D is not sufficiently large, i.e.,* $c > \frac{(5\bar{c}-2a)}{3}$.

Since the choice of R&D organization depends on the amount of cost reduction from R&D, it is easy to understand that social welfare will also be affected with the amount of cost reduction. Expected welfare is given by

$$EW(C) = p^2 W_0(c,c) + 2p(1-p)W_0(c,c) + (1-p)^2 W_0(\bar{c},\bar{c}), \quad \text{for } c > \frac{(5\bar{c}-2a)}{3} \qquad (6)$$

and

$$EW(NC) = p^2 W_0(c,c) + 2p(1-p)W_0(c,\bar{c}) + (1-p)^2 W_0(\bar{c},\bar{c}), \quad \text{for } c < \frac{(5\bar{c}-2a)}{3}, \qquad (7)$$

where, the argument in $W_0(.,.)$ shows the number of firms producing with cost c and with cost $\bar{c}$ and $W_0(.,.)$ shows the summation of industry profit and consumer surplus for the corresponding situation.

3 Licensing

In this section we extend the model of the previous section by allowing the firms to take decision on licensing ex-post R&D. We consider the following game. In stage 1, firms decide whether to do non-cooperative R&D or cooperative R&D. In stage 2, they decide on technology licensing. In stage 3, they compete like Cournot duopolists. We solve the game through backward induction.

It is clear from our framework that licensing is not an option if firms do cooperative R&D since, if successful, they share the information about the new innovation while doing R&D. However, given non-cooperative R&D, the firms may have incentive for knowledge sharing ex-post R&D provided there is unilateral success in R&D. We assume that, if the firms do non-cooperative R&D then, in case of unilateral success in R&D, the successful firm has the option to give a take-it-or-leave-it licensing offer to the unsuccessful firm. Under licensing, the licenser can charge non-negative up-front fixed-fee, F and per-unit output royalty, r.[5]

Before examining these firms' preference over cooperative R&D and non-cooperative R&D with the option for licensing afterwards, let us first examine the optimal licensing contract and payoffs of these firms. Since, these firms are symmetric, without loss of generality we assume that, in case of unilateral success in R&D, firm 1

[5] One may think that the firms can make a similar contract under cooperative R&D where the contract is contingent upon the R&D outcome, saying that in case of unilateral success in R&D, the successful firm will give the technology to the unsuccessful firm but against a payment consisting of fixed fee and output royalty. However, if the possibility of coordination in the R&D stage under cooperative R&D helps the unsuccessful firm to acquire the knowledge about the new innovation then this contingent contract under cooperative R&D becomes ineffective.

succeeds in R&D and decides whether to license the technology to firm 2 or not. Therefore, in this situation firm 1 maximizes the following expression:

$$\underset{F,r}{Max}\, F + rq_2 + \pi_1(c, c+r) \tag{8}$$

$$\text{s.t., } F + rq_2 + \pi_1(c, c+r) \geq \pi_1(c+\bar{c}) \tag{9}$$

$$\pi_2(c, c+r) - F \geq \pi_2(c, \bar{c}) \tag{10}$$

$$\text{and} \quad F \geq 0,\ q_i \geq 0,\ i = 1,2.^{6} \tag{11}$$

Solution of the problem given by (8) – (11) will provide the following result.

Proposition 2: *If the firms do not make a cooperative contract ex-ante R&D then, in case of unilateral success in R&D, the successful firm will always license its technology to the unsuccessful firm. The licensing contract will involve only output royalty equal to* $(\bar{c} - c)$.

Since the proof is similar to Mukherjee and balasubramanian (2001), we are leaving the details here.

Now, we are in a position to consider the optimality between cooperative R&D and non-cooperative R&D with the option for licensing afterwards. We should note that if $c < \frac{(5\bar{c}-2a)}{3}$ then these firms will not do cooperative R&D but will do non-cooperative R&D followed by licensing in case of unilateral success in R&D. Hence, in this situation, it is trivial that firms will always prefer non-cooperative R&D with the possibility of licensing afterwards compared to cooperative R&D.

But, for $c > \frac{(5\bar{c}-2a)}{3}$, firms will prefer both cooperative R&D and 'non-cooperative R&D with the possibility of licensing afterwards' compared to non-cooperative regime. Since, profits of these firms under both-success and no-success remain same under cooperative R&D and 'non-cooperative R&D with the possibility of licensing', preference between cooperative agreement ex-ante R&D and 'non-cooperative R&D with the option for licensing' depends on the profits of these firms in case of unilateral success in R&D. The ith firm will prefer 'non-cooperative R&D with the option for licensing' compared to cooperative R&D provided

$$p(1-p)(\pi_i(c,\bar{c}) + rq_j^* + \pi_i(\bar{c},c)) > 2p(1-p)\pi_i(c,c),$$

$$\text{or, } \pi_i(c,\bar{c}) + rq_j^* + \pi_i(\bar{c},c) > 2\pi_i(c,c), \tag{12}$$

where, $i, j = 1,2$, $i \neq j$ and q_j^* shows the optimal output of the jth firm under licensing. Demand and cost specifications show that the condition (12) satisfies always.

[6] Antitrust law may be responsible for non-negative constraint on licensing contract.

We summarize the above discussion in the following proposition.

Proposition 3: *These firms always prefer non-cooperative R&D with the option for licensing afterwards compared to cooperative R&D.*

The reason for the above result is easy to understand. If firms do cooperative R&D then, in case of unilateral success in R&D, the successful firm needs to share the knowledge with the unsuccessful firm and the successful firm faces relatively higher competition from the unsuccessful firm compared to a situation where the successful firm does not share the knowledge with the unsuccessful firm. But if firms do non-cooperative R&D and have the option for licensing afterwards then, in case of unilateral success in R&D, the successful firm will always gain from licensing its technology to the unsuccessful firm. Here the successful firm can eliminate the possibility of higher competition from the unsuccessful firm by designing a suitable licensing contract. Since these firms are symmetric and have similar probability of being a licenser or licensee, both firms will always do non-cooperative R&D instead of forming a cooperative R&D agreement when there is a possibility of license ex-post R&D.

One should take the result of Proposition 3 with a caution. In this paper, cooperative R&D only helps the firms to benefit from knowledge sharing. We have examined relative profitability of knowledge sharing at the time of doing R&D compared to knowledge sharing after getting the innovation. But, in our framework, there is no benefit from cost saving or synergies under cooperative R&D. If R&D involves fixed cost production as in Marjit (1991) then cost saving provides other incentive for doing cooperative R&D. As a result, firms may prefer to do R&D in one lab instead of operating two labs, as described in this paper.[7] The possibility of getting benefit from synergies as in Kabiraj and Mukherjee (2000) also provides another incentive for doing cooperative R&D. With sufficiently higher incentive for getting benefits from cost saving or synergies under cooperative R&D, firms might do cooperative R&D for some parametric configurations even if they have the option for licensing ex-post R&D. However, even in this situation, our basic argument holds, i.e., the possibility of licensing ex-post R&D reduces the incentive for doing R&D. Since, the possibility of knowledge sharing under licensing helps the firms to increase their profits under non-cooperative R&D, firms have lower incentive to do cooperative R&D in presence of licensing ex-post R&D.

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[7] If the firms operate a single lab under cooperative R&D then the payoff of the i th firm, $i = 1,2$, will be $p\pi_i(c,c) + (1-p)\pi_i(\bar{c},\bar{c}) - \frac{K}{2}$, where K is the fixed cost of doing R&D. Hence, the firms would use a single lab instead of two labs under cooperative R&D provided $\frac{K}{2} > p(1-p)[\pi_i(c,c) - \pi_i(\bar{c},\bar{c})]$.

Further, it should be noted that we consider a situation where firms would make the licensing contract ex-post R&D. However, these firms can make the same licensing contract ex-ante R&D contingent on the R&D outcome.[8] For example, these firms can do non-cooperative R&D and make a licensing contract ex-ante R&D saying that if there is any technology transfer ex-post R&D then the licensee will pay an output royalty at a rate $r^* = (\bar{c} - c)$. But, whether the firms do the licensing agreement ex-ante or ex-post R&D, it is clear that the firms would not do cooperative R&D when they have the option for knowledge sharing through technology licensing.

It is also worth mentioning the similarity of the cooperative R&D mentioned in this paper and a licensing contract with fixed fee only. If the firms make a licensing contract with up-front fixed fee only then both firms will produce with a marginal cost of production c. Further, the symmetry of these firms makes them equally likely to be a licenser and a licensee. Therefore, if the firms make a licensing contract with an up-front fixed fee only then the expected payoff of the i th firm will be

$$V_i(LF) = p^2\pi_i(c,c) + p(1-p)(\pi_i(c,c) + F^*) + (1-p)p(\pi_i(c,c) - F^*) + (1-p)^2\pi_i(\bar{c},\bar{c}), \tag{13}$$

where F^* is the optimal value of the fixed fee charged by the licenser. The expression (13) is same as the expression (3). This implies that, under cooperative R&D agreement, firms can replicate the licensing contract with fixed fee but cooperative R&D does not help the firms to replicate the licensing contract with output royalty.

In case of unilateral success in R&D, the effective marginal cost of production of the unsuccessful firm is same under non-cooperative R&D with and without the possibility of licensing. This is because the effective marginal cost of production of the unsuccessful firm will be the summation of c and the per-unit output royalty $(\bar{c} - c)$. Therefore, in case of unilateral success in R&D, optimal output and profit of the unsuccessful firm will be same under non-cooperative R&D with and without licensing.

Therefore, expected welfare under non-cooperative R&D with the possibility of licensing afterwards will be

$$EW(NCL) = p^2 W_0(c,c) + 2p(1-p)W_l(c,\bar{c}) + (1-p)^2 W_0(\bar{c},\bar{c}), \tag{14}$$

where, W_l shows the summation of consumer surplus and industry profit. It should be noted that now industry profit includes royalty payment also. We have seen that optimal output and profit of the unsuccessful firm will be same under non-cooperative R&D with and without licensing. Therefore, optimal output and profit, excluding royalty income, of the successful firm will be same under non-cooperative R&D with and

[8] In a paper Scotchmer (1996) showed the benefit from ex-ante licensing contract when second generation product infringes patent of the first generation product.

without licensing. Hence, we find that $W_l = W_0 + (\bar{c} - c)q_{uns}$, where q_{uns} shows the optimal output of the unsuccessful firm in case of unilateral success in R&D under non-cooperative R&D.

4 Welfare comparison

Now, we are in a position to compare social welfare under two regimes: one where firms do not have the option for licensing ex-post R&D and second, where the firms have the option for licensing ex-post R&D.

Let us first consider the situation where $c > \frac{(5\bar{c}-2a)}{3}$. In this situation, firms do cooperative R&D when they do not have the option for licensing ex-post R&D. In presence of licensing these firms will do non-cooperative R&D. Therefore, corresponding welfare expressions are (6) and (14). Given the demand and cost specifications, comparison of (6) and (14) shows that (6) is always greater than (14). Hence, social welfare is higher in absence of licensing when $c > \frac{(5\bar{c}-2a)}{3}$.

Next, consider the situation where $c < \frac{(5\bar{c}-2a)}{3}$. Here firms will do non-cooperative R&D irrespective of the option for licensing ex-post R&D. Therefore, here the corresponding expressions for welfare are (7) and (14). It is easy to understand that in this situation welfare is higher in presence of licensing. This is because the possibility of licensing does not change the optimal output decisions of these firms but, in case of unilateral success in R&D, licensing helps the successful firm to increase its profit from royalty income.

We summarize the above discussion in the following proposition.

Proposition 4: *Consider* $c > (<) \frac{(5\bar{c}-2a)}{3}$. *Then the possibility of licensing ex-post R&D reduces (increases) social welfare compared to a situation where the firms do not have the option for licensing ex-post R&D.*

5 Endogenous R&D costs

So far we have assumed that probability of success in R&D is given exogenously. In this section, we will briefly discuss the situation where firms can influence the probability of success through their choice of R&D investment, as in Choi (1993). We will show that when firms can influence the probability of success in R&D then welfare can be higher in presence of licensing even for the situations where cooperative R&D is profitable than non-cooperative R&D in absence of licensing.

Assume that the unconditional probability of success in R&D increases with R&D investment, i.e., $p(x_i)$, $i = 1,2$, where x_i is firm i's R&D investment. We consider that $p'(x_i) > 0$, $p''(x_i) < 0$, $p'(0) = \infty$ and $p'(\infty) = 0$ for $i = 1,2$. Therefore,

expected profits of the ith firm under 'non-cooperative R&D without licensing', cooperative R&D and 'non-cooperative R&D with licensing' are respectively

$$V_i(NC) = p(x_i)p(x_j)\pi_i(c,c) + p(x_i)(1-p(x_j))\pi_i(c,\bar{c}) + (1-p(x_i))p(x_j)\pi_i(\bar{c},c) + (1-p(x_i))(1-p(x_j))\pi_i(\bar{c},\bar{c}) - x_i, \quad (15)$$

$$V_i(C) = p(x_i)p(x_j)\pi_i(c,c) + p(x_i)(1-p(x_j))\pi_i(c,c) + (1-p(x_i))p(x_j)\pi_i(c,c) + (1-p(x_i))(1-p(x_j))\pi_i(\bar{c},\bar{c}) - x_i, \quad (16)$$

and

$$V_i(NCL) = p(x_i)p(x_j)\pi_i(c,c) + p(x_i)(1-p(x_j))(\pi_i(c,\bar{c}) + rq_j^*) + (1-p(x_i))p(x_j)\pi_i(\bar{c},c) + (1-p(x_i))(1-p(x_j))\pi_i(\bar{c},\bar{c}) - x_i, \quad (17)$$

where $i, j = 1,2$ and $j \neq i$.

Respective first order conditions for profit maximization with respect to R&D invest are

$$p'(x_i)p(x_j)\pi_i(c,c) + p'(x_i)(1-p(x_j))\pi_i(c,\bar{c}) - p'(x_i)p(x_j)\pi_i(\bar{c},c) - p'(x_i)(1-p(x_j))\pi_i(\bar{c},\bar{c}) = 1, \quad (18)$$

$$p'(x_i)p(x_j)\pi_i(c,c) + p'(x_i)(1-p(x_j))\pi_i(c,c) - p'(x_i)p(x_j)\pi_i(c,c) - p'(x_i)(1-p(x_j))\pi_i(\bar{c},\bar{c}) = 1, \quad (19)$$

and

$$p'(x_i)p(x_j)\pi_i(c,c) + p'(x_i)(1-p(x_j))(\pi_i(c,\bar{c}) + rq_j^*) - p'(x_i)p(x_j)\pi_i(\bar{c},c) - p'(x_i)(1-p(x_j))\pi_i(\bar{c},\bar{c}) = 1. \quad (20)$$

It is easy to see that, in absence of licensing, cooperative R&D will be profitable compared to non-cooperative R&D if $c > \frac{(5\bar{c}-2a)}{3}$. If $c = \frac{(5\bar{c}-2a)}{3}$ then optimal R&D investments under cooperative and non-cooperative R&D are same and hence, expected will be same under non-cooperative and cooperative R&D. Given any positive and equal R&D investments of these firms, cooperative R&D will give higher expected profit compared to non-cooperative R&D if $c > \frac{(5\bar{c}-2a)}{3}$. Further, if $c > \frac{(5\bar{c}-2a)}{3}$ then optimal R&D investment of each firm will be more under cooperative R&D compared to non-cooperative R&D. Hence, expected profit of these firms under cooperative R&D will be higher than that of under non-cooperative R&D when $c > \frac{(5\bar{c}-2a)}{3}$. Similar argument will show that firms will not do cooperative R&D for $c < \frac{(5\bar{c}-2a)}{3}$.

Given the values of R&D investments, left hand side of (20) is greater than the left hand sides of (18) and (19). Due to the symmetry of these firms, both firms will invest more under 'non-cooperative R&D with licensing' compared to cooperative R&D and 'non-cooperative R&D without licensing'. Therefore, equilibrium R&D investments and probability of success in R&D will be highest under 'non-cooperative R&D with the possibility of licensing' compared to cooperative R&D and 'non-cooperative R&D without the possibility of licensing'.

Following the discussions of the previous section, we can say that, given the positive R&D investments of these firms, expected welfare would be lower under 'non-cooperative R&D with the possibility of licensing' compared to cooperative R&D. However, we have shown that equilibrium R&D investment and probability of success in R&D will be higher under 'non-cooperative R&D with the possibility of licensing' compared to cooperative R&D. If benefit from higher probability of success is sufficiently higher then social welfare will be higher under 'non-cooperative R&D with the possibility of licensing' compared to cooperative R&D.

Now, we will consider a specific functional form for the probability of success in R&D to provide an example showing higher welfare under 'non-cooperative R&D with the possibility of licensing' compared to cooperative R&D when we have endogenous costs of R&D. Suppose the probability function for the success in R&D faced by each of theses firms is given by $p(x_i) = \mu x_i^{\frac{1}{2}}$, $i = 1,2$. Further, for simplicity, assume that $a = 1$, $c = 0$ and $\bar{c} \in (0, \frac{2}{5})$.[9] Given the demand and cost specifications we find that probability of success in R&D under 'non-cooperative R&D with the possibility of licensing' equals to 1 for $\mu \geq \frac{3}{\sqrt{2(1-\bar{c})\bar{c}}}$. Assume that $\mu = \frac{3}{\sqrt{2(1-\bar{c})\bar{c}}}$. For this value of μ, optimal total R&D investment in the economy under 'non-cooperative R&D with licensing' is $\frac{4(1-\bar{c})\bar{c}}{9}$. Therefore, expected welfare under 'non-cooperative R&D with licensing' is

$$W_l = \frac{4(1-(1-\bar{c})\bar{c})}{9}. \tag{21}$$

When $\mu = \frac{3}{\sqrt{2(1-\bar{c})\bar{c}}}$, the probability of success and optimal total R&D investment in the economy under cooperative R&D are respectively $\frac{(1-\bar{c})}{3(1-\bar{c})}$ and $\frac{4(1-\bar{c})^3\bar{c}}{81(1-\bar{c})^2}$. Therefore, expected welfare under cooperative R&D is

$$W_c = \frac{[20+16(1-\bar{c})^2 - 4(1-\bar{c})\bar{c}]}{81}. \tag{22}$$

[9] Given these values of a and c, cooperative R&D is profitable for $\bar{c} \in (0, \frac{2}{5})$.

From (21) and (22), we find that $W_l > W_c$ since $\bar{c}^2 > 0$.

So, the above discussions imply that the possibility of endogenous R&D costs would modify Proposition 4 in the following way.

Proposition 5: *Possibility of licensing is more likely to reduce social welfare if the cost reduction from R&D is sufficiently small and the effect of R&D investment on the probability of success in R&D is sufficiently low.*

6 Conclusion

In this paper we examine whether the option for licensing is social welfare improving. We show that when licensing ex-post R&D is an option then the firms will always do non-cooperative R&D keeping the option for licensing open. But, when licensing is not an option then the firms will do cooperative R&D when cost reduction from R&D is sufficiently small.

Therefore, if cost reduction from R&D is sufficiently small then firms will do non-cooperative R&D when they have the option for licensing afterwards but will do cooperative R&D when they do not have the possibility of licensing. Licensing will not change the effective marginal cost of production of the licensee compared to no licensing. We show that, in this situation, consumer surplus and also social welfare will be more under cooperative R&D compared to 'non-cooperative R&D with the possibility of licensing afterwards'. Hence, if cost reduction from R&D is sufficiently small then the option for licensing is welfare reducing.

If cost reduction from R&D is not sufficiently small then the firms will do non-cooperative R&D irrespective of the possibility of licensing. Here effective costs of production remain same with and without the possibility of licensing. But the possibility of royalty payment increases expected profit of the firms when there is a possibility of licensing. Thus, in this situation, the option for licensing increases welfare.

If the firms can influence probability of success in R&D through their choice of R&D investment then the possibility of higher social welfare increases in presence of licensing. This is because the expected profit with the presence of licensing induces the firms to invest more in R&D, which increases the probability of success in R&D.

Therefore, whether presence of licensing increases welfare depends on the cost reduction from R&D and the influence of R&D investment on the probability of success in R&D. Thus, unlike previous studies, this paper shows that the possibility of licensing can reduce welfare even if licensing does not induce firms to exit the market or does not facilitate collusion. Hence, while encouraging licensing, an economy should be careful to consider its effect on other strategies of the firms such as R&D organization.

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