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On the Choice of R&D Organization*

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Abstract: This paper seeks to examine, in the context of Marjit (1991, Eco. Lett.) and Mukherjee and Marjit (2004, Gr. Dec. Nego.) models, the effect on the choice of R&D organization if the number of research lab is chosen by the firms optimally under R&D cooperation. Given the optimal form of R&D cooperation, the paper further studies the effect of introducing fee licensing under non-cooperative R&D. We show that our results substantially differ from those in the existing literature. The R&D cost, the success probability, and the size of innovation, all these play a crucial role.

Keywords: R&D organization; Cooperative and non-cooperative research; Technology licensing; Cournot competition;

JEL classifications: D43; L13; O32.

1. Introduction

The literature on research and development (R&D) discusses incentives of firms to invest in research. Often R&D involves a huge expenditure, but the firms even after investment do not know for sure whether success in R&D will come or not. This means R&D results are uncertain. Moreover, the firms have the problem of appropriating profits due to spillovers, imitation and diffusion of R&D outcomes in the backdrop of imperfect patent protection. Which market structure prevails is another important consideration for R&D incentives and investment.[1] While under non-cooperative R&D the innovating firm emerges as a monopolist (subject, however, to the appropriability problem), under cooperative R&D the firms can share R&D costs, output and uncertainty depending on the form of cooperation, and also can internalize the spillovers of R&D. Hence the choice of R&D organization, namely, the choice between cooperative and non-cooperative R&D, is an important consideration in the context of R&D investment.

While Katz (1986) finds that the competing firms have incentives to cooperate so as to share R&D expenses and results, the pioneering contribution on the choice between cooperative and non-cooperative R&D is made by d'Aspremont and Jacquemin (1988). The paper considers a duopoly with homogeneous goods, wherein the firms interact in research and final production. The paper highlights the role of spillovers in the choice of R&D organization. Kamien et al. (1992) has extended the model to the case of differentiated duopoly when there are several forms of R&D.[2] Suzumura (1992) has extended d'Aspremont and Jacquemin (1988) to the case of oligopoly with more general spillover assumption, and Amir et al. (2003) consider the problem with endogenous spillovers.

That uncertainty alone can be a source of R&D cooperation has been first drawn attention by Marjit (1991). Then Marjit (1991) results are examined in a number of papers. In his paper cooperative research is preferred to non-cooperative research for all low and high probability of success and non-cooperative R&D is chosen for intermediate success probabilities. Combs (1992) has introduced multiple research projects and has shown that cooperative research will occur only for high probability of success.[3] Kabiraj (2007) has introduced patent protection in

[1] See Arrow (1962), Gilbert and Newbery (1982), Yi (1999), Belleflamme and Vergari (2011) and Shibata (2014).
[2] In Kamien et al. (1992), the R&D activity takes the form of R&D competition, R&D cartel, RJV competition, or RJV cartel. They have d'Aspremont and Jacquemin (1988) framework with differentiated products.
[3] The Combs (1992) model is framed in such a way that the probability of success under cooperative research is twice that under non-cooperative R&D.

the context of Marjit (1991) to show that Combs (1992) result is just reversed if R&D investment is small, but Marjit (1991) result will reappear if R&D cost is large (but not too large). Then Mukherjee and Marjit (2004) have introduced technology transfer to study how it affects the choice of R&D organization when the firms do cooperative research either in a single lab or in both labs. Doing research in a single lab means that the firms share both R&D costs and results (this is RJV), but doing research in both labs means that the firms do research in both labs independently and simultaneously although they share R&D results of each lab. Recently, Chattopadhyay and Kabiraj (2015), and Kabiraj and Chattopadhyay (2015) have examined the choice of R&D organization in the context of Marjit (1991) by introducing incomplete information about R&D results.

The present paper is an extension of Marjit (1991) and Mukherjee and Marjit (2004) to the case when the R&D cooperating firms decide optimally whether they will do cooperative research in a single lab or in both of their labs. Thus the present paper seeks to examine, in the context of the above two models, the effect on the choice of R&D organization when the number of research labs is chosen optimally by the research cooperation. Then given the optimal choice of R&D cooperation, the paper further studies the effect of introducing technology licensing under non-cooperative research, hence it evaluates the results of Mukherjee and Marjit (2004).[4] We find that our results are substantially different from those in the existing literature.

In terms of addressing the problem, our paper is very close to Mukherjee and Marjit (2004), but to understand the contribution of our paper in the literature vis-à-vis theirs, we must take note of the differences between these two papers.

First, Mukherjee and Marjit (2004) have addressed the problem in Combs (1991) framework, whereas the present paper considers Marjit (1991) framework. In Marjit (1991), given R&D investment, each research lab is assumed to have a probability of success, ρ ($0 < \rho < 1$), independent of the R&D investment level. On the other hand, Combs (1992) considers a very specific research process. It assumes that there are n research projects, out of which only one project can yield successful outcome, and that in a single lab only one research project can be executed. Therefore, the probability of success under non-cooperative research is $\rho = \frac{1}{n}$. Since under research cooperation the firms operate two projects (chosen without replacement) simultaneously, one in each research lab, the probability of success under R&D cooperation is

[4] Some technology transfer papers directly relevant to the present work are Katz and Shapiro (1985), Marjit (1990) and Wang (1998).

therefore 2ρ. But if in Marjit (1991) framework cooperative research occurs in two labs, effectively the probability of success becomes $\rho(2-\rho)$; the reason is that under research cooperation each firm will come up with the innovation if at least one lab yields success. Thus, compared to non-cooperative R&D, the probability of success under cooperation is larger in both models when research occurs in both labs, but for completely different reasons. It may further be noted that when the firms do research in both labs under cooperation, the probability of getting success in R&D in Mukherjee and Marjit (2004) is larger than that of ours. Therefore, their results are biased in favor of cooperative R&D.

Second, and what is most important, in Mukherjee and Marjit (2004), whether the firms under cooperative research will do research in a single lab or both labs, is never a consideration. Their paper simply examines whether R&D will be cooperative or non-cooperative given that cooperative research occurs in a single lab or in both labs. In our paper the choice of optimal cooperative form is crucial to determine ultimately the choice of R&D organization. Hence, in our paper the firms first decide whether they will do cooperative research or non-cooperative research; then if it is cooperative research, they decide whether it will occur in a single lab or in both labs. Finally, as in other papers, they play Cournot game in the product market. In the analysis when we include the possibility of technology transfer, the firms under non-cooperative R&D decide, before product market competition, whether they will write a technology transfer agreement, ex post innovation. Note that under cooperative R&D, since both firms have always symmetric technologies, there is no possibility of technology transfer.

Finally, it should be noted that they have derived all results based on linear demand function. Instead, we have taken reduced form expressions of the payoffs. Hence our results are not constrained by any specific form of demand function, although we have illustrated our results for linear demand function. Since in our model the choice between cooperative and non-cooperative R&D is conditional on the choice of optimal form of cooperative research, we claim that our results are more sensible and enriched.

In the following section we present the model. Considering Marjit (1991) model as the benchmark case we see how Marjit (1991) results be affected with the inclusion of the optimal form of cooperation. In section 3 we introduce technology transfer to see the choice of R&D organization given that the R&D cooperation decides optimally whether to do research in a single lab or in both labs of the firms. Finally, section 4 summarizes the results and concludes the paper.

2. Model

We consider Marjit (1991) framework. Two firms interact at the research stage and production stage. In the first stage the firms decide whether they will do cooperative research or non-cooperative research, and if it is cooperative research, they decide the form of cooperation, that is, whether to do research in a single lab or in both labs; then they act accordingly. In the second stage they play a Cournot game subject to the outcome of the first stage. Initially the firms have symmetric technology given by a constant marginal cost of producing a homogeneous good. Now consider process innovation that reduces unit cost of production by a finite amount (say, $\varepsilon > 0$) if R&D efforts are successful. The corresponding R&D cost is $R > 0$, and the probability of success in R&D by a research lab is $\rho, 0 < \rho < 1$, independent of the R&D cost; thus, given $0 < \rho < 1$, there is uncertainty in the realization of R&D outcome.

We consider that under cooperative R&D, the firms write a contract on ex ante sharing R&D results. In Marjit (1991), under research cooperation firms do R&D in a single lab sharing both R&D costs and output. But we allow the research cooperation to decide whether the firms will do R&D in a single lab or in both labs of the firms. Hence when research occurs in both labs, the firms can share the knowledge if either of the labs is successful to innovate. This means the probability that a firm will come up with the innovation is larger compared to the case when the firms do research in a single lab. On the other hand, in case of doing R&D in a single lab, the firms share the R&D costs also. Thus there is a trade-off between the likelihood of the superior production technology and R&D costs.

We include the possibility of technology transfer under non-cooperative R&D, ex post innovation, from the low-cost firm to the high cost firm. In Marjit (1991), innovation is assumed to be `drastic' in the sense that when only one firm is successful to innovate, it emerges as a monopolist, hence under the assumption of `drastic' innovation, the possibility of technology transfer does not arise (or at least it has no special bite), assuming that the firms produce perfectly substitute goods. Hence in the present paper we assume non-drastic innovation yielding the post-innovation market structure to be always duopoly. Then under non-cooperative R&D if only one firm comes up with the low cost technology, the firm under consideration will explore the possibility of technology transfer to the high cost firm.

Irrespective of whether research is cooperative or non-cooperative, when both firms use superior technology, the second stage market operated payoff of each firm is denoted by π^{SS}, and if both use the old technology in production, their corresponding payoff will be π^{FF}. In case of asymmetric duopoly, when one firm has superior technology and the other has inferior technology, their payoffs are respectively π^{SF} and π^{FS}.[5] Clearly, under Cournot competition,

$$\pi^{SF} > \pi^{SS} > \pi^{FF} > \pi^{FS} \quad (1)$$

2.1 Benchmark Case: Marjit (1991) Model

Let us consider the Marjit (1991) model as the benchmark case with the modification that innovation is drastic, but as in Marjit (1991), consider cooperative R&D in a single lab, sharing both costs and research output, and that under non-cooperative R&D no technology transfer is allowed. Then the expected payoffs under cooperative and non-cooperative R&D are respectively given by

$$E\pi(C) = \rho\pi^{SS} + (1-\rho)\pi^{FF} - \frac{R}{2} \equiv E(C1) \quad (2)$$

and

$$E\pi(NC) = \rho^2\pi^{SS} + \rho(1-\rho)(\pi^{SF} + \pi^{FS}) + (1-\rho)^2\pi^{FF} - R \equiv E(NC1) \quad (3)$$

Then cooperative R&D is preferred to non-cooperative R&D if and only if

$$E(C1) > E(NC1) \quad \Leftrightarrow \quad \rho(1-\rho) < \frac{R}{2A} \quad (4)$$

where

$$A = [\pi^{SF} + \pi^{FS} - \pi^{SS} - \pi^{FF}]$$

and we have assumed that $A > 0$.[6]

Then Marjit (1991) results can be restated as follows.

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[5] Here the superscript S stands for `success' and $F$ for `failure'.
[6] We must have $A > 0$ for the linear demand function. To show this, define $x = f(\varepsilon)$; then for Cournot duopoly output $q(x)$, Cournot profit of a firm is $\pi(x) = [q(x)]^2$. Hence, $\pi^{SF} = \pi(2\varepsilon)$, $\pi^{SS} = \pi(\varepsilon)$, $\pi^{FF} = \pi(0)$, and $\pi^{FS} = \pi(-\varepsilon)$. Clearly, $\pi(x)$ function is strictly increasing and strictly convex, therefore, $\pi^{SF} - \pi^{SS} > \pi^{FF} - \pi^{FS}$, hence $A > 0$. Note that if innovation is drastic, then $\pi^{SF} = \pi^m$ (monopoly payoff) and $\pi^{FS} = 0$. In this case, necessarily $A > 0$.

Proposition 1 (Marjit, 1991)*:* *If R is not very large (i.e.,* $\frac{R}{2A} < \frac{1}{4}$*), then* $\exists\ \tilde{\rho}$ & $\hat{\rho}$, $0 < \tilde{\rho} < \hat{\rho} < 1$, *such that cooperative R&D is preferred to non-cooperative R&D* $\forall \rho \in (0, \tilde{\rho}) \cup (\hat{\rho}, 1)$ *; otherwise, non-cooperative R&D is preferred.*

In the next subsection we first consider the optimal form of R&D cooperation, that is, whether cooperative research will be conducted in a single lab or in both labs. Then we examine, without the possibility of technology transfer, whether R&D will be cooperative or non-cooperative.

2.2 Optimal Form of Cooperative Research vs. Non-cooperative Research

When the research cooperation decides to do research in a single lab, the firms share both R&D costs and R&D results. Hence the expected payoff of each firm under this situation is given by $E(C1)$ (see Eqn. (2)). But when the research cooperation conducts research in two labs simultaneously but allows the firms to share the knowledge of each other, this means each firm comes up with the innovation if at least one lab is successful to innovate. Hence the expected payoff of each firm under this situation is:

$$E(C2) = \rho(2-\rho)\pi^{SS} + (1-\rho)^2\pi^{FF} - R \tag{5}$$

Then the optimal form of cooperative research will be doing research in a single lab or in both labs according as:

$$E(C1) \gtreqless E(C2) \quad \Leftrightarrow \quad \frac{R}{2B} \gtreqless \rho(1-\rho) \tag{6}$$

where

$$B = [\pi^{SS} - \pi^{FF}] > 0$$

Clearly, the inequality in (6) can go in either direction (provided that R is not very large). Therefore, whether cooperative research will occur in a single lab or in both labs, depends on the value of the probability of success.

Lemma 1: *Suppose* $\frac{R}{2B} < \frac{1}{4}$. *Then* $\exists\ \underline{\rho}$ & $\overline{\rho}$, $0 < \underline{\rho} < \overline{\rho} < 1$, *such that* $\forall \rho \in (0, \underline{\rho}) \cup (\overline{\rho}, 1)$ *the firms will do cooperative research in a single lab and* $\forall \rho \in (\underline{\rho}, \overline{\rho})$ *they will do in both labs.*

Now consider the choice between cooperative and non-cooperative research, given that the research cooperation chooses the optimal form of R&D cooperation.

First note that

$$A \gtreqless B \quad \Leftrightarrow \quad \pi^{SF} + \pi^{FS} \gtreqless 2\pi^{SS} \tag{7}$$

The LHS of the inequality is the asymmetric duopoly industry profit whereas the RHS is the symmetric duopoly industry profit with both firms using superior technology. So the inequality in (7) can go in either direction depending on the size of innovation (ε). It can be shown for the linear demand function (and also with some restriction for the general demand function) that[7]

$$\exists \varepsilon^0 \mid \pi^{SF} + \pi^{FS} \gtreqless 2\pi^{SS} \iff \varepsilon \gtreqless \varepsilon^0 \tag{8}$$

We have the following two cases to consider the choice between cooperative and non-cooperative research.

Case 1: $\boldsymbol{\rho(1-\rho) > \frac{R}{2B}}$**, i.e.,** $\boldsymbol{\rho \in (\underline{\rho}, \overline{\rho})}$

Given Lemma 1, in this case if the firms do cooperative research, then research will be conducted in both research labs simultaneously. This will yield an expected payoff of a firm given by $E(C2)$ (see (5)). When this is compared with the expected payoff under non-cooperative research (i.e., $E(NC1)$), we have

$$E(C2) > E(NC1) \quad \text{iff} \quad 2\pi^{SS} > \pi^{SF} + \pi^{FS} \tag{9}$$

The above holds if and only if $\varepsilon < \varepsilon^0$ (see (8)). Hence we can write the following result.

Proposition 2: *Given* $\rho(1-\rho) > \frac{R}{2B}$*, (i.e.,* $\rho \in (\underline{\rho}, \overline{\rho})$*), cooperative R&D will occur if the size of the innovation is small (i.e.,* $\varepsilon < \varepsilon^0$*), but non-cooperative R&D will occur for large innovation (i.e.,* $\varepsilon > \varepsilon^0$*).*

This result shows that for the choice of R&D organization not only the success probability is important but also the size of the innovation is crucial to determine the form of research.[8]

Case 2: $\boldsymbol{\rho(1-\rho) < \frac{R}{2B}}$**, i.e.,** $\boldsymbol{\rho \in (0, \underline{\rho}) \cup (\overline{\rho}, 1)}$

[7] See Marjit (1990) and Wang (1998).

[8] In Kabiraj (2007), the size of the innovation determines the R&D investment under each of cooperative and non-cooperative research, hence the R&D institution.

Here under cooperative R&D, research will occur in a single lab, and this will yield an expected payoff of $E(C1)$ to each firm. We have already shown in the previous sub-section that,

$$E(C1) > E(NC1) \quad \text{iff} \quad \frac{R}{2A} > \rho(1-\rho)$$

and that the above inequality holds for all $\rho \in (0, \tilde{\rho})\cup(\hat{\rho}, 1)$ (see (4) and Proposition 1). But in the present subsection the number of research lab is a choice variable and therefore the above inequality is subject to the condition that $\rho(1-\rho) < \frac{R}{2B}$. We shall consider the following two subcases.

Subcase (i): $\varepsilon > \varepsilon^0$, i.e., the size of the innovation is large. In this case $A > B$ (see (7) and (8)), hence $\frac{R}{2A} < \frac{R}{2B}$. This means, $\tilde{\rho} < \underline{\rho}$ and $\hat{\rho} > \overline{\rho}$.

Proposition 3(a): *Suppose $\frac{R}{2B} < \frac{1}{4}$. Then cooperative R&D (with research in a single lab) is preferred to non-cooperative R&D for all $\rho \in (0, \tilde{\rho})\cup(\hat{\rho}, 1)$, and non-cooperative research for all $\rho \in (\tilde{\rho}, \underline{\rho})\cup(\overline{\rho}, \hat{\rho})$.*

Subcase (ii): $\varepsilon < \varepsilon^0$, i.e., the size of the innovation is small. In this case $A < B$, hence $\frac{R}{2A} > \frac{R}{2B}$. This means, $\tilde{\rho} > \underline{\rho}$ and $\hat{\rho} < \overline{\rho}$. Therefore, we have the following result.

Proposition 3(b): *Suppose $\frac{R}{2A} < \frac{1}{4}$. Then cooperative R&D (with research in a single lab) is preferred to non-cooperative R&D for all $\rho \in (0, \underline{\rho}) \cup (\overline{\rho}, 1)$.*

The results of this section can be summarized in the following table (Table 1).

Table 1: The choice of R&D organization (with no technology transfer)

	$\rho(1-\rho) < \frac{R}{2B}$ i.e., $\rho \in (0, \underline{\rho})\cup(\overline{\rho}, 1)$	$\rho(1-\rho) > \frac{R}{2B}$ i.e., $\rho \in (\underline{\rho}, \overline{\rho})$
$\varepsilon > \varepsilon^0$ (i.e., $A > B$)	Coop. R&D for $\rho \in (0, \tilde{\rho})\cup(\hat{\rho}, 1)$ Non-coop. R&D for $\rho \in (\tilde{\rho}, \underline{\rho})\cup(\overline{\rho}, \hat{\rho})$	Non-Coop. R&D
$\varepsilon < \varepsilon^0$ (i.e., $A < B$)	Coop. R&D for $\rho \in (0, \underline{\rho})\cup(\overline{\rho}, 1)$	Coop. R&D

We can now compare our results with those of Marjit (1991) and Mukherjee and Marjit (2004). When cooperative research is conducted in a single lab, both Marjit (1991) and Mukherjee and Marjit (2004) have shown that the interacting firms will go for cooperative R&D if and only if $\rho \epsilon (0, \widetilde{\rho})\text{U}(\hat{\rho}, 1)$ and non-cooperative R&D for $\rho \epsilon (\widetilde{\rho}, \hat{\rho})$. We have, however, allowed the research cooperation to choose the number of research lab optimally. In particular, we have shown that under cooperation research will occur in a single lab for all $\rho \epsilon (0, \underline{\rho})\text{U}(\overline{\rho}, 1)$, otherwise it will be conducted in both labs. Thus we have shown that, as in Marjit (1991) and Mukherjee and Marjit (2004), if the probability of success in R&D is either small or large, cooperative R&D is preferred to non-cooperative R&D irrespective of the size of the innovation, but in our paper the size of the innovation determines the exact interval of probability for choosing cooperative R&D. When the probability of success is in the intermediate range, contrary to Marjit (1991), non-cooperative R&D is to be preferred to cooperative R&D provided that the size of the innovation is large; otherwise cooperative R&D is to be chosen. Hence the size of the innovation is important in the choice of optimal R&D organization. In their papers cooperative R&D is chosen when the success probability is large, but in our paper, for large ρ, R&D will not occur in both labs under cooperation.

3. The Choice of R&D Organization under Technology Transfer

We have already noted that in Marjit (1991) model, innovation size is assumed to be large so that when only one firm succeeds in R&D, it emerges as a monopolist. Under this situation possibility of technology transfer will not arise. In the present paper we have assumed that innovation is non-drastic or `minor'. Then in a situation when only one firm comes up with the innovation, in the production stage the firms have asymmetric technologies. Hence there is a possibility of technology transfer from the low cost to the high cost firm, and when profitable the firms will strike a technology transfer deal. This is ex post information sharing under non-cooperative R&D. In contrary, under cooperative R&D the firms write a contract on sharing the research result whoever is successful in R&D, and this occurs irrespective of whether R&D occurs in a single lab or in both labs. Therefore, cooperative R&D implies ex ante information sharing. Clearly, under non-cooperative research when both firms fail to succeed or both are successful, the question of technology transfer will not arise.

Now it is easy to understand that if at the production stage the firms possess asymmetric technologies, there always exists a profitable royalty licensing contract where the low cost firm charges a (quantity based) royalty equal to the unit cost difference of the firms. In this case in the post-transfer situation the licensee gets the same payoff as before, but the licensor enhances its profit by means of royalty income.

In the context of the problem of the present paper, it is more interesting to study the case of fee licensing where technology is licensed against a fixed fee.[9] It is easy to show that fee licensing is profitable if and only if the post-licensing industry profit is larger than the pre-transfer industry profit, i.e., $2\pi^{SS} > \pi^{SF} + \pi^{FS}$. We have already noted that this condition will be satisfied if and only if the size of the innovation is not large, i.e., $\varepsilon < \varepsilon^0$ (see (8)). Therefore, if $\varepsilon > \varepsilon^0$, there will be no technology transfer under the fee contract, hence the analysis will degenerate to the previous section (in particular, see the analysis of Case (1) and subcase (i) of Case 2).[10]

So in this section, to see the effect of ex post knowledge sharing under non-cooperative research we restrict to fee licensing and $\varepsilon < \varepsilon^0$ (i.e., innovation size is small). Later we discuss the possible consequence if royalty licensing is also an option for the innovator.[11]

Assumption: $\varepsilon < \varepsilon^0$ i.e., innovation size is below a critical level.

Under this situation the firm which comes up with the innovation transfers its technology to the other firm and extracts, by means of fee licensing, all surplus. Therefore, the expected payoff of a firm under non-cooperative research with technology transfer is:

$$E(NC2) = \rho^2\pi^{SS} + \rho(1-\rho)(\pi^{SF} + L) + (1-\rho)\rho\,\pi^{FS} + (1-\rho)^2\pi^{FF} - R$$

where L is the license fee given by $L = \pi^{SS} - \pi^{FS}$. Hence we have

$$E(NC2) = \rho(2-\rho)\pi^{SS} + (1-\rho)^2\pi^{FF} - R \tag{10}$$

[9] In fact, there are cases where the firms cannot write a royalty contract. See Katz and Shapiro (1985) and Mukherjee (2001).

[10] To recall the results, when $\varepsilon > \varepsilon^0$, cooperative R&D will be chosen for all $\rho \in (0, \tilde{\rho}) \cup (\hat{\rho}, 1)$ and non-cooperative R&D for all $\rho \in (\tilde{\rho}, \hat{\rho})$ (see Table 1).

[11] In fact, when both fee and royalty licensing are available to the patent holder, royalty licensing will strictly dominate fee licensing from the perspective of the patentee (see Wang (1998)).

Now, first consider the situation when cooperative research occurs in a single lab. This happens if $\rho(1-\rho) < \frac{R}{2B}$ (i.e., $\rho \in (0, \underline{\rho}) \cup (\overline{\rho}, 1)$). Then comparing $E(NC2)$ and $E(C1)$,

$$E(C1) > E(NC2) \quad \text{iff} \quad \frac{R}{2B} > \rho(1-\rho) \tag{11}$$

Proposition 4(a): *Given the possibility of ex post information sharing under non-cooperative R&D, cooperative research (with research taking place in a single lab) is optimal* $\forall\, \rho \in (0, \underline{\rho}) \cup (\overline{\rho}, 1)$.

Thus in this case the qualitative result of Marjit (1991) remains unaffected even with introduction of ex post information sharing.

Now assume that cooperative research occurs in both labs. This will be the scenario when $\rho(1-\rho) > \frac{R}{2B}$ (i.e., $\rho \in (\underline{\rho}, \overline{\rho})$). Then if we compare $E(NC2)$ and $E(C2)$, we have $E(C2) = E(NC2)$. This means in this case the firms are indifferent between non-cooperative R&D with licensing and cooperative R&D with R&D taking place in both labs.

Proposition 4(b): *Given the possibility of technology licensing under non-cooperative R&D, if* $\rho(1-\rho) > \frac{R}{2B}$ *i.e.,* $\rho \in (\underline{\rho}, \overline{\rho})$, *the firms are indifferent between the two R&D organization, viz., cooperative R&D (with R&D in both labs) and non-cooperative R&D (with technology transfer).*

We are now in a position to compare our results with those of Marjit (1991) and Mukherjee and Marjit (2004).

To see the impact of introducing technology licensing in Marjit (1991) model, first we must restrict to the assumption that the size of the innovation is below a critical level (i.e., $\varepsilon < \varepsilon^0$). Then we find that when the probability of success in R&D is either high or low, we have similar to Marjit (1991) result, that is, cooperative research is preferred to non-cooperative R&D (even with the possibility of technology transfer under non-cooperative research), and under this situation cooperative research will occur in a single lab. But if the success probability is in the intermediate range, non-cooperative R&D is the chosen form of R&D organization in Marjit (1991), but in our paper firms are indifferent between cooperative and non-cooperative R&D. This is completely different result compared to the literature. If it is cooperative R&D, research will occur in both labs, and if it is non-cooperative R&D, technology transfer will occur before the firms are engaged in product market competition. In Mukherjee and Marjit (2004), however, when cooperative research occurs in both labs, it dominates non-cooperative research. It may further be noted that Mukherjee and Marjit (2004) have introduced technology transfer in Combs (1992) structure and they have shown that the possibility of technology transfer increases the incentive for non-cooperative R&D compared to RJV. In contrast, in our paper with the possibility of technology transfer, cooperative research weekly dominates non-cooperative research for all probabilities of success.

The above analysis is based on the assumption that under technology licensing the firms can write only the fee licensing contract. When both fee and royalty licensing contracts are available,[12] following Wang (1998), in a homogeneous good duopoly royalty licensing strictly dominates fee licensing from the perspective of the innovator, and this is independent of the size of the innovation. Therefore, under non-cooperative R&D when firms come up with asymmetric technologies, they will write a royalty contract which will generate a larger profit to the innovator compared to fee licensing, that is, $E(NCR) > E(NC2)$, where $E(NCR)$ is the expected profit of a firm under royalty licensing contract. Therefore, once we include the possibility of royalty licensing, we have following changes of the previous results.

First, when $\rho \in (\underline{\rho}, \overline{\rho})$, we have now $E(NCR) > E(NC2) = E(C2)$. This means under this scenario, firms will certainly go for non-cooperative research.

Second, when $\rho \in (0, \underline{\rho}) \cup (\overline{\rho}, 1)$, we have $E(C1) > E(NC2)$ (see (12)), but $E(NCR) > E(NC2)$. Hence there can be situations when $E(NCR) > E(C1) > E(CN2)$ implying that non-cooperative R&D can be preferred to cooperative R&D when royalty licensing is available. Thus when both fee and royalty licensing contracts are available, it is more likely that the firms will choose non-cooperative R&D as the optimal R&D organization.

4. Conclusion

This paper extends the Marjit (1991) model and discusses the choice between cooperative and non-cooperative R&D in the situation when the interacting firms choose optimally the number of research lab under R&D cooperation. The paper also considers the possibility of technology transfer ex post innovation under non-cooperative R&D. In Marjit (1991) cooperative R&D occurs in a single lab hence the firms share both research costs and output. On the other hand,

[12] Note that in a homogeneous good duopoly two-part tariff licensing contracts will degenerate to royalty contract only, because the optimal fee under two-part tariff licensing contracts will be zero.

Mukherjee and Marjit (2004) consider Combs (1992) structure to study the effect of technology transfer on the choice of R&D organization assuming that cooperative R&D occurs either in a single lab (hence RJV) or in both labs of the firms to prevent the duplication of R&D process. In our paper we have derived substantially different results compared to those in the literature. We find that the choice of R&D organization not only depends on the size of investment and probability of success in R&D, but also it depends on the size of the innovation. Whether research under cooperation will occur in a single lab or in both labs, that depends on success probability. Cooperative R&D will occur in a single lab for both low and high probability of success, and it will be in both labs if the probability of success belongs to an intermediate interval. The possibility of technology transfer arises only when the size of the innovation is below a critical level. We have shown that given the possibility of technology transfer under non-cooperative R&D and the optimal choice of the form of R&D cooperation, if the probability of success is of the intermediate level, the firms are indifferent between these two forms of R&D organization, however under cooperation research will occur in both labs; otherwise cooperative R&D will dominate, with research in a single lab. In the absence of the possibility of technology transfer cooperative R&D will again dominate provided that the size of the innovation is below the critical level. When the size of the innovation is above that critical level, cooperative R&D will occur only for low and high success probabilities, and for the intermediate values of the success probability non-cooperative R&D will occur. While in our analysis we have considered fee licensing under technology transfer, we have derived implications of the availability of royalty licensing in this context. We have noted, in particular, that royalty licensing will tilt the choice towards non-cooperative R&D.

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