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Uncertain R&D Outcomes and Cooperation in R&D*

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Abstract: *The present paper provides a brief survey of some of the papers dealing with R&D uncertainty. This helps us identify which factors are more favourable for cooperative R&D and which factors are not. The paper provides the analysis under a unified framework. We take the classic paper by Marjit (1991) as the benchmark case, and then proceeds to examine whether, or to what extent, Marjit result will undergo a change with respect to different assumptions related to R&D investment.*

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1. Introduction

Economic growth and development of a country depends, to a large extent, on the country's capability of doing research and development (R&D) successfully. But R&D activity involves a huge expenditure in setting a research lab, installing scientific instruments and recruiting scientific personnel. It requires well-directed and well-coordinated efforts. Even after such investment, an R&D firm does not know *a priori* whether it will come out with a successful innovation. This means, R&D outcome is uncertain. Often a success comes only after many failures. There is also uncertainty in commercializing and marketing the innovation. Even when success occurs, the innovator does not know whether it will be able to appropriate the required amount of profits before the innovation becomes obsolete. This is because of the problem of spillovers, free riding and imitation of the R&D outcome by the rivals who become competitive at the market place. All these problems lead to under-investment in R&D.[1] So it is an important concern of the policy makers about how to provide sufficient incentives to the private firms for doing R&D.

Given the concern for under-investment in R&D, most of the governments extend fiscal support to the investors in the form of R&D subsidy, cheap credit facility and tax concessions. To the problem of imitation and leaking out of knowledge, the government of a country provides patent protection to the new innovations so that the imitators cannot use or copy the innovation. However, it all depends on the effectiveness and enforcement of patent laws. Weak patent protection can hardly protect innovations from copying. Patent protection cannot fully protect the innovation, it raises the cost of imitation.[2]

Under these circumstances, cooperative R&D is suggested to be the way-out of the problem of high R&D cost, uncertainty and spillovers of knowledge. By cooperating the firms can avoid duplicating scarce resources, and share research cost and output as well as uncertainty (Katz, 1986). Cooperative R&D is an *ex ante* agreement among the member firms on sharing R&D expenses and results. Most of the countries now-a-days promote cooperative research.[3] Most popular form of cooperative research is research joint venture or RJV. Under RJV, the firms

[1] There are theoretical and empirical literature showing under-investment in R&D due to spillovers of knowledge. See, for instance, Spence (1984), Jaffe (1986), Ornaghi (2006), and Bakhtiari and Breunig (2018).
[2] Griliches (1990) found to have inverse relation between the degree of patent protection and the level of spillovers.
[3] In USA, the National Cooperative Research Act 1984 was passed, and following this a large number of cooperative ventures had been registered (Vonortas, 1997).

conduct research in a single lab and share R&D cost and output. The firms can also write a contract to do R&D independently in their own labs, but share the R&D outcome of any lab.

This has led to the question of whether R&D will be cooperative or non-cooperative. This is the problem of the choice of R&D institution or organization. A substantial literature has emerged discussing this question. The pioneering work in this field is d'Aspremont and Jacquemin (1988). The paper focuses on R&D spillovers and studies whether R&D investment will be cooperative or non-cooperative. When spillovers are high, firms generally go for cooperative research. The work has been extended by Kamien et al. (1992) to the case of differentiated duopoly, and by Suzumura (1992) to the case of oligopoly. Mota (1992) discussed the choice under vertical product differentiation. Amir et al. (2003) studies the problem when spillovers are endogenous.

These works, however, do not consider uncertainty in R&D outcome. Marjit (1991) was pioneer to show that uncertainty alone can result in cooperative research. It was shown that if probability of success in R&D is either high or low, cooperative research should occur, otherwise non-cooperative R&D would be preferred. Then following Marjit (1991) a number of papers have been contributed to the literature examining the choice problem (see, for instance, Combs (1992); Choi (1992, 1993), Kabiraj (2006, 2007), Mukherjee and Marjit (2004), Kabiraj and Chattopadhyay (2015), and Kabiraj and Kabiraj (2019)).[4] All these papers have assumed that the product market is non-cooperative. However, cooperation in production may give additional incentive to R&D (d'Aspremont and Jacquimin (1988) and Kamient et al. (1992)). In a three-firm framework, Kabiraj and Mukherjee (2000) have studied whether cooperation in production will induce the firms to cooperate in R&D, and vice versa. Silipo and Weiss (2005) have studied the choice between cooperative and non-cooperative R&D in the presence of both spillovers and uncertainty.

The purpose of the present paper is to provide a brief survey of some of those works dealing with R&D uncertainty. This will help us identify which factors are more favorable for cooperative R&D and which factors are not. We provide the analysis in the same frame. We consider Marjit (1991) as the benchmark case, and then examine whether, or to what extent, Marjit result will undergo a change with respect to different assumptions related to R&D

[4] Mukherjee and Ray (2009) discussed the problem when there is uncertainty in patent approval, but the R&D outcome is certain. Kabiraj (2018) studied the problem in a three-firm framework when cooperative research takes the form of RJV or knowledge sharing.

investment. In this sense, the present paper is a review of Marjit (1991). In the context of Marjit (1991) model we consider various scenarios like: product or process innovation; drastic or non-drastic innovation; patent protection may or may not be available; imitation may or may not be possible; technology transfer may or may not be allowed; cooperative R&D be conducted in a single or more than one lab; possibility of more than one innovation; and incomplete information. We show that patent protection and technology transfer will increase incentives for non-cooperative research whereas imitation and incomplete information will tilt the choice towards cooperative R&D. However, the qualitative result of Marjit in these cases will remain unaltered. On the other hand, duplicating research under cooperation will substantially change the Marjit result. We also see how the size of the innovation, whether small or large, may affect the choice of R&D organization. Readers, perhaps, will understand how tinkering one or the other assumption might generate a different result.

The plan of the paper is the following. In section 2, we first provide Marjit (1991) model as the benchmark case, and then in a number of subsections we study the effect of the change of one or the other assumption underlying the model and examine to what extent Marjit (1991) results are robust. In section 3, we suggest some possible extensions for future research. Finally, section 4 concludes the paper.

2. Framework of Analysis

Consider, initially, a symmetric duopoly market for a homogeneous product. Two firms, firm 1 and firm 2, simultaneously interact in R&D and production. They play a two-stage game. Assuming that non-cooperative research is always profitable, the firms in the first stage decide whether to conduct R&D cooperatively or non-cooperatively. Then in the second stage, subject to the realization of the R&D outcome, they play a la Cournot and compete non-cooperatively in the product market.

Each research lab requires an investment $R > 0$ targeting a specified (product or process) innovation, but the research outcome is uncertain, that is, research may lead to a success or failure. When R is invested, the probability of success of a research lab is $\rho, 0 < \rho < 1$. If both firms come up with the innovation, the market will be symmetric duopoly, but if only one firm comes up with the innovation, the market will be either monopoly or asymmetric duopoly depending on the size and nature of innovation. Below we first provide briefly the Marjit (1991) model as the benchmark case and identify some assumptions underlying the model stated implicitly or explicitly. Then relaxing one or the other assumption we examine to what extent Marjit (1991) results are sensitive to a particular assumption.

2.0 Benchmark Case: Marjit (1991) Model

Marjit (1991) assumes process innovation that reduces the unit cost of production. Further, it is assumed that the innovation is `drastic' (or major) in the sense that the firm which alone adopts the innovation emerges as a monopolist in the product market and the other firm ceases to operate. Finally, it is assumed that under cooperative R&D firms conduct research in a single lab, sharing both R&D cost and R&D result, hence they form an RJV. Denoting the pre- and post-R&D symmetric duopoly profits of a firm by π and π^d respectively and monopoly profit by π^m,[5] the expected payoffs of a firm under cooperative (C) and non-cooperative (NC) R&D will be given by,

$$E(C0) = \rho\pi^d + (1-\rho)\pi - \frac{R}{2} \tag{1}$$

$$E(NC0) = \rho^2\pi^d + \rho(1-\rho)\pi^m + (1-\rho)^2\pi - R \tag{2}$$

Therefore, cooperative R&D is to be preferred to non-cooperative R&D if and only if

$$E(C0) > E(NC0) \quad \Leftrightarrow \quad \rho(1-\rho) < \frac{R}{2[\pi^m - (\pi^d + \pi)]} \tag{3}$$

Clearly, the RHS of (3) is positive and constant, and the LHS, $\rho(1-\rho)$, is strictly inverted U-shaped with a unique maximum at $\rho = \left(\frac{1}{2}\right)$ and the value of the function is 0 both at $\rho = 0$ and $\rho = 1$. Then Marjit (1991) result can be stated in the following proposition.

Proposition 1 [Marjit (1991) Result]*: If R is not very large,* $\exists\ \underline{\rho}\ \&\ \overline{\rho}$, $0 < \underline{\rho} < \overline{\rho} < 1$, *such that cooperative R&D is preferred to non-cooperative R&D* $\forall \rho \in (0, \underline{\rho}) \cup (\overline{\rho}, 1)$ *; otherwise, non-cooperative R&D is preferred.*

[5] In the paper, as we can see, no result will change if $\pi \geq 0$.

Thus Marjit (1991) result states that cooperative R&D will occur if the probability of success is either small or large. When the probability of success is in an intermediate range, non-cooperative R&D will occur.

It can be noted that although Marjit (1991) assumed (drastic) process innovation, it can easily be interpreted as product innovation We may assume that initially production is not viable because each firm's marginal cost of production is sufficiently high (so $\pi = 0$). But the process innovation reduces costs and makes the production viable; hence this is equivalent to product innovation.

In general, irrespective of whether process innovation is drastic or non-drastic, let π^{SS} denote the payoff of a firm when both the firms adopt the successful innovation, and π^{FF} denote the payoff when none has successful innovation. Similarly, when only one firm has the successful innovation, its payoff is π^{SF} and the other firm's payoff is π^{FS}. Then under Cournot competition we must have:

$$\pi^{SF} > \pi^{SS} > \pi^{FF} > \pi^{FS}$$

Clearly, when innovation is drastic, we have: $\pi^{SF} = \pi^{m}$, $\pi^{SS} = \pi^{d}$, $\pi^{FS} = 0$ and $\pi^{FF} = \pi$, and if the innovation is non-drastic, then $\pi^{SF} < \pi^{m}$ and $\pi^{FS} > 0$. So under process innovation, (1) (2) and (3) can be rewritten, more generally as:

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

$$E(NC*) = \rho^2\pi^{SS} + \rho(1-\rho)(\pi^{SF} + \pi^{FS}) + (1-\rho)^2\pi^{FF} - R \qquad (2^*)$$

$$E(C*) > E(NC*) \quad \Leftrightarrow \quad \rho(1-\rho) < \frac{R}{2[\pi^{SF}+\pi^{FS}-\pi^{SS}-\pi^{FF}]} \qquad (3^*)$$

Here we assume that $[\pi^{SF} + \pi^{FS} - \pi^{SS} - \pi^{FF}] > 0$.[6] So Marjit result, as stated in Proposition 1, holds for non-drastic innovation.

In the following analysis we focus on the following assumptions stated explicitly or implicitly in Marjit (1991) model.

(A1) Single process innovation;

[6] For the linear demand function, we have necessarily $[\pi^{SF} + \pi^{FS} - \pi^{SS} - \pi^{FF}] > 0$.

(A2) Cooperative R&D occurring in a single lab;

(A3) Neither patent protection available, nor imitation of technology possible;

(A4) Technology transfer under non-cooperative R&D not allowed;

(A5) There is no asymmetry of information.

We shall relax one or the other assumption stated above and examine whether, or to what extent, Marjit (1991) results will undergo a change. In particular, we show that the qualitative result of Marjit (1991) will remain unchanged even if we introduce patent protection, imitation, technology transfer or incomplete information in the analysis although incentives for cooperative or non-cooperative research will be affected.[7] On the other hand, if we consider cooperative research in two labs (hence duplicating research), the result of Marjit (1991) will substantially change. We shall also compare Marjit (1991) result with the case when there are more than one conceivable innovation.

2.1 Patent Protection and Imitation

First consider that patent protection for a new innovation is available, hence it prevents imitation. Further note that patent protection cannot affect the expected cooperative payoff because both firms have always the same access to information -- patent is granted to the R&D cooperation.[8] Under non-cooperative R&D if only one firm is successful to innovate, it gets patent protection. But when both the firms are successful, we assume that each firm will get patent protection with probability ½. This partly takes care of the fact that getting a patent protection may sometimes be uncertain (Mukherjee and Ray, 2009). Assuming drastic innovation along with patent protection, the expected payoff under cooperative R&D will be as usual given by (1), but the expression of the expected payoff under non-cooperative R&D will be accordingly modified to get:

$$E(NC1(a)) = [\frac{\rho^2}{2} + \rho(1-\rho)]\pi^m + (1-\rho)^2\pi - R \quad (4)$$

[7] In an interesting paper Bandyopadhyay and Mukherjee (2014) have shown that the possibility of entry by a non-innovating firm may also affect the incentive for cooperative R&D depending on the extent of spillover of knowledge.

[8] Given the possibility of infringement of patents, Marjit et al. (2001) have shown that the patent infringement agreements between the innovating firms may act as cooperation in R&D.

Then comparing (1) and (4), cooperative R&D is to be preferred to non-cooperative R&D if and only if $E(C0) > E(NC1(a))$, that is, if and only if

$$\rho(1-\rho) < \frac{R}{2[\pi^m-(\pi^d+\pi)]} - \frac{[\pi^m-2\pi^d]}{2[\pi^m-(\pi^d+\pi)]}\rho^2 \quad (5)$$

Since the RHS of (5) is a falling (and concave) function of ρ, comparing Marjit (1991) (hence (3)), one can easily see that the probability interval for non-cooperative R&D goes up, therefore, patent protection gives a larger incentive for non-cooperative R&D. Note that

$$RHS(\rho = 1) < 0 \quad \text{for} \quad R < \pi^m - 2\pi^d$$

Therefore, when $R < \pi^m - 2\pi^d$, $\exists\tilde{\rho}$ such that non-cooperative R&D is preferred $\forall\rho \in (\tilde{\rho}, 1)$.[9]

Now consider that patent protection is not available and each firm is capable to imitate the other's innovation perfectly. Hence in this case under non-cooperative R&D, the market will always be duopoly. Then, the expected payoff of a firm under non-cooperative R&D will be:

$$E(NC1(b)) = [\rho^2 + 2\rho(1-\rho)]\pi^d + (1-\rho)^2\pi - R \quad (6)$$

Hence,

$$E(C0) > E(NC(1(b)) \quad \Leftrightarrow \quad \rho(1-\rho) < \frac{R}{2(\pi^d-\pi)} \quad (7)$$

Thus even when imitation is possible, the basic qualitative result of Marjit (1991) remains unaltered. But comparing the RHS of (3) and (7), we see that $\frac{R}{2(\pi^d-\pi)} > \frac{R}{2[\pi^m-(\pi^d+\pi)]}$, this means the relevant probability interval for cooperative R&D goes up, hence imitation increases incentives for cooperative research.

So we can write the following proposition.

Proposition 2: *Patent protection in Marjit (1991) model enhances R&D incentives for non-cooperative R&D whereas imitation does reduce it.*

2.2 Technology Transfer under Non-cooperative R&D

The possibility of technology transfer under non-cooperative R&D arises when only one firm comes up with a non-drastic process innovation successfully[10] and the innovator shares its knowledge with the other firm against some payment. Further, assume that there is neither

[9] We show later that in Combs (1992) non-cooperative R&D is preferred to cooperative only for small values of the probability of success.

[10] Mukherjee and Marjit (2004) have introduced technology transfer in Combs (1992) framework and Kabiraj and Kabiraj (2019) in Marjit (1991) framework. The latter paper studies the choice of R&D organization when the form of R&D cooperation is also endogenously determined.

patent protection nor imitation of the innovation. We consider fee licensing, that is, licensing of the superior technology under a fixed fee contract. The licensing contract takes place only on *ex post* innovation when it is profitable.

Following Marjit (1990) and others, fee licensing in a duopoly is profitable if and only if the post licensing industry profit is larger than the pre-licensing industry profit,[11] that is,

$$2\pi^{SS} > \pi^{SF} + \pi^{FS}$$

For the linear demand function and also for the general demand function (but with some restriction), the condition will hold if and only if $\varepsilon < \varepsilon^0$, that is, the size of the innovation is below a critical level. In the remaining analysis we continue to assume that

$$\pi^{SF} + \pi^{FS} \gtrless 2\pi^{SS} \iff \varepsilon \gtrless \varepsilon^0$$

Therefore, given that the size of the innovation is small, the expected payoff of a firm under non-cooperative R&D (with technology transfer) is:

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

where F is the license fee given by $F = \pi^{SS} - \pi^{FS}$. Hence,

$$E(NC2) = \rho(2-\rho)\pi^{SS} + (1-\rho)^2\pi^{FF} - R \qquad (8)$$

Since we have considered non-drastic process innovation, the expected payoff under cooperative R&D will be given by the expression of $E(C*)$ in (1*)

Therefore, given that technology transfer is profitable (i.e., $\varepsilon < \varepsilon^0$), cooperative R&D will occur if and only if,

$$E(C*) > E(NC2) \iff \rho(1-\rho) < \frac{R}{2(\pi^{SS} - \pi^{FF})} \qquad (9)$$

This means, the qualitative result of Marjit (1991) remains unchanged even if we allow the possibility of technology transfer. Comparing the RHS of (3*) and (9), we see that

$$\frac{R}{2[\pi^{SF} + \pi^{FS} - \pi^{SS} - \pi^{FF}]} > \frac{R}{2(\pi^{SS} - \pi^{FF})}, \text{ since } \varepsilon < \varepsilon^0$$

This means, the probability interval of cooperative research falls under technology transfer, hence technology transfer increases incentives for non-cooperative research.[12]

Proposition 3: *Possibility of technology transfer increases the incentive for non-cooperative R&D.*

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[11] If, in this structure, we include the possibility of a royalty contract, then royalty contract will strictly dominate fee contract, and royalty contract is always profitable (see Wang, 1998).

[12] See also Mukherjee (2005) for similar result.

2.3 Cooperative Research in Two Labs

Marjit (1991) assumed that cooperative research occurs in one lab. By this the firms can save their R&D costs. In Combs (1992), cooperative R&D occurs in each of their labs. Doing research in two labs implies duplicating the research effort. There is no R&D cost saving. Yet in the context of Marjit (1991) model it can be shown that doing cooperative research in two labs independently and sharing the results of R&D can sometimes be a better option.[13] Under cooperative agreement if at least one firm is successful, both the firms will have access to the innovation. This occurs with probability $\rho(2-\rho) > \rho$.

Assuming drastic innovation, the expected payoffs of each firm under cooperative R&D will be:

$$E(C3) = \rho(2-\rho)\pi^d + (1-\rho)^2\pi - R \qquad (10)$$

The expected payoff under non-cooperative R&D is given by $E(NC0)$ in (2).

We can check that in this case

$$E(NC0) > E(C3)\ \forall\rho \qquad (11)$$

because $\pi^m > 2\pi^d$ for homogeneous good. Thus if cooperative research is to conduct in two labs, then cooperative research will never occur. Although under cooperative research success occurs with a higher probability, but this gain is not sufficient to compensate the loss due to having no cost saving under cooperative R&D. Therefore duplicating research with drastic innovation does not yield any incentive for cooperative research vis-à-vis non-cooperative research.[14]

Proposition 4: *When cooperative research is to occur in two labs, non-cooperative R&D will strictly dominate cooperative R&D.*

It will be interesting in this context to compare the results with the case of Combs (1992) type research. Combs (1992) assumed to have multiple research projects (say, $m \geq 2$) out of which only one project is successful. Hence under non-cooperative R&D, the probability of success is $\rho = (1/m)$. Under cooperative research the R&D cooperation will select two projects, one for each lab; hence the probability of success under cooperative research is $2\rho = (2/m)$.

At this moment without restricting to drastic or non-drastic innovation, the expected payoff of a firm under cooperative R&D will be:

[13] This can be the case when the probability of success lies in an intermediate interval. See Kabiraj and Kabiraj (2019).

[14] Note that `drastic' innovation means innovation size is sufficiently large and we get the result that non-cooperative research strictly dominates cooperative research. If, instead of drastic innovation we consider non-drastic innovation, then cooperative research will be the choice if and only if the size of the innovation is sufficiently small.

$$E(C3a) = 2\rho\pi^{SS} + (1-2\rho)\pi^{FF} - R \qquad (12)$$

But the expected payoff under non-cooperative R&D will be given by $E(NC*)$ in (2*)

Therefore,

$$E(C3a) > E(NC*) \quad \Leftrightarrow \quad \rho > \frac{\pi^{SF}+\pi^{FS}-2\pi^{SS}}{\pi^{SF}+\pi^{FS}-(\pi^{SS}+\pi^{FF})} \equiv \rho^0 < 1 \qquad (13)$$

Combs (1992) assumed product innovation (or drastic process innovation), i.e., $\pi^{SF} = \pi^m$ and $\pi^{FS} = 0$. Further, in Combs (1992), $\pi^{FF} = 0$, (although it is not required for the result). Then (13) is reduced to the following Combs (1992) condition:

$$\rho > \frac{\pi^m - 2\pi^d}{\pi^m - \pi^d} \equiv \rho^c\ ; \quad 0 < \rho^c < 1 \qquad (14)$$

This gives that cooperative R&D occurs when the probability of success is above a critical level, i.e., $\rho \in (\rho^c, 1]$. In contrary, in the context of Marjit (1991) with cooperative research in two labs, cooperative R&D never occurs (see (11)).

Now consider non-drastic innovation, hence consider (13). We have already taken that $\pi^{SF} + \pi^{FS} \gtreqless 2\pi^{SS}$ according as $\varepsilon \gtreqless \varepsilon^0$. Therefore if $\varepsilon > \varepsilon^0$ (including the case of drastic innovation), (13) yields $0 < \rho^0 < 1$ and we shall get back Combs (1992) result. On the other hand, if we assume $\varepsilon \leq \varepsilon^0$, we will have $\rho^0 \leq 0$. In this case cooperative R&D is always preferred to non-cooperative R&D irrespective of the size of ρ. The size of the innovation determines the critical value of ρ.

2.4 R&D under Incomplete Information

In Marjit (1991) there is no asymmetry of information. So we can think asymmetric information about the success and failure of R&D. Under cooperative R&D this will not matter because the firms do research jointly. But under non-cooperative R&D, assume that the firms have asymmetric information, that is, whether or not a firm is successful to innovate is private information. However, the rival has a prior belief about the outcome. Details of the model can be found in Kabiraj and Chatterjee (2015). It is shown that incomplete information about the R&D outcome reduces the expected payoff of a firm under non-cooperative R&D, therefore, compared to complete information, incomplete information increases incentives for cooperative research. However, the qualitative result of Marjit (1991) goes through.[15]

[15] Chattopadhyay and Kabiraj (2015) have shown that under incomplete information about the size of the innovation, the qualitative result of Marjit (1991) will hold irrespective of whether it is quantity or price competition in the product market.

2.5 Conceivable Two Innovations

In this subsection we consider conceivable two products (say X and Y) which could be innovated by the firms. To simplify the algebra, assume that products are independent and market demands for the products are identical.

As before, Innovation of each such good involves an investment $R > 0$, and innovation is uncertain. Further, one firm cannot take more than one research project at a time. We continue to assume no patent protection and no imitation,[16] as in Marjit (1991). While the probability of success of one research lab is ρ, but a firm chooses X or Y with probability ½.

Then expected payoff under non-cooperative R&D will be given by,

$$E(NC5) = (\tfrac{1}{2})\,\rho\pi^m + (\tfrac{1}{2})[\rho^2\pi^d + \rho(1-\rho)\pi^m] - R \qquad (15)$$

Now consider cooperative R&D. If it occurs in a single lab, the firms can choose any product. then the expected payoff of a firm under cooperative R&D will be

$$E(C5(i)) = \rho\pi^d - \frac{R}{2}.$$

Then

$$E(C5(i)) > E(NC5) \text{ if and only if } \frac{R}{2(\pi^m - \pi^d)} > \rho - (\rho^2/2).$$

One can check that the RHS is an increasing function of ρ, hence cooperative R&D is to be preferred if and only if the probability of success is small, otherwise non-cooperative R&D is preferred. This is reverse of Combs (1992) result.

On the other hand, if cooperative research occurs in two labs, they can take the same research project in both labs or different research projects in different labs. The corresponding expected payoffs of a firm will be respectively,

$$E(C5(ii)) = [\rho^2 + 2\rho(1-\rho)]\pi^d - R = \rho(2-\rho)]\pi^d - R$$

$$E(C5(iii)) = [2\rho^2 + 2\rho(1-\rho)]\pi^d - R = 2\rho\pi^d - R$$

[16] For the case of patent protection or imitation and for further details see Kabiraj (2006).

Since we have $\mathrm{E}(C5(iii)) > E(C5(ii))$, the research cooperation will take different research projects in different labs. Then cooperative R&D will be preferred to non-cooperative R&D if and only if

$$E(C5(iii)) > E(NC5) \iff \rho > \rho^* \equiv \frac{2[\pi^m - 2\pi^d]}{\pi^m - \pi^d} \tag{16}$$

Now,

$$\rho^* < 1 \quad \text{iff} \quad \pi^m < 3\pi^d \tag{17}$$

Therefore, if $\pi^m < 3\pi^d$, cooperative R&D will dominate non-cooperative R&D for all $\rho \in (\rho^*, 1]$. This is similar to Combs (1992) result. On the contrary, if $\pi^m \geq 3\pi^d$, (so that $\rho^* \geq 1$), non-cooperative R&D will dominate cooperative R&D.

3. Possible Extensions

In our brief survey on the choice of R&D institution or organization, we have restricted to Marjit (1991) framework and discussed whether, or to what extent, Marjit Result will undergo a change with respect to different assumptions related to R&D investment. However, there are some issues which are important but not yet fully explored in the literature. The future researchers and scholars may find it interesting to explore these issues further.

We have shown that the size of the innovation is an important determinant of the choice between cooperative and non-cooperative research. The present work assumes that the level of R&D investment, and hence the size of the innovation, is exogenous. In our context, therefore, one may endogenously determine the size of the innovation and then examine the choice of R&D organization in the presence of uncertainty in R&D. It might also be interesting to study the implication of the R&D cost having its variable component.

In our analysis, R&D success is uncertain, but the probability of success is assumed constant and exogenously fixed. However, probability of success, to a large extent, depends on the R&D organization itself and on the level of R&D investment. This means, probability of success in cooperative R&D might not only differ from that in the non-cooperative R&D, but, more importantly, it can be endogenously determined. To the extent there is coordination problem under cooperative research, the same level of R&D investment will lead to different probabilities of success under cooperative and non-cooperative R&D. This consideration will perhaps provide a new dimension and further insight into the choice between cooperative and non-cooperative R&D.

4. Conclusion

The present paper has reviewed the choice between cooperative and non-cooperative R&D under various scenarios when R&D success is uncertain. In particular, we have studied the effect of the change of one or the other assumption underlying Marjit (1991) model. Generally low probability of success or large uncertainty induces the choice in favor of cooperative research. Similarly, imitation possibility and incomplete information about the size of the innovation tilts the choice towards cooperative R&D. On the other hand, availability of patent protection, or the compulsion of doing research in multiple labs will reduce the incentive for cooperative research.

We have also suggested some possible extensions of the present work. Research in this direction is likely to give a further insight into the problem of R&D and the choice of R&D organization.

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