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Cooperative vs. Non-Cooperative R&D Incentives under Incomplete Information

Abstract

This paper studies incentives for cooperative research vis-à-vis non-cooperative research in an incomplete information framework. We show that with quantity competition under asymmetric information, the expected payoff from non-cooperative research goes down compared to the case of symmetric information; hence RJV incentives of the firms are larger under asymmetric information. In either case, however, the larger is the size of the cost-reducing innovation the lower is the incentive for cooperative research. Finally in our model, incomplete information does not affect the consumers' welfare, but the firms become worse off.

Key words: Cooperative R&D, non-cooperative R&D, RJV, incomplete information, consumers' welfare.

JEL Classification Index: D43, L13, O31.

1. Introduction

Technological progress and economic development go hand in hand. However, technological progress requires well-directed and well-coordinated R&D efforts and it involves huge investment and uncertainty in achieving success. Even when the R&D succeeds, there is no guarantee that the innovators will be able to recover the costs of R&D investment and efforts because of the possibility of imitation, spillovers and leaking out of knowledge. So providing a required amount of R&D incentives to the private investors is an important policy concern. To prevent or reduce the threat of imitation and leaking out of knowledge, a strong and enforceable patent protection may be called for – after all, patent protection makes imitation costly. As a way out of the problem of high R&D cost and uncertainty, policy makers encourage cooperative research, or in particular, research joint venture (RJV) in which the private investors share the R&D cost as well as the research outcome.[1] Free riding problem is then also reduced.

There is already an extensive literature on the choice of R&D organization. This literature discusses, in particular, the choice between cooperative and non-cooperative R&D. For instance, Marjit (1991) introduces uncertainty in R&D outcome. d'Aspremont and Jacquemin (1988) and Suzumura (1992) discuss the choice under spillovers. Motta (1992) discusses the choice when products are vertically differentiated. Choi (1992, 1993) studies cooperative R&D with moral hazard. Combs (1992) extends the model to the case when R&D cooperation means coordinating multiple research projects. Kabiraj and Mukherjee (2000) discuss the choice between cooperative and independent research in a three-firm framework. Mukherjee and Marjit (2004) introduce technology transfer with the choice of R&D organization. Silipo and Weiss (2005) consider the problem with both spillovers and uncertainty.[2] Kabiraj (2006) studies the effect of imitation and patent protection in the context of innovations of two products and Kabiraj (2007) introduces synergy in R&D cooperation. On the other hand, Mukherjee and Ray (2009) consider the

[1] Following the National Cooperative Research Act 1984 a large number of cooperative ventures have been registered in the US. For instance, see Vonortas (1997) and DeCourcy (2005).
[2] Also see Silipo (2008) for different forms of research cooperation and the related issues.

problem when the R&D outcome is certain but there is uncertainty in patent approvals. Such an uncertainty, it is shown, may induce the firms to do cooperative research.

Surprisingly, no work so far has studied the effect of incomplete information in the choice between cooperative and non-cooperative R&D. Once we incorporate asymmetric information into the problem, the important questions that one may raise are the following: What is the incentive for non-cooperative R&D under incomplete information? Does it go up or down compared to the case of complete information? Does this alter the choice of R&D organization? How does this comparison depend on the size of the innovation and probability of success? What could be the possible welfare effect of incomplete information for the consumers and producers? And so on.

Hence the purpose of the present paper is to extend the analysis of Marjit (1991) to the case of asymmetric information about the R&D outcome and then discuss the choice between cooperative and non-cooperative research. We assume that under non-cooperative R&D each firm can observe only whether it itself is successful, and given the information about its own success or failure, it knows only the conditional probabilities of success or failure of its rival firm. The amount of cost reduction resulting from a successful R&D effort, however, is equal for both the firms. Thus, two possible unit costs are relevant for consideration, the cost when R&D succeeds and that when R&D fails. When the game reaches the stage of competition in the product market, each firm has private information about its own unit cost, and only a probabilistic notion about its rival firm's unit cost. Thus, based on the levels of unit costs, each firm can have two discrete types: low, when R&D has been successful, and high, when R&D has failed.[3] On the other hand, since under RJV firms conduct their research in a single lab and contribute to R&D efforts, all the partners have equal knowledge of and access to the R&D outcomes.

[3] In a different context though, Das Varma (2003) also treats cost reduction due to adoption of a process innovation as private information which constitutes types of firms which compete in an imperfectly competitive market and bid for obtaining the process innovation. He checks for the existence of a Bayesian-Nash equilibrium of the auction which ensures an efficient allocation of the concerned process innovation. The difference in treatment with our paper is that we consider cost reduction due to own R&D efforts rather than an adoption of a process innovation through auction and we consider discrete types. Also in our context the amount of cost reduction is common knowledge, but when the game proceeds to the stage of

Then the firms are to decide ex ante whether they will cooperate in R&D and share R&D costs and outcomes. They will cooperate in research if and only if the *ex-ante* the expected payoff from cooperation is strictly larger.

We derive the following results. First, the presence of incomplete information reduces the expected payoff of non-cooperative research; hence incentives for cooperative research vis-a-vis non-cooperative research are larger under incomplete information. Second, if the R&D cost is not large, cooperative research occurs if and only if the probability of success in R&D is either low or high. On the other hand, the larger the size of the innovation, the lower is the incentive for cooperative R&D. Note that asymmetric information has two opposing effects. It benefits the firm to the extent it holds private information. It hurts the firm because it does not exactly know the rival's type. Finally, the existence of incomplete information hurts the firms, not the consumers; hence the overall welfare of the economy may fall.[4]

The paper is organized as follows. In section 2 we set up the model and discuss the problem. Section 3 derives welfare implications of incomplete information. Section 4 concludes the paper.

2. Model

We consider an interaction of two symmetric firms both in R&D and production. Call them firm 1 and firm 2. In the first stage the firms conduct R&D and in the second stage they compete in the product market non-cooperatively. R&D, however, can be either cooperative or non-cooperative. In either case, the R&D outcome is stochastic. We assume that if an amount $R > 0$ is invested in R&D and the R&D is successful, the unit cost of production falls from the present unit cost $c > 0$ to $c - \varepsilon$. Here $\varepsilon > 0$ represents the amount of cost reduction due to the successful innovation. Let $\alpha \in (0,1)$ be the

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product market competition, each firm is uncertain about the type of its contender, and thus each firm has private information about its actual unit cost.

[4] See, in this context, Mukherjee and Ray (2007) which discusses the effects of process patents on innovation and welfare.

probability of success; therefore, failure occurs with probability $(1-\alpha)$.[5] Throughout the analysis we assume that the innovation is minor or non-drastic in the sense that even if only one firm succeeds in the innovation effort, it still cannot emerge as a monopolist. Hence product market competition is always a duopoly in our model. Further, cooperative research is in the form of research joint venture (RJV) by which the firms share the R&D costs as well as R&D outcomes, but under non-cooperative research each firm invests in its own lab.

Under RJV, since both the firms conduct research jointly, they have symmetric information about the outcome of the research. But under non-cooperative research, the research outcome is perfectly observed by respective firms alone and not by their contenders. Hence, at the production stage, there is asymmetry of information about the R&D outcome. Each firm knows whether it is itself successful or not, but it knows only a prior probability distribution over the outcomes of the other firm's research, and this probability distribution along with its domain is common knowledge. Hence, with non-cooperative research, the firms in the product market will play a Bayesian game. Therefore the firms will have to decide ex ante whether they will cooperate in R&D or not. We assume that both the firms are risk neutral.

We consider the following sequential move game. In the beginning (i.e., at the R&D stage) the firms decide whether they will go for cooperative or non-cooperative R&D based on their expected payoff estimation. Then at the production stage they will choose quantities simultaneously. If it is non-cooperative R&D in the first stage, then they play the Bayesian Nash game in the second stage, and if it is cooperative R&D in the first stage, it is simple Nash game in the second stage. In the following analysis we consider quantity competition in the product market with perfect substitute goods.

Let the market demand for the products be given by

$$p = \max\{0,\ a - q_1 - q_2\};\ a > \mathrm{c} \tag{1}$$

[5] We discuss the case of continuous distribution of the R&D outcome in a different paper.

where p is the price of the product and q_i is the supply of firm i. We now estimate the expected payoffs of the firms from the choice of each of cooperative and non-cooperative R&D.

2.1 Benchmark Case: Complete Information

This is borrowed from Marjit (1991). The expected payoff of each firm under non-cooperative R&D is,

$$\Pi^{NC} = \alpha^2 \pi(c-\varepsilon, c-\varepsilon) + \alpha(1-\alpha)[\pi(c-\varepsilon, c) + \pi(c, c-\varepsilon)] + (1-\alpha)^2 \pi(c,c) - R \quad (2)$$

and that under cooperative research,

$$\Pi^{C} = \alpha\pi(c-\varepsilon, c-\varepsilon) + (1-\alpha)\pi(c,c) - (R/2) \quad (3)$$

Then the firms will go for cooperative research if and only if $\Pi^C > \Pi^{NC}$, that is,

$$(R/2) > [\pi(c-\varepsilon, c) + \pi(c, c-\varepsilon) - \pi(c-\varepsilon, c-\varepsilon) - \pi(c,c)]\alpha(1-\alpha) \quad (4)$$

Given the demand function (1), if c_i and c_j be the unit costs of firms i and j respectively, the payoff expression of firm i is given by $\pi_i(c_i, c_j) = \dfrac{(a-2c_i+c_j)^2}{9}$.

Hence the inequality (4) can be reduced to obtain

$$(R/2) > \frac{4\varepsilon^2}{9}\alpha(1-\alpha) \quad (5)$$

Since the RHS of (5) is strictly concave in α with a unique maximum at $\alpha = 1/2$ and RHS is 0 at both $\alpha = 0$ and $\alpha = 1$, then if R is not very large, the above inequality holds for both small and large α, that is, if the probability of success is either high or low, cooperative research is preferred over non-cooperative research. We can now see the effect of incomplete information on the choice of R&D organization.

2.2 Incomplete information

<u>Non-cooperative R&D</u>

At the end of the R&D stage each firm knows whether it is successful in R&D or not (failure), but the other firm does not know, that is, each firm knows whether it has high or low unit cost of production, but its rival knows only the probability distribution; hence there is asymmetric information. We need to find out the Bayesian Nash equilibrium in quantities. Here each player is of two types, viz., successful (S) or failed (F), hence the Bayesian Nash equilibrium strategy of player i is $q_i = (q_i^S, q_i^F)$. Since the players are otherwise symmetric, the symmetric strategy choice will be $q_1^S = q_2^S = q_S$ and $q_1^F = q_2^F = q_F$ where (see Appendix 1)

$$q_S = \frac{[2(a-c)+(3-\alpha)\varepsilon]}{6} \qquad q_F = \frac{[2(a-c)-\alpha\varepsilon]}{6} \tag{6}$$

The corresponding payoff of each player in cases of success and failure are respectively, $\pi^S = q_S^2$ and $\pi^F = q_F^2$. Now under non-cooperative research when a firm invests $R > 0$, it gets a gross payoff of π^S with probability α and π^F with probability $(1-\alpha)$. Hence ex ante the expected payoff of a firm from non-cooperative research is

$$\tilde{\Pi}^{NC} = \alpha\pi^S + (1-\alpha)\pi^F - R \tag{7}$$

On substitution, the expression can be reduced to obtain,

$$\tilde{\Pi}^{NC} = \frac{(a-c)^2}{9} + \frac{2(a-c)\alpha\varepsilon}{9} + \frac{\alpha\varepsilon^2(9-5\alpha)}{36} - R \tag{8}$$

2.3 Cooperative R&D

Here each firm invests $(R/2)$ in the RJV and whether the RJV succeeds or fails, the firms are always symmetric with respect to R&D outcome. Since success occurs with probability α and failure with probability $(1-\alpha)$, ex ante the expected payoff of each firm from R&D cooperation is,

$$\tilde{\Pi}^C = \Pi^C = \frac{(a-c)^2}{9} + \frac{\alpha\varepsilon}{9}[2(a-c)+\varepsilon] - (R/2) \tag{9}$$

Cooperative vs Non-cooperative R&D

We are now in a position to state the results in terms of the following propositions.

Proposition 1: *Incomplete information about the R&D outcome reduces the expected payoff under non-cooperative R&D. Cooperative R&D incentives vis-à-vis non-cooperative R&D incentives are, therefore, larger under incomplete information.*

Proof: The expected payoff from non-cooperative R&D under complete information is given by Eqn. (2) which can be reduced to get (see Appendix 2)

$$\Pi^{NC} = \frac{(a-c)^2}{9} + \frac{2(a-c)\alpha\varepsilon}{9} + \frac{\alpha\varepsilon^2(5-4\alpha)}{9} - R \tag{10}$$

Then we can easily check that $\widetilde{\Pi}^{NC} < \Pi^{NC}$.

Finally, we have

$$\widetilde{\Pi}^{C} - \widetilde{\Pi}^{NC} > \Pi^{C} - \Pi^{NC}$$

therefore, cooperative R&D incentives vis-à-vis non-cooperative R&D incentives are larger under incomplete information. ■

Note that the expected payoff under cooperative R&D remains unaffected with the introduction of asymmetry of information.

Proposition 2: *If R is not very large, then cooperative R&D is preferred to non-cooperative R&D if the probability of success is either low or high. Non-cooperative R&D is preferred if the probability of success is of the intermediate level.*

Proof: The result holds because $\widetilde{\Pi}^{C} > \widetilde{\Pi}^{NC}$ if and only if,

$$(R/2) > \frac{5\varepsilon^2}{36}\alpha(1-\alpha) \tag{11}$$

and the RHS of (11) is inverted U-shaped over $\alpha \in (0,1)$. ■

Note that inequality (11) is quite similar to inequality (5). Hence the result underlying Proposition 3 holds irrespective of whether information is symmetric or asymmetric. If R is large enough, cooperative R&D is always preferred.

Now to see the effect of asymmetry of information on the choice of R&D organization, we compare inequalities (5) and (11). The RHS of each of (5) and (11) is strictly concave over $\alpha \in (0,1)$ with a unique maximum at $\alpha = 1/2$, but the RHS of (5) is larger than the RHS of (11) $\forall \alpha \in (0,1)$.

Thus incomplete information enhances the scope for cooperative research. This result follows from the fact that asymmetric information extends the probability interval for which the expected payoff under cooperative research is larger. In that sense also incomplete information increases incentives for cooperative research. In *Figure* 1, condition (5) is satisfied for all $\alpha \in (0,\underline{\alpha}) \bigcup (\overline{\alpha},1)$, and condition (11) holds for $\alpha \in (0,\underline{\underline{\alpha}}) \bigcup (\overline{\overline{\alpha}},1)$; $\underline{\alpha} < \underline{\underline{\alpha}} < \overline{\overline{\alpha}} < \overline{\alpha}$. Thus for $\alpha \in (\underline{\alpha},\underline{\underline{\alpha}}) \bigcup (\overline{\overline{\alpha}},\overline{\alpha})$, cooperative R&D occurs under incomplete information but not under complete information. Since asymmetric information generates uncertainty for the players about the extent of efficiency of the rivals, they reduce risk by means of cooperating in R&D. Conditions (5) and (11) together suggest that the larger the size of the innovation, the lower is the incentive for cooperative research; however, incentives for cooperative research fall at a slower rate under incomplete information.

3. Welfare Implication

Given the analysis of the previous section, consider the following cases, depending on the values of α, i.e., the probability of success in reducing the unit cost by an amount ε.

Case (1): $\alpha \in (0,\underline{\alpha}) \bigcup (\overline{\alpha},1)$

Here under both complete and incomplete information the optimal choice of R&D organization is cooperative research. Hence the expected payoff of each firm under complete and incomplete information are equal (i.e., $\Pi^C = \tilde{\Pi}^C$) and given by (9). The corresponding industry output in either situation is given by $2[\alpha q(c-\varepsilon, c-\varepsilon) + (1-\alpha)q(c,c)]$. Hence when the probability of success in R&D is too low or too high, incomplete information has no effect on consumer's welfare and producers' profits.

Case (2): $\alpha \in (\underline{\underline{\alpha}}, \overline{\overline{\alpha}})$

In this case under both complete and incomplete information the firms will choose non-cooperative R&D. Then the payoffs of each firm under complete and incomplete information are respectively given by (2) and (7) (or alternatively, by (10) and (8)). We have already shown in Proposition 1 that $\tilde{\Pi}^{NC} < \Pi^{NC}$. Therefore incomplete information reduces each firm's expected profit.

Now to see the effect on consumers' welfare, consider the (expected) industry output under these situations. The aggregate output under complete information is,

$$\begin{aligned} Q^{NC} &= 2[\alpha^2 q(c-\varepsilon, c-\varepsilon) + \alpha(1-\alpha)(q(c-\varepsilon, c) + q(c, c-\varepsilon)) + (1-\alpha)^2 q(c,c)] \\ &= 2[\frac{(\mathrm{a - c})}{3} + \frac{\alpha\varepsilon}{3}] \end{aligned} \tag{21}$$

and that under incomplete information

$$\begin{aligned} \tilde{Q}^{NC} &= 2[\alpha^2 q_S + \alpha(1-\alpha)(q_S + q_F) + (1-\alpha)^2 q_F] \\ &= 2[\frac{(\mathrm{a - c})}{3} + \frac{\alpha\varepsilon}{3}] \end{aligned} \tag{22}$$

Hence, $Q^{NC} = \tilde{Q}^{NC}$, that is, consumers' welfare is not affected by incomplete information.

Case (3): $\alpha \in (\underline{\alpha}, \underline{\underline{\alpha}}) \bigcup (\overline{\overline{\alpha}}, \overline{\alpha})$

This is the most interesting case in the sense that for these values of α the firms will choose non-cooperative R&D under complete information but cooperative R&D under incomplete information, that is, incomplete information changes the choice of R&D organization. Then the expected payoffs of each firm under these regimes are given by

Π^{NC} and $\tilde{\Pi}^{C}$. These are given by the expressions (10) and (9), respectively. Since for these values of α we have $\Pi^{NC} > \Pi^{C}$, i.e., $(R/2) < \frac{4\varepsilon^2}{9}\alpha(1-\alpha)$, then comparing $\tilde{\Pi}^{C}$ and Π^{NC} we have $\tilde{\Pi}^{C} < \Pi^{NC}$, that is, incomplete information not only changes the choice of R&D organization but it also reduces each firm's expected payoff.

To see the effect on aggregate output, we have Q^{NC} given by equation (21), but $\tilde{Q}^{C}$ is given by

$$\tilde{Q}^{C} = 2[\alpha q(c-\varepsilon, c-\varepsilon) + (1-\alpha)q(c,c)] = 2[\frac{(\text{a - c})}{3} + \frac{\alpha\varepsilon}{3}] \tag{23}$$

Hence, $Q^{NC} = \tilde{Q}^{C}$, that is, again incomplete information has no effect on output. The welfare results are summarized in the following proposition.

Proposition 3: *Given the probability of success in R&D, as we move from complete information to incomplete information regime,*
(a) Consumers' welfare remains unaffected;
(b) The firms become strictly worse off except for very low or high probabilities of success; and
(c) The overall welfare of the economy goes down except when the probability of success is either too small or too large.

Note that in Mukherjee and Ray (2009), uncertainty in patent approvals may induce cooperative research, and compared to non-cooperative R&D regime, under cooperative research both consumers and producers strictly gain. On the contrary, in our paper incomplete information may also induce cooperative research (Case (3) above), but under this situation firms are strictly worse off although the consumers' welfare remains unchanged. Hence incomplete information that induces cooperative research may lead to a lower level of social welfare.[6]

[6] In a different context, with asymmetric R&D costs, Mukherjee and Ray (2014) have shown that entry reduces the profits of the incumbents and hence it can reduce welfare.

4. Conclusion

In this paper we have extended the model of Marjit (1991) to the case of asymmetric information about the R&D outcome in the context of the choice of R&D organization. We have derived two key results. First, if the firms do not know each other's costs post R&D, then they have an added incentive to cooperate and enter into an RJV agreement. Second, the firms may become worse off under this scenario while consumers may not get better off. As a result, total social welfare, consisting of both consumers' and producers' surplus may fall. This leads to a policy dilemma in the context of the choice of R&D organization. While policies are directed against product market cooperation, R&D cooperation is generally encouraged. But, following our results, if the firms perceive asymmetric information at the stage of final goods production with respect to the R&D outcomes of the rival, cooperative research may be welfare reducing.

Appendix

Appendix 1

Let q_j^e be the expected output of firm j as perceived by firm i. If at the end of R&D stage firm i comes up with unit cost c_i, its problem is : $\max_{q_i}[a - q_i - q_j^e - c_i]q_i$. This leads to its reaction function, $q_i(c_i) = \dfrac{(a - c_i - q_j^e)}{2}$. Then $\underset{c_i}{E}\, q_i(c_i) = q_i^e = \dfrac{(a - q_j^e - (\alpha(c-\varepsilon) + (1-\alpha)c)}{2}$. Under symmetry assumption $q_i^e = q_j^e = q^e$, hence $q^e = \dfrac{a - c + \alpha\varepsilon}{3}$. This gives

$$q_i^S = q_i(c-\varepsilon) = \frac{1}{2}[a - (c-\varepsilon) - \frac{(a - c + \alpha\varepsilon)}{3}] = \frac{1}{6}[2(a-c) + (3-\alpha)\varepsilon]$$

Similarly, $q_i^F = q_i(c) = \dfrac{1}{6}[2(a-c) - \alpha\varepsilon]$.

Appendix 2

Under quantity competition, $\pi_i(c_i, c_j) = \dfrac{(a - 2c_i + c_j)^2}{9}$. Hence,

$$\begin{aligned}
\Pi^{NC} &= \alpha^2\pi(c-\varepsilon, c-\varepsilon) + \alpha(1-\alpha)[\pi(c-\varepsilon, c) + \pi(c, c-\varepsilon)] + (1-\alpha)^2\pi(c,c) - R \\
&= \alpha^2\frac{(a-c+\varepsilon)^2}{9} + \alpha(1-\alpha)\left[\frac{(a-c+2\varepsilon)^2}{9} + \frac{(a-c-\varepsilon)^2}{9}\right] + (1-\alpha)^2\frac{(a-c)^2}{9} - R \\
&= \frac{(a-c)^2}{9} + \frac{2(a-c)\alpha\varepsilon}{9} + \frac{\alpha\varepsilon^2}{9}(5-4\alpha) - R
\end{aligned}$$

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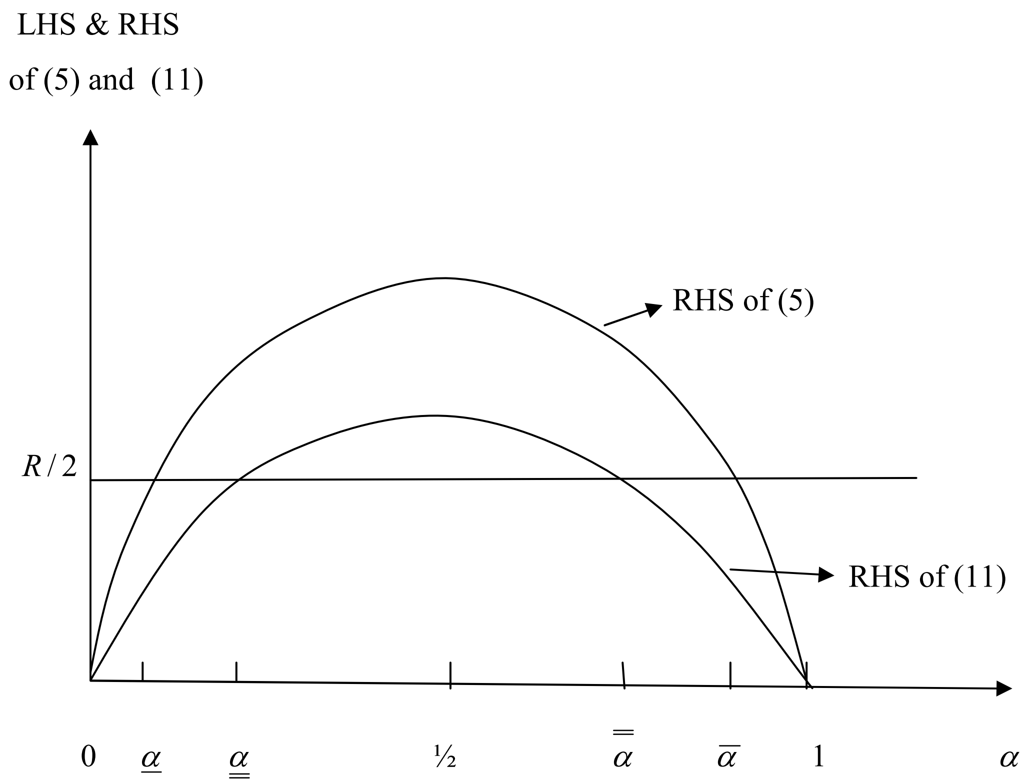

Figure 1: Choice of Cooperative and Non-cooperative R&D