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

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Abstract

This paper studies incentives for cooperative research vis-à-vis non-cooperative research under incomplete information. 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 size of the cost-reducing innovation reduces incentives for cooperative research. We further show that the non-cooperative R&D incentive increases with the variance of the R&D outcome. Similar results also hold for price competition. Finally we show that incomplete information does not at all affect the consumers' welfare but the firms become worse off.

Key words: Cooperative R&D, non-cooperative R&D, RJV, patent protection, imitation.

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

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[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.

(2009) consider the 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? If the size of the innovation is continuous with a given mean and a constant variance, how is the choice between cooperative and non-cooperative R&D affected by these parameters? Does the choice depend on the nature of the product market competition (i.e., quantity competition or price competition)? 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, the R&D outcome is private information. Each firm knows its R&D outcome, but the other firm or competitor knows only the prior probability distribution over the outcomes. Hence under non-cooperative R&D, at the stage of ex post competition in the product market each firm knows its own unit cost of production, but it does not know the other firm's unit cost. 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. 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 ex ante the expected payoff from cooperation is strictly larger. We discuss the problem in a duopoly set up under both quantity and price competition.

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. In case the size of the innovation is continuous, the choice between cooperative and non-cooperative R&D depends on the variance of the R&D outcome, given the R&D cost. The larger the variance, the lower is the incentive for cooperative research. The qualitative results under price competition are the same as that under quantity competition. 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.

The paper is organized as follows. In section 2 we set up the model and discuss the problem under quantity competition at the product stage. Section 3 outlines the problem under price competition. Section 4 derives welfare implications of incomplete information. Section 5 is a conclusion.

2. Model

We consider the 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 of $c > 0$ to $c - \varepsilon$. Here $\varepsilon > 0$ represents the size of the innovation. Let $\alpha \in (0,1)$ be the probability of success;

therefore, failure occurs with probability $(1-\alpha)$.[3] 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 monopoly. 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 the respective firms only, not by their contenders. Hence 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. Threfore 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 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 either quantities or prices 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 subsection we consider quantity competition in the product market with a homogeneous good, and in the next section we consider price competition with differentiated products.

2.1 Quantity Competition

[3] We also discuss the case of continuous distribution of the R&D outcome.

Let us consider the case when the firms in the product market each with unit cost of production c compete in quantities a la Cournot, and they produce perfectly substitute goods. Let the market demand for the product be given by

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

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 each of cooperative and non-cooperative R&D.

2.1.1 Benchmark Case: Complete Information

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

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

and that under cooperative research,

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

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

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

Given the demand function (1), if c_i and c_j be the unit costs of firm 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 get

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

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.

2.1.2 Incomplete information

Non-cooperative R&D

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, 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 failure (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)

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

The corresponding payoffs 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

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

On substitution, the expression can be reduced to get,

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

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,

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

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 R&D outcome reduces the expected payoff under non-cooperative R&D.*

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 $\tilde{\Pi}^{NC} < \Pi^{NC}$. Hence the result. ■

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

Proposition 2: *Cooperative R&D incentives vis-à-vis non-cooperative R&D incentives are larger under incomplete information.*

Proof: The result holds because, $\tilde{\Pi}^{C} - \tilde{\Pi}^{NC} > \Pi^{C} - \Pi^{NC}$. ■

Proposition 3: *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 $\tilde{\Pi}^{C} > \tilde{\Pi}^{NC}$ 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 exactly similar to inequality (5). Hence the result underlying Proposition 3 is true independent of whether information is symmetric or asymmetric. If R is large, 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) $\forall \alpha \in (0,1)$. Hence we have the following results.

Proposition 4: *Incomplete information enhances the scope of 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.

[FIGURE 1 HERE]

To analyze the effect of the size of innovation on the choice of the R&D organization again we may look at the conditions (5) and (11) and then can state the following result.

Proposition 5: *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.*

So far we have assumed only two possible outcomes of research, that is, success or failure, and the size of the innovation is constant. In the following subsection we consider the size of the innovation ε to be continuous over the relevant domain (so that the market remains duopoly). We then examine how it affects the incentive for conducting cooperative research.

2.1.3 Continuous Distribution

Let us suppose that the size of the innovation is continuous over the relevant domain. Thus as R is invested, it reduces the unit cost of production by an amount ε which is a random and independent draw from the given interval with mean $\bar{\varepsilon}$ and constant variance σ_{ε}^2, or equivalently, the post R&D unit cost of a firm is $\tilde{c} = c - \varepsilon$ with mean $\bar{c} = c - \bar{\varepsilon}$ and variance $\sigma_{\tilde{c}}^2 = \sigma_{\varepsilon}^2$.

Here strategy of each firm is type dependent, hence at the Bayes Nash equilibrium firm i has strategy $\{q(\tilde{c})\}$ with (see Appendix 3),

$$q(\tilde{c}) = \frac{a - \tilde{c} - q^e}{2}$$

where $q^e = \dfrac{a - \bar{c}}{3}$ is the expected output of the rival firm as perceived by each firm.

Hence a firm of type $\tilde{c}$ (i.e., ε) has at the product stage a (gross) profit

$$\pi(\tilde{c}) = [a - q(\tilde{c}) - q^e - \tilde{c}]\, q(\tilde{c}) = \frac{1}{36}[2a - 3\tilde{c} + \bar{c}]^2$$

Then ex ante the expected payoff from non-cooperative R&D of each firm will be[4]

$$\overline{\Pi}^{NC} = \underset{\tilde{c}}{E}\, \pi(\tilde{c}) - R = \frac{(a - c + \bar{\varepsilon})^2}{9} + \frac{1}{4}\sigma_{\varepsilon}^2 - R \qquad (12)$$

Similarly, we can derive ex ante the expected payoff of each firm under cooperative research to be,

[4] The corresponding expression of the expected payoff from non-cooperative R&D under complete information will be: $\Pi^{NC} = \dfrac{(a - c + \bar{\varepsilon})^2}{9} + \dfrac{5}{9}\sigma_{\varepsilon}^2 - R$. Hence $\Pi^{NC} > \overline{\Pi}^{NC}$.

$$\overline{\Pi}^C = \underset{\tilde{c}}{E}\frac{(\mathrm{a} - \tilde{\mathrm{c}})^2}{9} - (R/2) = \frac{(a - c + \bar{\varepsilon})^2}{9} + \frac{1}{9}\sigma_{\varepsilon}^2 - (R/2) \tag{13}$$

Now, comparing (12) and (13), $\overline{\Pi}^C > \overline{\Pi}^{NC}$ if and only if

$$(R/2) > \frac{5}{36}\sigma_{\varepsilon}^2 \tag{14}$$

We have the following result.

Proposition 6: *The larger the variance of the size of the innovation the smaller is the incentive for cooperative research.*

Thus our paper draws attention to the importance of variance of the size of the innovation or R&D outcome in the choice of R&D organization. Larger σ_{ε}^2 raises the possibility that under non-cooperative case one firm comes up with a large innovation while the other with a small innovation. Then if R&D cost is not large enough, the firms will go for non-cooperative research.

3. Bertrand Competition

In this section we consider price competition at the production stage. Consider that the firms produce differentiated products. Let the demand as faced by firm i be given by,

$$q_i = b - \beta p_i + \theta p_j; \quad b > 0; \beta > \theta > 0 \tag{15}$$

If c_i and c_j be the unit costs of firms i and j respectively, then this price game has Bertrand Nash price solutions

$$p_i = \frac{b(2\beta + \theta) + 2\beta^2 c_i + \beta\theta\, c_j}{4\beta^2 - \theta^2}$$

Using the above we can get the payoffs

$$\pi_i(c_i, c_j) = \beta\left[\frac{b(2\beta + \theta) - (2\beta^2 - \theta^2)c_i + \beta\theta\, c_j}{4\beta^2 - \theta^2}\right]^2 \tag{16}$$

Now, if there are only two outcomes as before (i.e., success and failure), then under complete information, following (4), the cooperative R&D is preferred over non-cooperative R&D if and only if

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

which, in the present model, reduces to (see Appendix 4)

$$(R/2) > 2\theta(2\beta^2-\theta^2)\left(\frac{\beta\varepsilon}{4\beta^2-\theta^2}\right)^2\alpha(1-\alpha) \quad (17)$$

Hence we have similar result as in the quantity game.

We now introduce incomplete information in the price game but for simplicity consider the case of continuous distribution of innovation with constant mean and variance, as before. We can then derive (see Appendix 5) the expected payoff of each firm under non-cooperative and cooperative R&D respectively as,

$$\hat{\Pi}^{NC} = \frac{\beta[b-(\beta-\theta)(c-\bar{\varepsilon})]^2}{(2\beta-\theta)^2}+\frac{1}{4}\beta\sigma_\varepsilon^2 - R \quad (18)$$

and

$$\hat{\Pi}^{C} = \frac{\beta[b-(\beta-\theta)(c-\bar{\varepsilon})]^2}{(2\beta-\theta)^2}+\frac{\beta(\beta-\theta)^2}{(2\beta-\theta)^2}\sigma_\varepsilon^2 - (R/2) \quad (19)$$

Hence $\hat{\Pi}^{C} > \hat{\Pi}^{NC}$ if and only if,

$$(R/2) > \left(\frac{1}{4}-\frac{(\beta-\theta)^2}{(2\beta-\theta)^2}\right)\beta\sigma_\varepsilon^2 > 0 \quad (20)$$

Structurally, this is very similar to the inequality (14). Hence price competition under both complete and incomplete information leads to similar results as obtained under quantity competition. Therefore, the nature of the product market competition does not play any significant role in the choice of R&D organization irrespective of whether information is symmetric or asymmetric.

4. Welfare Implication

Let us restrict our analysis to the scenario where the firms compete in quantities in the product market and there are only two possible outcomes of R&D viz., success and failure, as in subsections 2.1.1 and 2.1.2. 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 payoffs 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 either 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 payoff.

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

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

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 7: *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.

5. 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 see that the qualitative results are not much different from the case of complete information. However, incentives for cooperative research go up under incomplete information. On the other hand, larger variance of the R&D outcome tends to tilt the choice towards non-cooperative R&D. We have discussed the problem under both quantity and price competition. Contrary to the common wisdom, the nature of product market competition does not make the analysis much different in terms of the results. The paper has also discussed welfare implication of incomplete information. While consumers are indifferent between two regimes of information, producers strictly prefer complete information.

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, $q_i(c_i) = \frac{(a - c_i - q_j^e)}{2}$. Then $\underset{c_i}{E}\, q_i(c_i) = q_i^e = \frac{(a - q_j^e - (\alpha(c-\varepsilon) + (1-\alpha)c)}{2}$. Under symmetry assumption $q_i^e = q_j^e = q^e$, hence $q^e = \frac{a - c + \alpha\varepsilon}{3}$. 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, $q_i^F = q_i(c) = \frac{1}{6}[2(a-c) - \alpha\varepsilon]$.

Appendix 2

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

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

Appendix 3

Following Appendix 1, the reaction function of firm i is: $q_i(c_i) = \frac{(a - c_i - q_j^e)}{2}$. Then, $\underset{c_i}{E}\, q_i(c_i) = q_i^e = \frac{(a - q_j^e - \bar{c})}{2}$. By symmetry, $q_i^e = q_j^e = q^e = \frac{a - \bar{c}}{3}$. Hence for any c_i, firm i's profit is

$$\pi_i(c_i) = [a - q_i(c_i) - q_j^e - c_i]q_i(c_i) = \frac{1}{36}(2a - 3c_i + \bar{c})^2 = \frac{1}{36}[2(a - \bar{c}) - 3(c_i - \bar{c})]^2$$

Hence ex ante the expected payoff of firm i is,

$$\Pi^{NC} = \underset{c_i}{E}\,\pi(c_i) - R = \frac{1}{36}[4(a - \bar{c})^2 + 9\sigma_{c_i}^2] - R = \frac{(a - c + \bar{\varepsilon})^2}{9} + \frac{1}{4}\sigma_\varepsilon^2 - R$$

which is the Eq. (12)

Under cooperative research if the RJV comes up with the marginal cost $\tilde{c}$, each firm's payoff in the product market is $\frac{(a - \tilde{c})^2}{9}$. Hence ex ante the expected payoff of each firm under cooperative research is

$$\overline{\Pi}^C = \underset{\tilde{c}}{E}\,\frac{(a - \tilde{c})^2}{9} - (R/2) = \underset{\tilde{c}}{E}\,\frac{[(a - \bar{c}) - (\tilde{c} - \bar{c})]^2}{9} - (R/2) = \frac{(a - c + \bar{\varepsilon})^2}{9} + \frac{1}{9}\sigma_\varepsilon^2 - (R/2)$$

This is Eq. (13).

<u>Appendix 4</u>

From (16), we can write

$$\pi_i(c - \varepsilon, c - \varepsilon) = \beta\left[\frac{b - (\beta - \theta)c}{2\beta - \theta} + \frac{(2\beta^2 - \theta^2 - \beta\theta)\varepsilon}{4\beta^2 - \theta^2}\right]^2;$$

$$\pi_i(c - \varepsilon, c) = \beta\left[\frac{b - (\beta - \theta)c}{2\beta - \theta} + \frac{(2\beta^2 - \theta^2)\varepsilon}{4\beta^2 - \theta^2}\right]^2;$$

$$\pi_i(c, c - \varepsilon) = \beta\left[\frac{b - (\beta - \theta)c}{2\beta - \theta} - \frac{\beta\theta\varepsilon}{4\beta^2 - \theta^2}\right]^2$$

$$\pi_i(c, c) = \beta\left[\frac{b - (\beta - \theta)c}{2\beta - \theta}\right]^2$$

Then,

$$\pi(c - \varepsilon, c) + \pi(c, c - \varepsilon) - \pi(c - \varepsilon, c - \varepsilon) - \pi(c, c)] = 2\theta(2\beta^2 - \theta^2)\left(\frac{\beta\varepsilon}{4\beta^2 - \theta^2}\right)^2$$

Appendix 5

Here firm i's problem is: $\max_{p_i} (p_i - c_i)(b - \beta p_i + \theta p_j^e)$

Then firm i's reaction function is: $p_i(c_i) = \dfrac{(b + \beta c_i + \theta p_j^e)}{2\beta}$.

Hence, $\underset{p_i}{E}\, p_i(c_i) = p_i^e = \dfrac{(b + \beta \overline{c} + \theta p_j^e)}{2\beta}$.

By symmetry, $p_i^e = p_j^e = p^e = \dfrac{b + \beta \overline{c}}{2\beta - \theta}$

Hence, for any given c_i, firm i's profit from the product market is:

$$\pi_i(c_i) = [b - \beta p_i(c_i) + \theta p_j^e](p_i(c_i) - c_i)$$
$$= \frac{1}{4\beta(2\beta - \theta)^2}\left[2\beta\{b - (\beta - \theta)\overline{c}\} - \{(2\beta^2 - \beta\theta)(c_i - \overline{c})\}\right]^2$$

Therefore, ex ante the expected payoff from non-cooperative R&D is

$$\hat{\Pi}^{NC} = \underset{c_i}{E}\, \pi_i(c_i) - R = \frac{\beta[b - (\beta - \theta)(c - \overline{\varepsilon})]^2}{(2\beta - \theta)^2} + \frac{\beta}{4}\sigma_\varepsilon^2 - R$$

Under cooperative research, for any $\hat{c}$, the equilibrium price is $p(\hat{c}) = \dfrac{b + \beta\hat{c}}{2\beta - \theta}$.

Hence, the payoff of a firm from the product market is

$$\pi(\hat{c}) = [b - (\beta - \theta)p(\hat{c})](p(\hat{c}) - \hat{c})$$
$$= \frac{\beta}{(2\beta - \theta)^2}\left[b - (\beta - \theta)\hat{c}\right]^2$$
$$= \frac{1}{(2\beta - \theta)^2}\left[\{b - (\beta - \theta)\overline{c}\} - \{(\beta - \theta)(\hat{c} - \overline{c})\}\right]^2$$

Hence ex ante the expected payoff of each firm under cooperative research is

$$\hat{\Pi}^{C} = \underset{\hat{c}}{E}\, \pi(\hat{c}) - (R/2) = \frac{\beta[b - (\beta - \theta)(c - \overline{\varepsilon})]^2}{(2\beta - \theta)^2} + \frac{\beta(\beta - \theta)^2}{(2\beta - \theta)^2}\sigma_\varepsilon^2 - (R/2)$$

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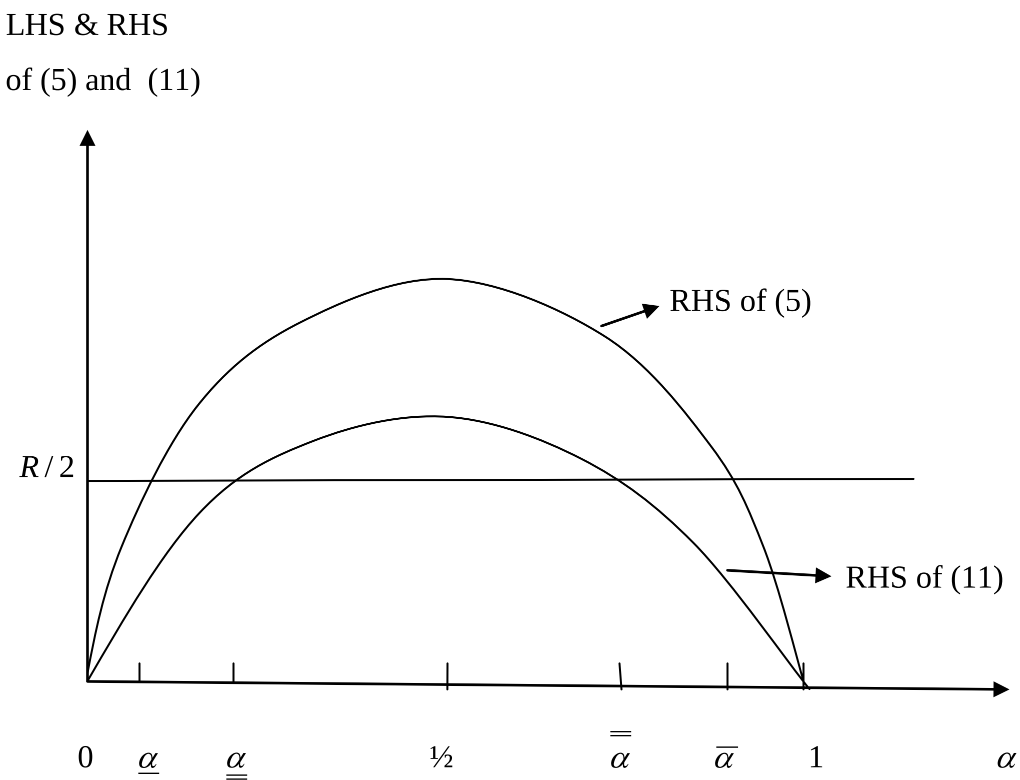

Figure 1: Choice of Cooperative and Non-cooperative R&D