Economics Bulletin

Volume 35, Issue 1

Incomplete information and R&D organization

Srobonti Chattopadhyay
Vidyasagar College for Women

Tarun Kabiraj
Indian Statistical Institute, Kolkata

Abstract

This paper studies the choice of cooperative versus non-cooperative R&D under incomplete information about the innovation size of the rival. It is assumed that the R&D outcome is stochastic and continuously distributed with a given mean and a constant variance. We show that the incentive for cooperative research is smaller the larger is the variance of the R&D outcome, irrespective of the nature of the product market competition (Cournot versus Bertrand).

We shall be held responsible for errors and omissions, if any. Editor's Note: This paper was originally published as Srobonti Chattopadhyay and Tarun Kabiraj, (2015) "Incomplete information and R&D organization", Economics Bulletin, Vol. 35 No. 1 p.A3. Due to a software error out of the control of the author, the original has been withdrawn and is republished here.

Citation: Srobonti Chattopadhyay and Tarun Kabiraj, (2015) "Incomplete information and R&D organization", *Economics Bulletin*, Volume 35, Issue 1, pages 14-20

Contact: Srobonti Chattopadhyay - srobonti@gmail.com, Tarun Kabiraj - tarun@isical.ac.in.

Submitted: March 11, 2015. **Published:** March 11, 2015.

1. Introduction

The literature on R&D organization discusses the choice between cooperative and non-cooperative R&D. For instance, d'Aspremont and Jacquemin (1988) and Suzumura (1992) discuss the choice under R&D spillovers, Marjit (1991) under uncertain R&D outcomes, and Silipo and Weiss (2005) under both Spillovers and uncertainty. Combs (1992) extends the analysis to the case of multiple research projects, Kabiraj (2007) introduces synergy in R&D cooperation, Mukherjee and Marjit (2004) introduce technology transfer with the choice of R&D organization, and Choi (1992, 1993) introduces moral hazard. Then Kabiraj (2006) studies the effect of imitation and patent protection, and Mukherjee and Ray (2009) introduce uncertainty in patent approvals. Finally, Kabiraj and Mukherjee (2000) discuss the choice between cooperative and independent research in a three-firm framework and Motta (1992) discusses the choice when products are vertically differentiated.

None of the above works, however, discusses the problem of choice of the R&D organization under incomplete information. Hence the purpose of the present paper is to extend the literature to the case of incomplete information about the types of competing firms. Consider process innovation which reduces the unit cost of production by an amount $\varepsilon > 0$ which is a random variable and is realized before the product market competition begins. Under cooperative research the firms have symmetric access to information and hence the firms know exactly the size of the innovation at the stage of final goods production. But under non-cooperative R&D, we assume that the R&D outcome is private information. Each firm knows the realization of its R&D outcome, but its rival firm knows only the prior distribution of the size of the innovation. 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 its contender's unit cost with certainty.

Then the question arises: what will be the choice of R&D organization under this situation? One closely related paper that discusses the problem under incomplete information is by Kabiraj and Chattopadhyay (2014)[1], but this paper assumes only two possible research outcomes (like success and failure) and that the firms compete in quantities a la Cournot in the product market. The present paper, therefore, considers the scenario involving a continuum of research outcomes. Thus we assume that the size of the innovation is continuously distributed over a given interval. In particular, we assume that the size of the innovation is continuous with a given mean and a constant variance. Then the question is: how is the choice between cooperative and non-cooperative R&D affected by these parameters? Does a larger variance increase or decrease incentives for cooperative research? We also like to examine in this context whether the nature of product market competition has any significant effect on the choice of R&D organization. Hence we consider both quantity as well as price competition in the product market.

[1]Brocas (2004) analyzes the problem of cooperative R&D when information is incomplete; he considers a scenario with incomplete information in which, when R&D cooperation is not efficient, the regulator may intervene by means of designing contractual rules that would improve performance from the viewpoint of social welfare. In contrast to Brocas' model, we assume complete information under cooperative R&D, and that firms have incomplete information about the outcomes only when R&D is non-cooperative.

We assume research joint venture (RJV) as the form of R&D cooperation, and under RJV the firms share both R&D costs and outcomes. Then the firms are to decide *ex ante* whether they will share research outcomes and expenses or conduct R&D independently. They will cooperate in research if and only if *ex ante* the expected payoff from cooperation is strictly larger. We address the problem in a duopoly set up under each of quantity and price competition. We show that the larger is the variance of the size of the innovation, the smaller is the incentive for cooperative research, and this result is robust independent of the nature of product market competition (Cournot versus Bertrand). Hence in our paper the nature of product market competition does not play any significant role in the choice of R&D organization. Our analysis highlights the role of the variance of R&D outcomes in the choice of research organization.

The paper is organized as follows. Section 2 presents the model and results and section 3 concludes the paper.

2. Model

Consider the interaction of two firms both in R&D and production. We call them firm 1 and firm 2. While R&D interaction can be either cooperative or non-cooperative, product market interaction is always non-cooperative. In the product market they play either Cournot game or Bertrand game. And under cooperative research the firms share both R&D cost and outcomes equally, hence cooperative research takes the form of RJV. On the other hand, under non-cooperative research each firm invests in its own lab. In any case, the R&D outcome is stochastic. Given an initial unit cost of $c > 0$ for each firm, if an amount $R > 0$ is invested in R&D, it reduces unit cost of production to $c - \varepsilon$. Hence, $\varepsilon > 0$ represents the size of the innovation. We restrict ourselves to the assumption that the innovation is non-drastic or minor 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. Assume that ε is continuously distributed over a given interval with a given density and distribution function. In particular, we assume that the distribution has a given mean and a constant variance.

When the firms work together to conduct the research, both can equally observe the outcome and hence, under RJV, both the firms are symmetrically informed about the extent of cost reduction due to R&D. However, when the firms conduct research non-cooperatively, only the respective firms observe the R&D outcomes perfectly. Thus no firm can *ex ante* be sure about the level of unit cost of its contender and hence there is asymmetry of information about the R&D outcome. Here each firm can have a multitude of types based on the volume of reduction in its unit cost following its R&D. Each firm knows a prior probability distribution over the types of its rival. The probability distribution and the interval over which the types are distributed are common knowledge. So this is a sequential move game where, when the stage of product market competition is reached, under non-cooperative research the firms choose their strategies (quantity or price as the case may be) based on their expectations about their rivals' types. We assume both the firms to be risk-neutral. Thus, under non-cooperative R&D organization, we have a Bayesian game where the firms maximize their expected payoffs and have to make a decision *ex ante* about conducting the R&D cooperatively or non-cooperatively.

We consider the following two-stage game. In the first stage the firms decide whether they will cooperate or non-cooperate in R&D based on their estimated expected payoff. Then at the production stage they play a quantity (Cournot) or price (Bertrand) game. 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 a 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 subsection we consider price competition with differentiated products.

2.1 Quantity Competition

Assume that under quantity competition, the firms produce perfectly substitute goods. And the market demand for the product in inverted form is given by

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

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.

Consider first non-cooperative research at the R&D stage. Each firm invests R in its own research lab and comes up with a cost reduction 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 firm i $(\text{i} = 1{,}2)$ is $c_i = c - \varepsilon$ with mean $E(c_i) = \bar{c} \equiv c - \bar{\varepsilon}$ and variance $\sigma_{c_i}^2 = \sigma_\varepsilon^2$.

Under incomplete information the firms play Bayes Nash game, hence the strategy of each firm is type dependent, that is, at the Bayesian Nash equilibrium firm i has strategy $\{q(c_i)\}$. 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,

$$\underset{c_i}{E}\, q_i(c_i) = q_i^e = \frac{(a - q_j^e - \bar{c})}{2}.$$

By symmetry, $q_i^e = q_j^e = q^e = \dfrac{a - \bar{c}}{3}$. Hence for any c_i, firm i's gross 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,

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

Now consider RJV in the R&D stage. 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

$$\Pi^{C} = \underset{\tilde{c}}{E}\frac{(a-\tilde{c})^2}{9} - (R/2) = \underset{\tilde{c}}{E}\frac{[(a-\bar{c})-(\tilde{c}-\bar{c})]^2}{9} - (R/2) = \frac{(a-c+\bar{\varepsilon})^2}{9} + \frac{1}{9}\sigma_{\varepsilon}^2 - (R/2) \tag{3}$$

Now, comparing (2) and (3), $\Pi^{C} > \Pi^{NC}$ if and only if

$$(R/2) > \frac{5}{36}\sigma_{\varepsilon}^2 \tag{4}$$

We have the following result.

Proposition 1: *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.

2.2 Price Competition

In this subsection 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,

$$q_i = b - \beta p_i + \theta p_j; \quad b > 0; \beta > \theta > 0 \tag{5}$$

First assume that the firms play a non-cooperative game in the R&D stage. Under incomplete information let p_j^e be the expected price to be charged by firm j as perceived by firm i. Then firm i's problem is:

$$\max_{p_i} (p_i - c_i)(b - \beta p_i + \theta p_j^e)$$

This leads to firm i's reaction function:

$$p_i(c_i) = \frac{(b + \beta c_i + \theta p_j^e)}{2\beta}.$$

Hence,

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

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:

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

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

$$\hat{\Pi}^{NC} = \underset{c_i}{E}\, \pi_i(c_i) - R = \frac{\beta[b - (\beta - \theta)(c - \overline{\varepsilon})]^2}{(2\beta - \theta)^2} + \frac{\beta}{4}\sigma_\varepsilon^2 - R \qquad (6)$$

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

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

This gives the *ex ante* expected payoff of each firm under cooperative research to be

$$\hat{\Pi}^{C} = \underset{\hat{c}}{E}\, \pi(\hat{c}) - (R/2) = \frac{\beta[b - (\beta - \theta)(c - \overline{\varepsilon})]^2}{(2\beta - \theta)^2} + \frac{\beta(\beta - \theta)^2}{(2\beta - \theta)^2}\sigma_\varepsilon^2 - (R/2) \qquad (7)$$

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

$$(R/2) > \left(\frac{1}{4} - \frac{(\beta - \theta)^2}{(2\beta - \theta)^2}\right)\beta\sigma_\varepsilon^2 > 0 \qquad (8)$$

Structurally, this is very similar to the inequality (4). 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.

3. Conclusion

Research and development activities involve high R&D costs, and also there is a threat of imitation and leaking out of knowledge. As a way out of underinvestment in R&D the policy makers seem to encourage cooperative research. In this paper we have considered the scenario when the R&D outcome is stochastic and continuous and at the stage of product market competition firms have asymmetric information about the rivals' cost structure. Hence the paper discusses the choice of R&D organization under incomplete information. We have considered both price competition and quantity competition in the product market and assumed that the size of the innovation is continuously distributed with a given mean and a constant variance. We have shown that as the variance goes up, incentives for cooperative research falls, and this does not depend on the nature of the product market competition.

References

Brocas, I. (2004) "Optimal regulation of cooperative R&D under incomplete information" *The Journal of Industrial Economics* **52**, 81-120.

Choi, J.P. (1992) "Cooperative R&D with moral hazard" *Economics Letters* **39**, 485-491.

Choi, J.P. (1993) "Cooperative R&D with product market competition" *International Journal of Industrial Organization* **11**, 553-571.

Combs, K.L. (1992) "Cost sharing vs. multiple research projects in cooperative R&D" *Economics Letters* **39,** 353-357.

d'Aspremont, C. and A. Jacquemin (1988) "Cooperative and non-cooperative R&D in duopoly with spillovers" *American Economic Review* **5**, 1133-37.

DeCourcy, J. (2005) "Corporate R&D and strategic trade policy" *Canadian Journal of Economics* **38**, 546-573.

Kabiraj, T. (2007) "On the incentives for cooperative research" *Research in Economics* **61**, 17-23.

Kabiraj, T. (2006) "On the incentives for cooperative and non-cooperative R&D in duopoly" *Arthaniti (New Series)* **5**, 24-33.

Kabiraj, T. and S. Chattopadhyay (2014) "Cooperative vs. non-cooperative R&D incentives under incomplete information" *Economics of Innovation and New Technology* (forthcoming) [DOI: 10.1080/10438599.2014.991138]

Kabiraj, T. and A. Mukherjee (2000) "Cooperation in R&D and production – A three-firm analysis" *Journal of Economics* **71**, 281-304.

Marjit, S. (1991) "Incentives for cooperative and non-cooperative R and D in duopoly" *Economics Letters* **37**, 187-191.

Motta, M. (1992) "Cooperative R&D and vertical product differentiation" *International Journal of Industrial Organization* **10**, 643–661.

Mukherjee, A. and S. Marjit (2004) "R&D organization and technology transfer" *Group Decision and Negotiation* **13**, 243-258.

Mukherjee, A. and A. Ray (2009) "Unsuccessful patent application and cooperative R&D" *Journal of Economics* **97**, 251-263.

Silipo, D.B. and A. Weiss (2005) "Cooperation and competition in an R&D market with spillovers" *Research in Economics* **59**, 41-57.

Suzumura, K. (1992) "Cooperative and non-cooperative R&D in an oligopoly with spillovers" *American Economic Review* **82**, 1307-20.