Rochester Center for

Economic Research

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Working Paper No. 317
March 1992

University of

Rochester

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January 1992

*I would like to thank Debraj Ray for general discussions on this topic and Amitava Bose for his remarks during the presentation of a related paper at the Indian Statistical Institute, Calcutta. The usual disclaimer applies.

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ABSTRACT

We discuss alternative organizational forms of research and development in a symmetric duopoly framework. Firms play non–cooperative game at the output stage but can collaborate at the R and D stage. In the absence of patent protection, technology licensing that prevents imitative R and D may emerge as an equilibrium outcome. In general, greater probabilities of "success" in R and D rule out non–cooperative arrangement at the R and D stage. With side–payments, delegative R and D, where firms move sequentially, tend to dominate the cooperative form.

SECTION I Introduction

In recent years considerable amount of theoretical research has been done in the context of R & D behavior of the oligopolistic firms. Most of the existing literature till mid 80s have been concentrating on the analysis of non–cooperative R & D strategies of the competing firms until very recently the phenomena of "cooperative R & D" and R & D "joint–ventures" became relatively interesting areas of research. As D'Aspremont and Jacquemin (1988) have noted, there are quite a few examples of firms cooperating in the R & D projects but continuing to be rivals in the product market. Motivation for cooperation in R & D and welfare impacts of such partial cooperation on full–cooperation (when firms also collude in the product market) have been discussed in detail by Katz (1986), Ondover and Willig (1985), Suzumura (1990), Gandol and Scotchmer (1989), Kamien, Muller and Zang (1990), etc. Recently Marjit (1991)[1] has shown that even in the absence of "spillovers", firms will be interested in cooperating in R & D projects with "very high" or "very low" success probabilities, while they continue to choose non–cooperative output levels in the product market.

Parallel to this literature, rather small but intensive research is being done to analyze R & D preemptive technology licensing where the incumbent firm decides to share the market with an entrant just to kill its incentive for further R & D. Gallini (1984)[2] has discussed a model where the incumbent does the R & D and the entrant only licenses it from the incumbent. Rockett (1990) discusses optimal licensing contract when imitation is potentially possible and shows that the "quality" of technology can be a variable of choice faced by the principal. If one looks closely at both of these literature, certain unifying theme comes up on the surface. All the above mentioned papers talk about some kind of organizational arrangement of R & D between competing firms. Typically the firms can go for non–cooperative independent R & D ventures. They can go for cooperative R & D arrangement or can "delegate" the activity of R & D to one firm and share the knowledge subsequently. The interesting question is that if we start with a "symmetric" firm, then what kind of incentives will lead these firms to choose among different alternative arrangements. The purpose of this paper is to build up a structure where these alternatives can be analysed and some simple conjectures can be drawn regarding the situations which lead to the emergence of alternative organizational forms involving R & D activities. Projects with moderate chance of "success" or "failure" will generally lead to non–cooperative R & D. Where "success" probability is high both delegation and cooperation turn out to be more lucrative rather than non–cooperative R & D.

The paper proceeds as follows: In the next section I present the description of the market and R & D activities of the firms along with the definitions of alternative forms of arrangements. In the third section comparisons are made among different types of alternatives. The last section contains some concluding remarks.

SECTION II The Basic Model

Condider an industry with two firms engaged in a Cowrnot–Nash game. They have equal constant marginal costs (c) to start with. I shall assume, just for simpler calculations, that initially both of them earn negligible profits. Innovation takes the form of a reduction in c and if it at all takes place it is "drastic" in nature. So that if only one firm is independently successful in innovating a new technology, it emerges as a monopolist. Innovative activity or R & D involves setting up a R & D lab with a cost F and given the lab is in operation p is the "success" probability of innovation and (1–p) is the "failure" rate. There is no relationship between p and F except that one has to invest F prior to the drawing of the cost functions through a random process. If both these firms simultaneously emerge as successful, they play a symmetric Cowrnot–Nash game in the post innovation situation. Throughout the paper I assume that the firms can not collude in the product market due to anti–Trust regulations.

As is obvious, I do not assume any spillovers. Given this set up, let me define three alternative arrangements which I am going to discuss in detail.

a) Here firms do independent R & D with independent draws and there is no communication at the R & D stage. We call it "non-cooperative R & D" or "NCR."

b) Here firms cooperate in R & D. If it is a success, it is true for both of them. Similarly they equally share failure. They jointly set up a lab by equally sharing F. We call this arrangement "cooperative R & D" or "CR".

c) In this situation one firm moves first by setting up the lab and doing the R & D. In the next stage it can sell the R & D output to the other firm. The information is shared against a lump-sum fee determined by a simple bargaining rule. Firms compete subsequently in the product market. We call this arrangement "delegative R & D" or "DR".[3]

At first we shall look at all possible sub-game perfect equilibria under each arrangement by calculating the pay-offs. Then we shall compare the relative benefits and costs which will generate the range of parameter values under which a specific arrangement will pareto-dominate the others.

Following symbols will be used in the formal presentation of the analysis.

π_m – monopoly profit in the post-innovation situation

$\hat{\pi}$ – symmetric duopoly pay-off

P_s – price of selling the R & D output under DR.

Following assumptions will be made in the forthcoming sections.

A1) Even if both firms independently end up being successful and have to be satisfied with the symmetric duopoly profits, still it is profitable to do R & D. In other words,

$$p\hat{\pi} > F \quad (1)$$

A2) We think about only one shot innovation and therefore if any of the firms obtains the "new" technology there is no scope for further innovation. With this structure, I can now state the following propositions:

Proposition 1 Under NCR, given (A1) firms find it profitable to do R & D simultaneously.

Proof: Under NCR the pay-off to each firm is given by

$$p(1-p)\pi_m + p^2\hat{\pi} - F \qquad (2)$$

note that (2) has been computed under the basic assumptions of "zero" initial pay-off and "drastic" innovations.

Now,

$$p(1-p)\pi_m + p^2\hat{\pi} - p\hat{\pi}$$
$$= p(1-p)\ \pi_m - p(1-p)\ \hat{\pi}$$
$$= p(1-p)\ (\pi_m - \hat{\pi}) > 0 \qquad \text{as } \pi_m > \hat{\pi} \text{ and } 0 < p < 1$$

Therefore, $p(1-p)\ \pi_m + p^2\ \hat{\pi} > p\hat{\pi}$

But from (A1) we know that $p\hat{\pi} > F$ Hence, $p(1-p)\ \pi_m + p^2\hat{\pi} > F$ QED

Proposition 2 Under CR, given (A1), both firms find it profitable to do R & D.

Proof: Under CR the pay-off to each firm is given by,

$$p\hat{\pi} - \tfrac{1}{2}F \qquad (3)$$

given (A1) it is obvious that $p\hat{\pi} > \frac{1}{2}F$ QED

The DR case is a bit complicated. We shall first draw the extensive form game and then calculate the equilibrium pay-offs, Without loss of generality let us assume that firm 1 invests F. Then following situations can arise as described by the tree.

s → success in R & D

f → failure in R & D

r → reveal the information to the 2nd firm against a fee p_s.

nr → not reveal the information

D → firm 2 chooses to do R & D

ND → firm 2 chooses not to do any R & D

We also define the following pay–offs.

$\pi_i(\theta, \delta, \gamma)$ denotes the pay–off to the ith firm (i = 1, 2) when in the 1st stage of the game the outcome is θ(=s), subsequent to that the strategy adopted by firm 1 is δ(= r, nr) and following that the 2nd firm chooses γ(=D, ND). Similarly π_i (θ, γ) is defined for θ = f and γ. The pay–offs are calculated to be the following (See Figure –1)

$\pi_1(s, r, D) = \hat{\pi} + P_s - F$ (Follows from (A2))

$\pi_1(s, r, ND) = \hat{\pi} + P_s - F$

$\pi_2(s, r, D) = \hat{\pi} - p_s - F$ (Follows from (A2))

$\pi_2(s, r, ND) = \hat{\pi} - p_s$

π_1 (f, D) = –F

π_1(f, ND) = –F

$\pi_2(f, D) = p\pi_m + (1-p)\,\hat{\pi} - F$

π_2(f, ND) = 0

$\pi_1(s, nr, D) = p\hat{\pi} + (1-p)\,\pi_m - F$

$\pi_1(s, nr, ND) = \pi_m - F$

$\pi_2(s, nr, D) = p\hat{\pi} - F > 0$

π_2(s, nr, ND) = 0

Given we start from s, we end up with two Nash–equilibria with pay–offs.

$$[\pi_1 (s, nr, D), \pi_2 (s, nr, D)] \text{ and } \pi_1 (s, r, ND), \pi_2 (s, r, ND)]$$

Proposition 3 For $p\hat{\pi} > F > (1-p)(\pi_m - 2\hat{\pi})$, $\exists P_s > 0$ *such that (s, r, ND) is the unique subgame perfect equilibrium of the R & D game.*

Proof: Since $p\hat{\pi} > F$, if the technology transfer does not take place, then the follower must go for independent R & D leaving an expected pay–off π_1 (s, nr, D) to the first mover. The first will prefer to transfer if

$$\hat{\pi} + p_s - F > p\hat{\pi} + (1-p)\,\pi_m - F$$

or

$$p_s > (1-p)(\pi_m - \hat{\pi}) \tag{4}$$

Similarly for the transferee

$$\hat{\pi} - p_s > p\hat{\pi} - F$$

or

$$p_s < (1-p)\,\hat{\pi} + F. \tag{5}$$

From (4) and (5), for technology transfer to be feasible

$$F > (1-p)(\pi_m - 2\hat{\pi}) \tag{6}$$

What we show till now is that if firm 1 succeeds in R & D, it will share the knowledge with the 2nd firm and the 2nd firm refrains from doing further R & D provided the condition in the proposition holds.

Going one step back we now consider the possiblity of the failure of the first mover. In that case the equilibrium pay–off is –F. So the first mover actually goes for R & D if

$$p(\hat{\pi} + p_s - F) + (1-p)(-F) > 0 \tag{6}$$

or

$$\hat{\pi} + p_s > F/p. \tag{7}$$

If (7) holds then the first mover chooses to go for R & D and at the subsequent stage the unique nash eqm. is (s, r, ND). From A(1) inequality (7) follows directly. Hence (s, r, ND) is the unique subgame perfect equilibrium of the game. QED.

Note that if $F < (1-p)(\pi_m - 2\hat{\pi})$ then $\nexists$ $p_s > 0$ such that technology transfer will take place. So the subgame perfect equilibrium is (s, nr, D) and the pay–offs are $p\hat{\pi} + (1-p)\pi_m - F$ for the first firm and $p\hat{\pi} - F$ for the second firm. Also observe that for (s, r, ND) to be a subgame perfect equilibrium, p must assume a high enough value. This can be varified from the fact that:

$$p\hat{\pi} > (1-p)(\pi_m - 2\hat{\pi}) \text{ (for proposition (3) to be valid)}$$

or $$p\hat{\pi} > \pi_m(1-p) - 2(1-p)\hat{\pi}$$

or $$\hat{\pi}(2-p) > \pi_m(1-p)$$

or $$p > \frac{\pi_m - 2\hat{\pi}}{\pi_m - \hat{\pi}} = \tilde{p}. \tag{8}$$

While determining the licensing fee for sharing the information in the post – R & D stage, the firms are assumed to follow a bargaining process.

Let us define $\bar{P}_s$ as the maximum fee that can be extracted from the 2nd firm. Then following must be true:

$$\bar{P}_s = (1-p)\hat{\pi} + F \tag{9}$$

$\underline{P}_s$ is the minimum price that the 1st firm is willing to accept.

Therefore:

$$\underline{P}_s = (1-p)(\pi_m - \hat{\pi}) \tag{10}$$

We assume that the cooperative bargaining framework yields the bargained licensing fee

$$\frac{\bar{P}_s + \underline{P}_s}{2} = \hat{P}_s = \frac{(1-p)\ \hat{\pi} + F + (1-p)\ (\pi_m - \hat{\pi})}{2}$$

$$= \frac{F + (1-p)\ \pi_m}{2} \tag{11}$$

Therefore, the individual pay–offs can be reduced to the following,

$$\pi_1(s,\ r,\ ND) = \hat{\pi} + \frac{F + (1-p)\pi_m}{2} - F$$

$$= \frac{2\hat{\pi} + (1-p)\pi_m - F}{2} \tag{12}$$

$$\pi_2(s,\ r,\ ND) = \hat{\pi} - \frac{F + (1-p)\pi_m}{2} = \frac{2\hat{\pi} - (1-p)\pi_m - F}{2} \tag{13}$$

(12) is positive by direct verification form (A1). To show that (13) is positive, note that,

$\frac{2\hat{\pi} - (1-p)\ \pi_m - F}{2} + F - p\hat{\pi} > 0$ must imply (13) > 0 [from (A1)] which is nothing but, $\frac{F - (1-p)\ (\pi_m - 2\hat{\pi}) > 0}{2}$. Hence, (13) is positive. Also observe that $\pi_1(s,\ r,\ ND) > \pi_2(s,\ r,\ ND)$. There exists a first–mover advantage in such a game.

SECTION III Comparisons

In this section we compare among NCR, CR and DR.

a) NCR and DR

We know that $\pi_1\ (s,\ r,\ ND) > \pi_2(s,\ r,\ ND)$. Therefore DR will be preferred to NCR iff

$$\pi_2(s,\ r,\ ND) - p(1-p)\ \pi_m - p^2\hat{\pi} + F > 0$$

or,

$$\frac{2\hat{\pi} - (1-p)\ \pi_m - F}{2} - p(1-p)\ \pi_m\ p^2\hat{\pi} + F > 0$$

or $$\tfrac{1}{2}F > [p(1-p)\ \pi_m + \frac{1-p}{2}\ \pi_m + p^2\hat{\pi}-\hat{\pi}] = S.$$

Now, $S = S(p)$ with $S(0) = \frac{1}{2}\pi_m - \hat{\pi}$

Also $$S'(p) = \pi_m - 2p\pi_m - \tfrac{1}{2}\pi_m + 2p\hat{\pi}$$

or

$$S'(p) \gtrless 0 \text{ iff } p \gtrless \frac{\pi_m}{4(\pi_m - \hat{\pi})} \qquad (14)$$

Remember that $p > \tilde{p} = \dfrac{\pi_m - 2\hat{\pi}}{\pi_m - \hat{\pi}}$ for (s, r, ND) to be the subgame perfect equilibrium. As shown in figure 2, $\tilde{p}$ can be greater or less than $\dfrac{\pi_m}{4(\pi_m - \hat{\pi})}$.

But the following proposition is immediate.

<u>Proposition 4</u> <u>For relatively high values of p, DR is preferred to NCR.</u>

<u>Proof:</u> As shown in Figure 2, for values of $p > \hat{p}$ $\frac{1}{2}F > S$ and hence DR is preferred to NCR. QED[3].

b) <u>CR and NCR</u>

<u>Proposition 5</u> <u>For relatively high values of p, CR is preferred to NCR.</u>

<u>Proof:</u> See Marjit (1991).

c) <u>CR and DR.</u>

DR will be preferred to CR

iff $$p\hat{\pi} - \tfrac{1}{2}F < \frac{2\hat{\pi} - (1-p)\ \pi_m - F}{2}$$

$$p\hat{\pi} - \tfrac{1}{2}F < \hat{\pi} - \frac{1-p}{2}\ \pi_m - F/2$$

or,

$$p\hat{\pi} < \hat{\pi} - \frac{(1-p)}{2}\pi_m$$

or,

$$\frac{(1-p)}{2}\pi_m < \hat{\pi}(1-p)$$

or,

$$\frac{\pi_m}{2} < \hat{\pi} \text{ which is a contradiction.}$$

Hence the 2nd mover will prefer CR to DR. It remains to be seen whether the transferor prefers CR to DR.

$$\frac{2\hat{\pi} + (1-p)\pi_m}{2} - p\hat{\pi}$$

or

$$\hat{\pi}(1-p) + \frac{1-p}{2}\pi_m > 0.$$

Hence, the transferor prefers DR to CR.

Proposition 5 If side-payments are allowed, firms will prefer DR to CR.

Proof: To prove this one has to show that total surplus in DR is greater than that in CR.

Total pay-off in DR is

$$\frac{2\hat{\pi} - (1-p)\pi_m - F}{2} + \frac{2\hat{\pi} + (1-p)\pi_m - F}{2} = 2\hat{\pi} - F$$

Total pay-off in CR is

$$p\hat{\pi} + p\hat{\pi} - F = 2p\hat{\pi} - F$$

Since $0 < p < 1$, DR dominates CR. QED.

SECTION IV Conclusion

This paper has discussed three alternative forms of R & D organizations, non–cooperation, cooperation and delegation. The general message is that if probability of success is fairly high, chances are low that independent R & D will confer monopoly benefits. Hence, cooperative and delegative R & D tend to dominate non–cooperation in this case. When patent rights can not be protected, technology licensing through delegative R & D can be the most dominant form of organization.

As we have set up the model, if patent right is guaranteed, delegation can not arise as a form of joint–venture. Then the comparison between cooperation and non–cooperation reveals that relatively moderate chance of success or failure will lead to non–cooperation.

Footnotes

1 There is a little error in Marjit (1991). With very low probability of success no R & D is the only subgame perfect equilibrium. However, the major result of the paper continues to hold with such modification.

2 Gallini (1984) assumes that for the best technology, repetitive R & D is not profitable. Once one of the firms obtains the technology, the other gives up research. But without patent protection imitative R & D is possible and licensing can emerge just to negate the duplicating effect of imitative R & D.

3 This arrangement assumes importance where subsequent to the successful innovation by a firm, the other one can get the same technology and compete in the market. It might come through independent R & D or through imitation and there is no patent law to prevent the second mover from acheiving this.

4 Note that in figure 2 there is a zone with low p where DR is preferred to NCR. But the intercept of the s(p) function might be greater than or less than $\frac{F}{2}$. Hence, one can not say anything positive about the existence of such a zone. However, for P close to 1, a region such as BC will definitely be there for $F > 0$.

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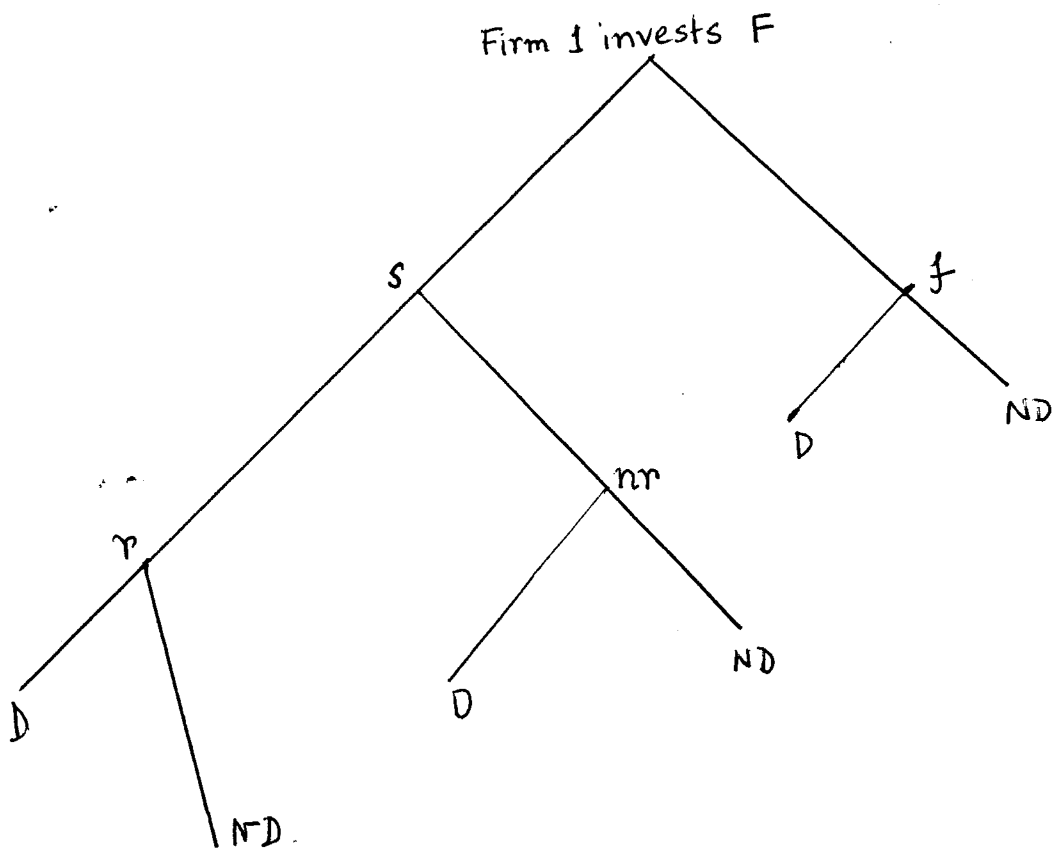
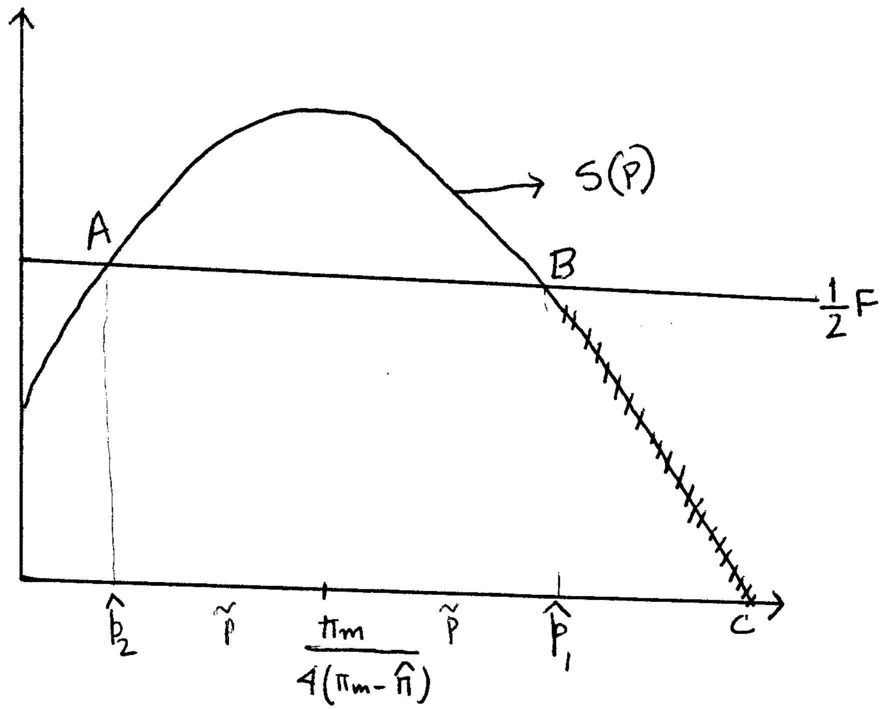


FIGURE-1



AB - Non-Cooperative zone
BC - Cooperative zone.

FIGURE-2.