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ABSTRACT

In a duopoly framework we show that among the set of firms competing with the technology leader, both relatively advanced and relatively backward firms will not be likely adopters of the superior technology. Instead the firms in the "middle" will invest for adopting the superior technology. This particularly characterizes the innovation characteristic of LDC markets where backward firms exist along with technological super-powers.

I. Introduction

Recent literature on the theory of industrial organization has focused extensively on patent races and the theory of innovations. Particular situations in which a monopolist incumbent and a potential entrant are locked in a *R* & D game, have been thoroughly discussed by authors such as Gilbert and Newbery (1982), Reinganum (1983), Tandon (1985) etc. A parallel literature on market structure and innovation has also been developed. Notable papers are by Loury (1979), Lee and Wilde (1980), Dasgupta and Stiglitz (1980).[1] The thrust of the latter theme has been to probe which type of market structure is conducive to innovations. These extremely rich papers have provided us with lucid analyses of realistic problems in a closed economy. As one goes through the existing work, one finds relatively fewer discussions on market structures we often come across in the less developed countries. In these countries we observe technologically far superior foreign firms coexisting with backward domestic firms operating backdated methods of production. It is often very hard for the advanced firm to block imitation and adoption by the local firms. In fact such imitations or adoptions are encouraged by the local governments. In this context *R* & D preempting technology licensing is an important issue. Gallini (1984) shows how sharing of patented knowledge might deter *R* & D of a potential entrant. As Tirole (1988) points out, there are very few papers which talk about technology licensing or patent-sharing when there is more than one existing firm in the market. In the 'incumbent-entrant' models, the entrant is assumed to be temporarily out of the market. Marjit (1989b) discusses a case where technology licensing takes place in a duopolistic framework and the behavior of joint Nash-Profits in the post licensing situation is studied. Gallini's (1984) structure incidentally has a cooperative outcome in the post-licensing situation. But a-priori there is no reason to believe that a collusive outcome will be necessarily sustained.

The purpose of this paper is to consider a situation where a LDC firm with a backdated technology faces an advanced foreign firm with a superior technology. However, the difference in initial technologies is such that the LDC firm can enjoy a positive (however small) market share in the initial Cournot-Nash equilibrium. We shall focus on the prospects of *R* & D by the latecomer, i.e., the LDC firm to adopt and/or imitate the technology of the foreign firm. We shall assume that the advanced firm has already reached a technological frontier and currently is not engaging in further *R* & D. This assumption is made to highlight the incentive to do *R* & D by the backward LDC firm. One intriguing question is which type of LDC firm is likely to have greater incentive to innovate, the one closer to the technology leader or the one further away from it. The answer to this question has some important implications with respect to the licensing literature. As Gallini (1984) points out that licensing might be induced by the threat of *R* & D, one has to know which type of a firm is more likely to pose a threat.[2]

II. The Model and its Assumptions

We shall consider a simple case with linear demand, constant marginal cost and uniform probability distribution of attaining any marginal cost in the range $[c_1, c_2]$ where c_1 is the best technology available and c_2 is the technology level of the LDC firm. If c is the attainable technology then $c \in [c_1, c_2]$ i.e., $c_1 \leq c \leq c_2$. The probability of achieving any c is given by $\left[\frac{1}{c_2 - c_1}\right]$. The demand function for the homogeneous good is given by $p = a - q$, where $a > 0$. The reduced form Cournot-Nash profit functions are given by π_1

(c_1, c_2) and $\pi_2(c_1,c_2)$, where $c_1 < c_2 < \left[\frac{a+c_1}{2}\right]$ so that $\pi_2(c_1, c_2) > 0$. The second firm has to invest an amount, F, as sunk *R* & D cost (say) to set up a research lab. However, the outcome is not certain. We assume that there is no relationship between *F* and attainable technology level. This is the cost one has to incur to enter into the *R* & D venture.

In a simple model we try to show that if *R* & D cost is reasonably high, only the "intermediate" firms, which are neither "too good" nor "too bad", are likely innovators. If the R & D cost is low, firms which are "too bad" can emerge as innovators but the better firms, close to the technology leader will not have any incentive to innovate. As we put forward the model, underlying intuitions behind such result will be clear.

The backward firm will innovate iff,

$$\left[\int_{c_1}^{c_2} \pi_2\ (c_1, c) \frac{1}{c_2 - c_1} dc - \pi_2\ (c_1, c_2)\right] > F \tag{1}$$

where $\pi_2\ (c_1, c)$ is the Cournot-Nash profits with a technology level c. Equation (1) can be rewritten as,

$$\left[\int_{c_1}^{c_2} [\pi_2\ (c_1, c) - \pi_2\ (c_1, c_2)] \frac{1}{c_2 - c_1} dc\right] \equiv R \tag{2}$$

The term in the bracket implies the profit gap at any c, given c_1 and c_2. We shall be interested in finding out the effect of a change in c_2 on R as defined in (2). With linear demand and constant marginal cost we get the following expressions,

$$\pi_2\ (c_1,c) = \frac{(a-2c+c_1)^2}{9}$$

$$\pi_2\ (c_1,c_2) = \frac{(a-2c_2+c_1)^2}{9}$$

Therefore,

$$\pi_2(c_1,c)-\pi_2(c_1,c_2) = \frac{4c^2-4ac-4cc_1-4c_2^2+4ac_2+4c_2c_1}{9}$$

Now by simplifying R we obtain,

$$R = \frac{4}{27}(c_1^2+c_1c_2+c_2^2)-\left[\frac{4(a+c_1)(c_2+c_1)}{18}\right]+\left[\frac{4ac_2+4c_1c_2-4c_2^2}{9}\right] \tag{3}$$

so that,

$$\left(\frac{dR}{dc_2}\right) = \frac{4}{27}\ (c_1+2c_2)-\left[\frac{2(a+c_1)}{9}\right]+\left[\frac{4a+4c_1-8c_2}{9}\right]$$

$$= \frac{6a+10c_1-16c_2}{27} \tag{3'}$$

It is quite obvious from (3') that, $\frac{dR}{dc_2} \gtreqless 0$ if $c_2 \lesseqgtr \frac{3a+5c_1}{8}$ (4)

Also note that $\left[\frac{3a+5c_1}{8}\right] < \left[\frac{a+c_1}{2}\right]$ as $(a-c_1) > 0$

For the case where $c_2 = c_1$, we obtain, $R = 0$ and for,

$c_2 = \left[\frac{a+c_1}{2}\right]$, we obtain $R = \left[\frac{(2c_1-2c_2)^2}{27}\right] > 0$

Note that R as a function of c_2 has been depicted in figure 1.

The behavior of R shows that if c_2 is extremely low, the incentive to do R & D is almost negligible. For $F > 0$, we can always find some c_2 very close to c_1, for which the latecomer will not have any incentive to innovate. For c_2 very high the initial market share of the latecomer is almost zero. In that case where $F < \left[\frac{(a-c_1)^2}{27}\right]$, even the worst firm will have net profit by engaging in R & D. We now have the following proposition.

Proposition

If $R\left[\frac{3a+5c_1}{8}\right] > F > R\left[\frac{a+c_1}{2}\right]$, *then* $[c_1,\tilde{c}_2] \equiv A_1$ *and* $\left[\hat{c}_2,\frac{a+c_1}{2}\right] \equiv A_2$ *such that for* $c_2 \epsilon A_1$, *or* $c_2 \epsilon A_2$, *there will be no R & D, where* $(\tilde{c}_2,\hat{c}_2)$ *solves* $R\ (c_2) = F$.

Proof: Since $0 < F < R\left[\frac{3a+5c_1}{8}\right]$, $\left(\frac{dR}{dc_2}\right) > 0$ for $c_1 < c_2\left[\frac{3a+5c_1}{8}\right]$ and $R\ (c_1) = 0$, some $c_2 = \tilde{c}_2$ for which $R(\tilde{c}_2) = F$ and for $c_1 \leq c_2 \leq \tilde{c}_2$, $R(c_2) \leq F$. Therefore, there is no incentive to innovate for $c_2 \epsilon A_1 \equiv [c_1,\tilde{c}_2]$.

Since $R\left(\frac{a+c_1}{2}\right) < F < R\left(\frac{3a+5c_1}{8}\right)$ and $\left(\frac{dR}{dc_2}\right) < 0$ for $\left[\frac{a+c_1}{8}\right] > c_2 > \left[\frac{3a+5c_1}{8}\right]$, some

$c_2 = \tilde{c}_2$ for which $R(c_2) = F$ and for $\left[\frac{a+c_1}{2}\right] > c_2 \geq \hat{c}_2$, $R(c_2) \leq F$. Therefore, there is no

incentive to innovate for $c_2 \epsilon A_2 \equiv \left[\hat{c}_2,\frac{a+c_1}{2}\right]$. QED.

Now it is obvious that for $c_2 \epsilon (\tilde{c}_2,\hat{c}_2)$ the latecomer will definitely innovate. This completes the proof that the firms in the middle are likely innovators. In fact the larger is

F, likely innovators tend to concentrate around $\left[\frac{3a+5c_1}{8}\right]$. If F is prohibitively large such that $F > R\left(\frac{3a+5c_1}{8}\right)$, there will not exist any innovative latecomer.

The intuition is fairly clear. Larger c_2 implies the "distance" that the latecomer can cover exante is longer and hence the difference between the maximum pay off and the existing pay off gets larger too. But probability weights attached to the pay offs also tends to get reduced. With uniform distribution, higher c_2 will imply positive equal weights to the low pay offs. On the other hand, pay offs with lower c_2 will get less weights now. Therefore, there is a "trade off" involved. For c_2 very low, prospective pay offs are themselves low. For c_2 very high, higher pay offs get very low weights. It is, therefore, likely that some interior c_2 should exist. In fact with Cournot-Nash equilibrium, cost-saving is more profitable for a firm with a larger market share. For firms with relatively poor technologies incremental profits are less.

III. A Generalization:

The "trade-off" discussed in the foregoing section is quite evident even with general reduced form profit functions.

$$\text{Let } \phi\ (c_2) = \int_{c_1}^{c_2} [\pi_2\ (c_1, c) - \pi_2\ (c_1, c_2)]dc \tag{5}$$

We suppress c_1 as our argument in the function ϕ (.) as c_1 is fixed in the analysis. The difference in [.] in (5) is a monotonically decreasing function of c_2 which takes the maximum value for $c = c_1$ and minimum value of zero for $c = c_2$.

This follows form the fact that $\left(\frac{\partial\pi_2}{\partial c}\right) < 0, \left(\frac{\partial\pi_2}{\partial c_2}\right) < 0$

This is obvious since $\left(\frac{\partial\phi}{\partial c_2}\right) > 0.$

$$\text{Now } R = \left[\frac{\phi(c_2)}{c_2 - c_1}\right] \tag{6}$$

and we have,

$$\left(\frac{dR}{dc_2}\right) \gtrless 0 \text{ if } \left(\frac{\partial\phi}{\partial c_2}\right) \gtrless \left[\frac{\phi(c_2)}{c_2 - c_1}\right]$$

$$\text{or } \left(\frac{\partial\phi}{\partial c_2}\right)\bullet\left(\frac{c_2}{\phi}\right) \gtrless \left[\frac{c_2}{c_2 - c_1}\right]$$

$$\text{or } \varepsilon_{\phi 2} \gtrless \left[\frac{c_2}{c_2 - c_1}\right] \tag{7}$$

Where $\varepsilon_{\phi 2} = \left[\frac{\partial\phi}{\partial c_2}\bullet\frac{c_2}{\phi}\right]$, note that even when the elasticity of $\phi(.)$ with respect to c_2 is greater than *1*, there is no guarantee that the incentive for R & D will tend to increase with c_2. Therefore, the possibility of the discussed "trade-off" is still present with general demand functions.

Once the basic intuition is understood, one can find out how sensitive the result is to changes in the probability distribution. Uniform distribution assigns equal probability to each c realizable in the range $[c_1, c_2]$. The result is sensitive to changes in distribution. For example, if one takes a degenerate distribution where probability of reaching c_1 is *1*, and "0" everywhere else, then $\left(\frac{dR}{dc_2}\right) > 0$ for all c_2. On the other hand if the distribution is such that with an increase in c_2 the weights assigned to lower values of c, decrease in rate, it is likely that with higher c_2 the incentive to do R & D will decrease rather than increase. However, such sensitivity does not necessarily make the result weak. There is no a priori reason to believe that a particular realization of c has a better chance to mature. With a uniform distribution we make every realization equally uncertain but a relatively backward firm starts with a handicap as it is staggered away from the technology frontier.

IV. Concluding Remarks

In this paper we have discussed incentive to do R & D for a latecomer in the technology race. Technology leader is kept passive and we focus only on the expected net revenue from R & D of a backward firm which enjoys a positive market share to start with and cannot expect to leap-frog its more formidable rival. On one hand this is a departure from the "incumbent-entrant" structure of the industrial organization literature where the R & D threat is coming from a potential entrant now outside the market. On the other, this tends to capture a large class of LDC markets where backward LDC firms coexist with a technological super-power and imitative and adoptive innovations are encouraged. The major results is that with a uniform distribution of technology outcomes and high sunk cost of R & D, neither "too good" nor "too bad" firms are likely innovators. The result becomes stronger with a larger sunk cost of R & D. Effort should be given in order to characterize the result with some general distributions. In the technology licensing literature this result is significant because it shows us which kind of weak rivals are likely to innovate and R & D preempting technology licensing should be geared towards them. For example, in Figure

1 firms having initial technologies between $\tilde{c}_2$ and $\hat{c}_2$ will have no further incentive to adopt provided they can get a technology between c_1 and $\tilde{c}_2$.

Footnotes

[1] Other works in this literature are by Nordhaus (1969), Reinganum (1982), Tandon (1982), Bhattacharya, Glazer and Sappington (1987).

[2] However, licensing might be induced even without the threat of *R* & D. For such an example see Marjit (1989 a). Licensing in a non-cooperative framework with the threat of *R* & D by the latecomer has been studied in Marjit (1989 b).

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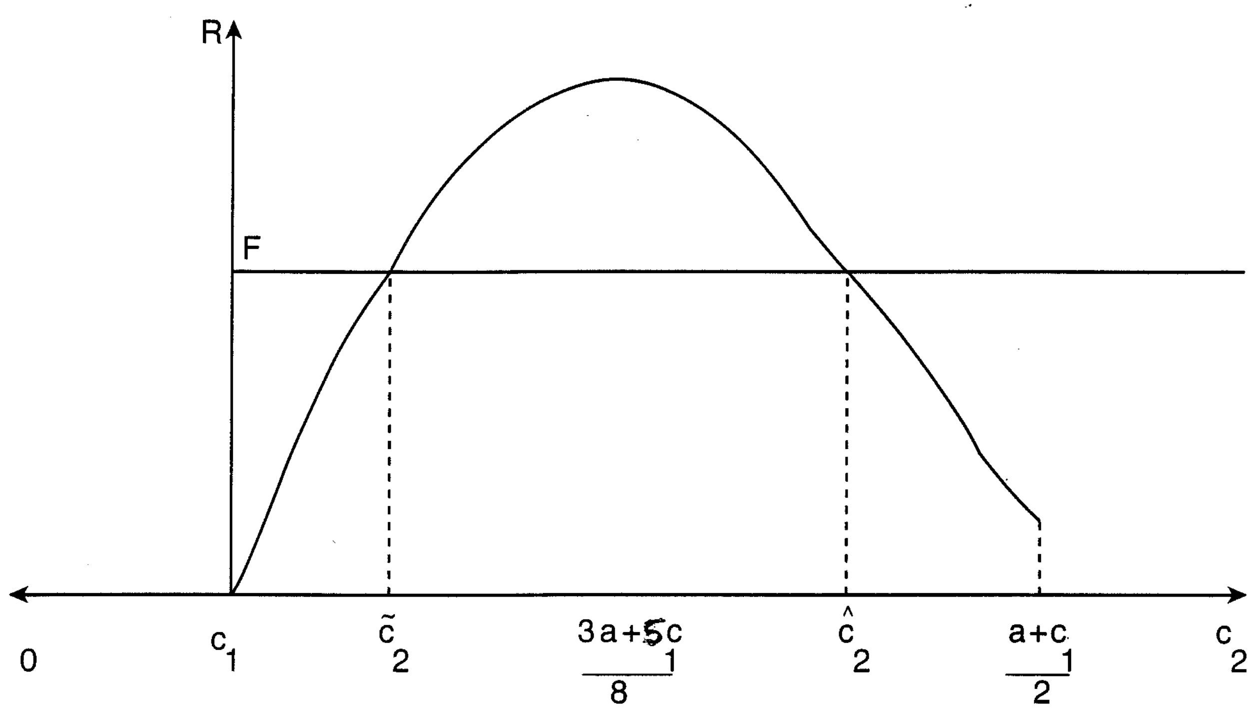

Figure 1