MARKET STRUCTURE AND DIFFUSION OF INNOVATION

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CERTIFICATE

This dissertation entitled **MARKET STRUCTURE AND DIFFUSION OF INNOVATION** submitted by SAMARPITA SETH in partial fulfilment for the M.Phil Degree of this University has not been previously submitted for any other degree of this or any other university and is her original work.

We recommend that the dissertation be placed before the examiners for evaluation.

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The responsibility of errors and omissions, if any, is solely mine.

(SAMARPITA SETH)

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Chapter-1

(Introduction and Literature Survey)

Introduction and Literature Survey

The importance of technological change and innovation in determining market structure and associated allocative efficiency was first highlighted by **Schumpeter** (1950) in his classic book **Capitalism, Socialism and Democracy**. Later on, **Solow** (1957) conducted a time series study of some American industries and concluded that a major part of the increase in industrial production was caused by technological change. Since then, economists have increasingly appreciated the economic significance of technological progress and it is now common to hear that a firm's, an industry's or even a nation's capacity to progress technologically underpins its long-run growth.

A large volume of literature deals with the issue of technology adoption and the associated costs and incentives for adoption. However, most of these studies employ a static formulation of innovation where a single innovation is either adopted instantly or never at all. But technical progress itself is a dynamic phenomenon associated with a sequence of multiple innovations. Different dimensions of such technology adoption, like timing of adoption, number of adoption etc., can be analysed only under a dynamic setup.

Among those few papers that deal with sequential technology adoption in a dynamic framework, the one proposed by **Mookherjee and Ray** (*Journal of Economic Theory 54*, 1991) is interesting. Here the authors analyse the nature of adoption of a sequence of n innovations in a duopoly market structure. In this thesis we examine some issues regarding sequential technology adoption. We simplify the model in **Mookherjee and Ray** (1991) and then use the simplified model to examine the impact of some additional issues on technology adoption viz. free entry, Stackelberg competition, substitutability and complementarity.

In the following section, we will review the related literature first and then analyse motivation and basic results.

LITERATURE SURVEY:

Schumpeter's (1950) discussion regarding the relation between firm size, market structure and innovation suggests that he was primarily concerned with the qualitative differences between innovative activities of small enterprises and those of large firms with formal R&D laboratories. However, empirical studies were conducted to verify **Schumpeterian** proposition from two angles: (i) relation between firm size and innovation (ii) relation between market structure and innovation.

The first group of papers interpreted the **Schumpeterian** (1950) idea of large firm's advantage in innovation as a proposition that innovative activity increases more than proportionately with firm size. Accordingly, the proposition was tested by regressing some measure of innovative activity on a measure of size. We briefly discuss some of these studies.

Galbraith (1952) and others provide several justifications of a positive effect of firm size on inventive activity. First, capital market imperfection confers an advantage of large firm in securing finance for risky R&D projects as large firms are assumed to have a stable internally generated fund. Second, there are returns from R&D function itself. Third, returns from R&D are higher where the innovator has a larger volume of sales over which fixed cost of innovation can be spread. Particularly, R&D is seen to be more productive in large firms as a result of complementarities between R&D and other activities like marketing, financial planning etc. which can better be developed in large firms. Lastly, diversified firms provide economies of scope and reduce risks associated with prospective returns to innovation.

Counter-arguments to this proposition were provided by **Sherer and Ross** (1990). First, as firms grow large, efficiency in R&D is undermined through excessive bureaucratic control. Second, as firms grow large, incentives of individual entrepreneurs may be reduced due to diminishing expectation to capture benefits from their individual efforts.

Over past few decades, empirical studies on the relationship between firm size and innovation have generated a number of robust empirical findings. One among them is that R&D increases more than proportionately up to a threshold size of firm, beyond which the relationship becomes proportional (**Scherer** (1965a, 1965b) et. al.). However, the finding is subject to several limitations. First, the relation between R&D and firm size is seen to depend upon a number of industry characteristics like cash flow, degree of diversification, complementary capabilities etc. And these are correlated with the firm size. So the findings regarding the relation between firm size and innovation are somewhere proportional, somewhere more than proportional and somewhere U-shaped depending upon how they control industry characteristics.

Secondly, firm size and business unit size should be differentiated. Studies by **Scott** (1984), **Cohen et al.** (1987), **Cohen & Klepper** (1994) and others found that, it is the size of business unit rather than that of firm as a whole that accounts for the close relationship between firm size and R&D. Thirdly, as **Fisher and Temin** (1973) suggest, the **Schumpeterian** (1950) hypothesis should be tested as a relationship between an innovative output and firm size and not between R&D (which is an innovative input) and firm size. **Kamien & Schwartz** (1970) also supported this view.

Another robust finding regarding firm size–innovation relation is that, R&D productivity tends to decline with size (**Bound et al.** (1984), **Acs and Audretsch** (1987, 1990, 1991), **Pavitt et al**. (1987) and others).

Recently **Cohen and Klepper** (1994) proposed that the findings of proportional or positive relationship between R&D and firm size and that of declining R&D productivity with firm size could be reconciled in the following way. First, to reap the returns to their innovations firms typically rely on the appropriability condition, which require them to exploit their innovation through their own output. Secondly, firms expect that their growth due to innovation will be limited by their existing size. These two conditions together suggest that, larger the output of the business unit, more the scope to spread the fixed cost of innovation. Consequently, larger business unit yields a higher return per unit of R&D expenditure. Now, if small and large firms face the same diminishing R&D schedule, larger firm will also realize lower innovative output per unit of R&D expenditure. Since it earns higher return per unit of R&D expenditure, it will reduce its R&D activity compared to that of small firms and thus be subject to lower average R&D productivity. Here lower R&D productivity does not reflect a large firm's disadvantage; rather it reflects large firm's superior ability to reap same profit from a lower R&D expenditure due to cost spreading advantage.

The second group of empirical literature on **Schumpeterian** (1950) hypothesis searched the impact of monopoly power on innovation. **Schumpeter's** (1950) discussion reveals that both ex-ante as well as ex-post market power provide incentive to innovation. Expectation of ex-post market power enables the firm to invest in R&D. Again; ex-ante market power helps to reduce the uncertainty associated with excessive rivalry, which undermines incentive to innovate. Further, profit derived from ex-ante market power provides internal financial resources necessary to invest in innovative activity.

The empirical literature, focussing principally on the effect of market concentration on innovative behavior of the firms yields some ambiguous results. Sometimes the effect is positive, sometimes negative and again sometimes relation is seen to be inverted-U shaped. **Phillips** (1966) argued that, causality might run from innovation to market structure instead. Theoretical support for this relation was found in the simulation model of **Nelson &Winter** (1978, 1982). On the other hand, presence of long-lived capital and costly adjustment by firms in the short run can explain the causality of innovation to concentration better. Lastly, according to **Comanor** (1967), the relation between market concentration and innovation is seen to depend upon a number of industry characteristics like industrial opportunity and appropriability conditions (e.g. product differentiation, technological and market uncertainty, industry's stage in product life cycle etc.). Understanding exactly how such characteristics may affect the bivariate

relation between concentration and innovative activity depends on the study of dynamic relationship among innovation entry and market structure.
This is so far as the empirical literature is concerned.

Another set of studies is devoted to explain the cases of technology spillover and diffusion in terms of theoretical models. **Nabaseth and Ray** (1974) and **Rogers** (1983) reports that some firms learn about new technology a decade ahead of others. They introduced cost of imitation and framed models to show a gradual learning-in-equilibrium along with a non-degenerate distribution of technical knowledge among firms in an industry.

In product life cycle models, spillover effect of technology is marked out as an important cause why product varieties tend to converge as an industry matures. Vast literature on product differentiation surveyed by **Anderson et al**. (1992) shows that Cournot competition leads to more similar products while Bertrand competition favours increased differentiation over time. **Duranton** (2000) framed models to show that if spillover effect is strong firms tend to locate closer to one another and there is progressive rise of homogeneity over heterogeneity.

Market size is introduced as a significant factor in product innovation by **Klepper** (1996). He takes as his starting point positive correlation between industry concentration ratio and mean firm profitability from innovation. Average and marginal cost reduction from new technology occurs in proportion to the size of firm output. Thus size begets size and entry is closed.

In the context of a competitive industry, **Jovanovic and Macdonald** (1994) introduced the diffusion caused by technological inequality among firms. Ultimately, innovation and imitation tend to be close substitutes and leaders who have already acquired better technology have less incentive to work for even better. This causes partial convergence of technology and output overtime.

Positive externality effect of spillover and diffusion has been established in almost all studies. **d' Aspremont and Jackquemin** (1988) framed game theoretic models to compare cooperative and non-cooperative behaviour among duopolists. If there is cooperation in R&D duplication and wasteful expenses can be avoided increasing producer's surplus but consumer surplus is reduced because of monopoly output and pricing outcome. Non-cooperation on the other hand, would reduce producer's surplus but increase consumer's surplus. If spillover effect is very strong, cooperative behaviour is socially more efficient.

Theoretical studies of Schumpeterian proposition are provided by **Arrow** (1962), **Libenstein** (1966), **Dasgupta and Stiglitz** (1980), **Loury** (1979), **Kamien and Schwartz** (1972, 1982), **Spence** (1984) and others.

Arrow (1962) in his pioneering paper explored that the same process innovation (which reduces marginal cost by a specified amount) will generate different extent of gains to the innovator depending on the nature of market structure (and associated product pricing). It was shown that net profit earned from the same technology would be highest under socially managed industry followed by competitive industry, which is again followed by monopolistic industry. So, he concluded that incentive to innovate is highest in socially managed industry and least in monopoly.

The **Dasgupta-Stiglitz** (1980) model made both market structure and innovative activity endogenous depending on basic elements like technology of research, demand conditions, nature of capital market etc. and tried to evaluate the Arrow's proposition. It was shown that given endogeneity of market structure, output produced under oligopoly with free entry and/or with entry barrier is less than that of socially optimal level while market economy spends too much on R&D in the form of duplication of technology compared to the socially optimal level.

The model proposed by **Loury** (1979) examined the impact of different market structure on R&D performance at both firm level and industry level under technological and market uncertainty. Major conclusions are as follows: (i) equilibrium level of firm investment declines with increase in number of firm in the industry. (ii) when increase in R&D investment of a single firm causes investments of others to decline, an increase in number of competitors in an industry leads to earlier expected date of introduction of innovation.(iii) if innovation technology is subject to diminishing returns increase in number of firms drives down the expected industry profit to zero in the limit. (iv) long run industry equilibrium with initial increasing returns and zero expected profit involve excess capacity in R&D technology.

Spence (1984) on the other hand, showed that increase in spillover will not only decrease incentive to spend on R&D and amount of equilibrium cost reduction, it will also reduce the R&D cost required for a given amount of cost reduction. So, if the incentive can be restored through subsidies then it is possible to get a range of values of spillover and concentration ratio where firm performs better as compared to without subsidy situation.

Again, **Kamien & Schwartz** (1972) analyzed the introduction decision of innovation by a firm under different rivalry structure, when there is first mover's advantage of innovation. It was shown that when hazard rate (probability of instantaneous adoption of innovation by rival) is less than the growth rate of reward from innovation, adoption date of firm under rivalry may preceed or succeeds that of non-rivalrous situation. But when hazard rate exceeds the expected growth rate of gain from innovation, firm will defer the adoption date to infinity. Further, under perfect competition with absence of rivalry, instant imitation and very small share of reward to the firm from innovation, it is not worthwhile to introduce the innovation at all.

Further, **Reinganum** (1985) concerned with the fact that at the time of adoption, firm will consider both gain as well as cost of adoption. If market is monopolized, firm will defer the introduction date and wait for adoption cost to fall until gain from innovation exactly matches the cost of innovation. But when market is not monopolized and entry is free, risk of deferring the adoption date is that rival may introduce the innovation earlier and take the first mover's advantage. So, there will be preemptive adoption implying that firm will adopt the technology earlier compared to what it would do if adoption date of rival would have been fixed. **Reinganum** (1985) model showed that if firms were identical ex-ante, it is impossible to identify which firm will take which adoption rank and there will be as many pre-commitment equilibrium as the number of firms.

Thus the central issue of the literature dealing with the incentive and cost of adoption of any innovation is the contradiction between static allocative efficiency subsequent to innovation and dynamic incentive for innovation ex-ante. Static efficiency claims that due to appropriability problem and spillover of any technology, surplus generated from an innovation cannot be reaped fully by the innovator. So in the long run it may be more important to create ex-ante innovation incentives at the cost of restricting diffusion ex-post as proposed by **Schumpeter** (1950). This is, in fact, the inherent logic behind patent protection and restriction of competitive pressure in industries having high potential for technological progress.

However, the concept of dynamic innovation incentive suggests that an increase in diffusion enable the follower to catch up faster and thereby creates an incentive to the leader firm to adopt the next innovation earlier. So competition acts as a stimulant to the industries with high potential for innovation as proposed by **Libenstein** (1966). Even **Schumpeterian** (1950) theory of capitalist development also emphasized the cyclical nature of innovation process where successive cycles are associated with different innovation and diffusion.

This contradiction regarding the effect of competitive pressure on the innovation incentives is finely sketched in **Mookherjee and Ray** (1991). In terms of a dynamic set up they analysed different dimensions of adoption of innovations. Lastly, they showed that nature of competition determines the nature of adoption. Under quantity competition, competitive pressure discourages innovation incentive (**Leibenstein** (1966)) while it enhances incentive under price competition (**Schumpeter** (1950)). However, the causality runs in the opposite direction.

In this way the debate between **Schumpeterian** (1950) and **Leibensteinian** (1966) proposition regarding the incentives for innovation has become a long-standing issue which is giving birth of a huge literature on the multi-dimensional aspects of technical progress till to date.

MOTIVATION and RESULTS:

The model proposed by **Mookherjee and Ray** (1991) starts with a single dominant firm (called the leader) facing a "competitive fringe" that is represented by a single firm (called the follower). Only the leader firm has access to a sequence of n process innovations denoted by 1,2,3,....,n to be adopted in the given order. However, two consecutive innovations can be adopted simultaneously also. Adoption of each innovation instantly reduces the leader's unit cost. Further, each adoption involves a fixed cost to be incurred by the leader firm only at the time of adoption.

The follower firm does not have access to innovation. Instead, it gradually imitates the innovation adopted by the leader. Imitation is costless. With diffusion, the follower's unit cost drifts down overtime approaching towards that of the leader. Rate of diffusion is parametrically given.

Further, two firms compete in a duopoly market with homogeneous product where aggregate demand curve is downward sloping. Under quantity competition, it is assumed that a unique Cournot-Nash equilibrium is attained. Under price competition, it is assumed that the follower's unit cost can not exceed the monopoly price charged by the leader. Here the leader firm limits the price of the follower. Therefore, the follower firm becomes a potential competitor only.

The basic propositions of the model that will be analyzed in our study are two:

First, under quantity competition, it is optimal for the leader to adopt the available technologies either instantly or never at all. Thus the available innovations will be adopted in a bunched manner at the beginning of quantity competition, if the leader decides to adopt them at all. Clearly, Leibensteinian "stick" is visible under quantity competition. But under price competition, the existing innovations might be adopted in a staggered manner in the sense that adoption of each innovation is followed by a period of diffusion. Thus industry might show alternate cycles of innovation and diffusion. Clearly, price competition reveals the cyclical nature of innovation as proposed by **Schumpeter** (1950).

Second, an increase in diffusion rate encourages innovation under price competition but it frustrates innovative incentive under quantity competition. Since under quantity competition innovation is encouraged by relative absence of competitive pressure, the leader firm adopts the available innovations at the beginning of the competition, if the innovations are to be adopted at all. After a period of early dominance, the leader faces competitive pressure as diffusion of the existing innovation reduces the follower's unit cost gradually approaching to the leader's one. This in turn discourages the leader's incentive to innovate. So an increase in diffusion rate erodes the leader's incentive faster in this case.

On the other hand, competition encourages innovation under price competition. Here after each adoption, the leader waits until the diffusion of the existing innovation makes the follower's cost closer the to the leader's one. Therefore, an increase in diffusion rate helps the follower's unit cost to catch up faster the leader's one. This in turn creates a competitive pressure to the leader to adopt the next innovation faster.

In the present work, we will re-examine the basic propositions under alternative variants of market forms based upon the nature of product market competition, the type of competition faced by the firms and the nature of substitutability of the goods produced by the competing firms in terms of a simple dynamic framework. We will use a game-theoretic approach in deriving these results. The basic solution concept will be that of Nash equilibrium and some concepts from dynamic programming.

Chapter 2 is devoted to the simplification of the basic model. The basic purpose behind it is to examine the basic propositions under this simplified framework. If the basic results remain unchanged, then this simplified framework will facilitate in introducing additional issues to the basic structure.

Simplification of the basic model is done in the following way:

(i) The sequence of n innovations is replaced by two innovation viz. T_1 and T_2.
(ii) The aggregate demand curve and cost curves faced by the two firms are made linear.

In Chapter 3 we re-examine the basic quantity competition result by introducing free entry under Cournot competition. The basic purpose is to verify the conjecture proposed by **Mookherjee and Ray** (1991) that the crucial characteristic distinguishing their two models of product market competition is actual versus potential competition rather than the strategic variable (price or quantity) chosen. However, it is found that the threat of potential competition under free entry does not change the adoption behaviour of the leader firm. Like the Cournot competition with an exogenously given number of firms, bunching of innovations takes place here also.

In Chapter 4 the basic adoption behaviour of the leader firm is examined when the nature of competition is of the Stackleberg type. Again, it is found that the basic adoption behaviour of the leader firm under Cournot competition remains unchanged even if it is replaced by the Stackleberg competition.

In Chapter 5 product differentiation under quantity competition is introduced. The basic purpose behind it is to examine how the adoption behaviour of the leader firm alters when the competing firms produce differentiated products. It is found that bunching of innovations takes place when the goods produced by the firms are substitutes. However, when the goods are complements, the possibility of staggered adoption might arise. Thus under quantity competition with complements, the adoption behaviour of the leader firm will be similar to that under price competition with homogeneous goods.

Chapter 6 is devoted to conclusion that summarises all the derived results.

Chapter-2

(The Basic Model)

The Basic Model

In this chapter the basic model proposed by **Mookherjee and Ray** (*Journal of Economic Theory 54*, 1991) will be discussed first. Then we will try to re-examine the basic proposition of the model in a simplified framework. This simplification of the basic model will help us to discuss additional issues later on.

The basic model starts with the following assumptions: -

(i) There is a single dominant firm (called the leader) facing a "competitive fringe" represented by a single firm (called the follower). Only the leader firm has access to a set of n process innovations denoted by 1,2,3,...., n to be adopted in the given order. However, two consecutive innovations can be adopted simultaneously also.

(ii) Both firms have constant marginal costs. The leader's marginal cost is c and the follower's marginal cost is r where $0 < c < r$.

(iii) Adoption of the k^{th} innovation instantly reduces the leader's unit cost from c^{k-1} to c^k, where $k = 1,2,3,\ldots,n$. Further, adoption of the k^{th} innovation involves a fixed cost X_k to be incurred by the leader.

(iv) The follower firm does not have access to anyone of the innovations. Rather, it imitates the technology adopted by the leader. Imitation is costless. But it allows the unit cost of the follower to drift down over time, approaching to the leader's current cost at some exogenous rate. Let us define c^k as the unit cost of the leader after adoption of the k^{th} innovation ($k = 1,2,3,\ldots,n$) and r^k, the corresponding unit cost of the follower. Then the diffusion process can be represented by the following equation:

$$r^k = e^{-\lambda t}(r - c^k) + c^k, \quad r^k > c^k \forall k$$

where $k = 1,2,3,\ldots\ldots,n$. λ is the constant rate of diffusion.

(iv) The two firms compete in a duopoly market with homogeneous product where the aggregate demand curve is $D(p)$ with $D'(p) < 0$, $D''(p) \leq 0$.

(v) Under quantity competition, it is assumed that a unique Cournot-Nash equilibrium is attained. Under price competition, it is assumed that the follower's unit cost can not exceed the leader's monopoly price at any instant of time. Here the leader firm limits the price of the follower and the latter becomes a potential competitor only.

Mookherjee and Ray (1991) demonstrated some interesting results in the basic model. These are:

(a) Under quantity competition, it is optimal for the leader to adopt the available innovations instantly and simultaneously if the innovations are to be adopted at all.

(b) Under price competition, innovations might be adopted in a staggered manner where each adoption is followed by a period of diffusion.

(c) An increase in the diffusion rate enhances the incentive to innovate under price competition, but it discourages innovation under quantity competition.

We now replicate the basic results in a simplified framework. This simplification is done with the following assumptions:

(a) There are only two technologies viz. T_1 and T_2 available to the leader firm.

(b) The aggregate demand curve is linear: $p = a - q$ where $q = q_1 + q_2$.

(c) Both firms have linear cost curves. The initial unit cost of the follower is r^0, while that of the leader is c^0. It is assumed that $r^0 > c^0$. Further, the diffusion process described in the basic model remains unchanged.

QUANTITY COMPETITION:

Under quantity competition, firms choose their output simultaneously. So with the aggregate demand function $p = a - q$ and cost functions cq_1 and rq_2 for firm 1 and firm 2 respectively, the instantaneous profit of the leader is given by

$$L(r,c) = \tfrac{1}{9}[a - 2c + r]^2.$$

We then solve the model using a backward induction logic. First, consider the case where T_1 has already been adopted. The leader is considering whether to adopt T_2 or not.

Note that, if T_2 is not adopted, the leader's expected discounted profit is given by

$$\int_0^\infty e^{-\rho t} L(r_t^1, c^1)dt, \text{ where}$$

$$r_t^1 = e^{-\lambda t}(r - c^1) + c^1.$$

Whereas if T_2 is adopted, the discounted profit of the leader is

$$\int_0^\infty e^{-\rho t} L(r_t^2, c^2)dt - X_2, \text{ where}$$

$$r_t^2 = e^{-\lambda t}(r - c^2) + c^2.$$

So the net discounted gain from adoption of T_2 :

$$E(r) = \int_0^\infty e^{-\rho t}[L(r_t^2, c^2) - L(r_t^1, c^1)]dt - X_2. \tag{1}$$

Clearly, if $E(r) > 0$, it will imply that T_2 will be adopted. Note that

$$E'(r) = \int_0^{\infty} e^{-\rho t}[L_r(r_t^2, c^2) - L_r(r^1, c^1)]dt. \tag{2}$$

To prove that $E'(r) > 0$, we have to show that

$$[L_r(r_t^2, c^2) - L_r(r_t^1, c^1)] > 0.$$

Now, $L(r_t^2, c^2) = \frac{1}{9}(a - 2c^2 + r_t^2)^2$

$$= \tfrac{1}{9}[a - 2c^2 + e^{-\lambda t}(r - c^2) + c^2]^2$$

$$= \tfrac{1}{9}[a - c^2 + e^{-\lambda t}(r - c^2)]^2.$$

Therefore, $L_r(r_t^2, c^2) = \frac{2}{9}[a - c^2 + e^{-\lambda t}(r - c^2)]e^{-\lambda t}$.

Similarly, $L(r_t^1, c^1) = \frac{1}{9}[a - c^1 + e^{-\lambda t}(r - c^1)]^2$.

$$L_r(r_t^1, c^1) = \tfrac{2}{9}[a - c^1 + e^{-\lambda t}(r - c^1)]e^{-\lambda t}.$$

Therefore, $L_r(r_t^2, c^2) - L_r(r_t^1, c^1) = \frac{2}{9}e^{-\lambda t}[(c^1 - c^2)(1 + e^{-\lambda t})] > 0,$ (3)

as $e^{-\lambda t} > 0$, and $c^1 > c^2$ by assumption.

Therefore, $E'(r) = \int_0^{\infty} e^{-\rho t}[L_r(r_t^2, c^2) - L_r(r_t^1, c^1)]dt > 0$

implying that, a reduction in the follower's cost due to diffusion reduces the leader's incentive to innovate. Hence, the leader firm will be willing to adopt T_2 instantly or never at all.

In this connection, we should mention that as $E(r)$ is decreasing with time, it is quite possible that $E(r) > 0$ at $t = 0$, but $E(r) < 0$ at $t = t^*$ where t^* is high. In this case the analysis will be same as the previous case.

We then solve for the optimal adoption decision of T_1. First consider the case where, following the adoption of T_1, T_2 is never adopted (i.e., where $E(r) < 0$ at $t = 0$). Here firm 1's decision is regarding adoption of T_1.

If T_1 is not adopted, costs are at the pre-innovation level c^0, r^0.

So the discounted profit of the leader is given by

$$\int_0^\infty e^{-\rho t} L(r_t^0, c^0)dt, \text{ where}$$

$$r_t^0 = e^{-\lambda t}(r^0 - c^0) + c^0.$$

If T_1 is adopted, the leader's discounted profit is

$$\int_0^\infty e^{-\rho t} L(r_t^1, c^1)dt - X_1, \text{ where}$$

$$r_t^1 = e^{-\lambda t}(r^0 - c^1) + c^1.$$

So the net discounted gain of the leader from adoption of T_1*

$$E(r) = \int_0^\infty e^{-\rho t}[L(r_t^1, c^1) - L(r_t^0, c^0)]dt - X_1. \tag{4}$$

* Use of the notation $E(r)$ is not very precise, but what is meant should be clear from the context.

Clearly, if $E(r) > 0$, it will imply that T_1 will be adopted.

$$\text{Therefore, } E'(r) = \int_0^\infty e^{-\rho t}[L_r(r_t^1, c^1) - L_r(r_t^0, c^0)]dt. \tag{5}$$

$$\text{Recall that, } L(r_t^1, c^1) = \tfrac{1}{9}[a - 2c^1 + r_t^1]^2$$

$$= \tfrac{1}{9}[a - c^1 + e^{-\lambda t}(r^0 - c^1)]^2.$$

$$\text{Therefore, } L_r(r_t^1, c^1) = \tfrac{2}{9}[a - c^1 + e^{-\lambda t}(r^0 - c^1)]e^{-\lambda t}.$$

$$\text{Similarly, } L_r(r_t^0, c^0) = \tfrac{2}{9}[a - c^0 + e^{-\lambda t}(r^0 - c^0)]e^{-\lambda t}.$$

Therefore, $L_r(r_t^1, c^1) - L_r(r_t^0, c^0) = \tfrac{2}{9}e^{-\lambda t}[(c^0 - c^1)(1 + e^{-\lambda t})] > 0$ as $c^0 > c^1$ and $e^{-\lambda t} > 0$.

$$\text{Therefore, } E'(r) = \int_0^\infty e^{-\rho t}[L_r(r_t^1, c^1) - L_r(r_t^0, c^0)]dt > 0,$$

implying that firm 1 will introduce the technology T_1 as soon as possible, or not at all.

Next consider the case where, following the adoption of T_1, T_2 is instantly adopted (i.e., $E(r) > 0$ at $t = 0$). Here firm 1's decision is whether to adopt T_1 or not. Because, T_2 is adopted only when T_1 is adopted. In case of not adoption of T_1, the leader's discounted profit:

$$\int_0^\infty e^{-\rho t} L(r_t^0, c^0)dt, \text{ where}$$

$$r_t^0 = e^{-\lambda t}(r^0 - c^0) + c^0.$$

In case of adoption of T_1, the leader's discounted profit

$$\int_0^\infty e^{-\rho t} L(r_t^2, c^2)dt - X_1 - X_2, \text{ where}$$

$$r_t^2 = e^{-\lambda t}(r^0 - c^2) + c^2.$$

Therefore, the net discounted gain from adoption of T_1 (and hence T_2)

$$E(r) = \int_0^\infty e^{-\rho t}[L(r_t^2, c^2) - L(r_t^0, c^0)]dt - X_1 - X_2 . \tag{6}$$

Now, if $E(r) > 0$ it will imply that both T_1 and T_2 will be adopted instantly.

$$\text{Note that, } E'(r) = \int_0^\infty e^{-\rho t}[L_r(r_t^2, c^2) - L(r_t^0, c^0)]dt. \tag{7}$$

$$\text{Now, } L(r_t^2, c^2) = \tfrac{1}{9}[a - c^2 + e^{-\lambda t}(r^0 - c^2)]^2.$$

$$\text{Therefore, } L_r(r_t^2, c^2) = \tfrac{2}{9}[a - c^2 + e^{-\lambda t}(r^0 - c^2)]e^{-\lambda t}.$$

$$\text{Similarly, } L_r(r_t^0, c^0) = \tfrac{2}{9}[a - c^0 + e^{-\lambda t}(r^0 - c^0)]e^{-\lambda t}.$$

Therefore, $L_r(r_t^2, c^2) - L_r(r_t^0, c^0) = \tfrac{2}{9}e^{-\lambda t}[(c^0 - c^2)(1 + e^{-\lambda t})] > 0$ as $c^0 > c^2$ and $e^{-\lambda t} > 0$.

$$\text{Therefore, } E'(r) = \int_0^\infty e^{-\rho t}[L_r(r_t^2, c^2) - L_r(r_t^0, c^0)]dt > 0$$

implying that T_1 and T_2 will be adopted instantly.

Thus, under quantity competition, it is optimal for the leader to adopt the innovations instantly, if they are to be adopted at all. Therefore, the leader will bunch up the innovations and adopt them at the very beginning of competition. Here, competition acts as a "stick" in the **Leibensteinian** sense as innovations are adopted in a bunched manner.

PRICE COMPETITION:

Under price competition, the leader firm practices limit pricing. This in turn implies that, the follower's marginal cost can not exceed the monopoly price charged by the leader at any instant of time i.e., $r_t \leq p_m(c_t)\ \forall\ t$. Since the goods produced by two firms are homogenous, price competition is characterised by absence of any market share of the follower firm. Here the follower firm becomes a potential competitor only.

Under the cost configuration (r, c) the instantaneous profit of the leader is

$$L(r, c) = (p - c)(a - p) = (r - c)(a - r).$$

The interesting result under price competition is the possibility of staggered adoption when one adoption is followed by a period of diffusion. In this way, the **Schumpeterian** "cycle" goes on.

We then demonstrate the possibility of phased adoption in our simplified framework. Consider the case where technology T_1 has already been adopted. The leader firm is considering whether to adopt T_2 or not. The net gain from adoption of T_2 is

$$E(r) = \int_0^\infty e^{-\rho t}\{L(r_t^2, c^2) - L(r_t^1, c^1)\}dt - X_2, \tag{8}$$

where $r_t^1 = e^{-\lambda t}(r^0 - c^1) + c^1$,

and $r_t^2 = e^{-\lambda t}(r^0 - c^2) + c^2$.

Clearly, $L(r_t^2, c^2) = (a - r_t^2)(r_t^2 - c^2)$

$$= e^{-\lambda t}(r^0 - c^2)(a - c^2) - e^{-2\lambda t}(r^0 - c^2)^2. \qquad (9)$$

Similarly, $L(r_t^1, c^1) = (a - r_t^1)(r_t^1 - c^1)$

$$= e^{-\lambda t}(a - c^1)(r^0 - c^1) - e^{-2\lambda t}(r^0 - c^1)^2. \qquad (10)$$

Substituting equations (9) and (10) in equation (8) we get

$$E(r) = \int_0^\infty e^{-\rho t}[e^{-\lambda t}\{(r^0 - c^2)(a - c^2) - (r^0 - c^1)(a - c^1)\} - e^{-2\lambda t}\{(r^0 - c^2)^2 - (r^0 - c^1)^2\}]dt - X_2.$$

Therefore, $E'(r) = \int_0^\infty e^{-\rho t}[e^{-\lambda t}\{(a - c^2) - (a - c^1)\} - e^{-2\lambda t}\{2(r^0 - c^2) - 2(r^0 - c^1)\}]dt$

$$= \int_0^\infty e^{-\rho t}[e^{-\lambda t}(c^1 - c^2) - 2e^{-\lambda t}(c^1 - c^2)]dt$$

$$= \int_0^\infty e^{-(\rho+\lambda)t}\{(c^1 - c^2)(1 - 2e^{-\lambda t})\}dt.$$

Since $e^{-(\rho+\lambda)t} > 0,\ c^1 > c^2$ and $2e^{-\lambda t}\begin{Bmatrix} > \\ < \end{Bmatrix} 1, \quad \therefore E'(r)\begin{Bmatrix} > \\ < \end{Bmatrix} 0.$ (11)

Condition in (11) implies a possibility of staggered adoption of T_2 under $E'(r) < 0$.

We then specify some conditions under which T_2 is actually adopted in a staggered manner. Now, $E(r)$ at $t = 0$ is given by

$$[E(r)]_{r=r^0} = \int_0^{\infty} e^{-(\rho+\lambda)t}[(c^1 - c^2)(a + r^0 - c^1 - c^2) - e^{-\lambda t}(c^1 - c^2)(2r^0 - c^1 - c^2)]dt - X_2$$

$$= (c^1 - c^2)(a + r^0 - c^1 - c^2)\int_0^{\infty} e^{-(\rho+\lambda)t}dt - (c^1 - c^2)(2r^0 - c^1 - c^2)\int_0^{\infty} e^{-(\rho+2\lambda)t}dt - X_2$$

$$= \frac{(c^1 - c^2)(a + r^0 - c^1 - c^2)}{\rho + \lambda} - \frac{(c^1 - c^2)(2r^0 - c^1 - c^2)}{\rho + 2\lambda} - X_2.$$

Therefore, $[E(r)]_{r=r^0} < 0$ at $t = 0$ if

$$\frac{(c^1 - c^2)(a + r^0 - c^1 - c^2)}{\rho + \lambda} - \frac{(c^1 - c^2)(2r^0 - c^1 - c^2)}{\rho + 2\lambda} < X_2.$$

$$\Rightarrow \frac{(c^1 - c^2)[(a + r^0 - c^1)(\rho + 2\lambda) - (2r^0 - c^1 - c^2)(\rho + \lambda)]}{(\rho + \lambda)(\rho + 2\lambda)} < X_2.$$

$$\Rightarrow \frac{(c^1 - c^2)[(a - r^0)\rho + (2a - c^1 - c^2)\lambda]}{(\rho + \lambda)(\rho + 2\lambda)} < X_2. \qquad (12)$$

Again, $E(r)$ at $t = 10$ is given by

$$[E(r)]_{r=r^{10}} = \int_0^{\infty} e^{-\rho t}[L(r_t^2, c^2) - L(r_t^1, c^1)]dt - X_2,$$

where $r_t^2 = e^{-\lambda t}(r^{10} - c^2) + c^2,$

$r_t^1 = e^{-\lambda t}(r^{10} - c^1) + c^1,$

and $r^{10} = e^{-10\lambda}(r^0 - c^1) + c^1$.

Therefore, $[E(r)]_{r=r^{10}} = (c^1 - c^2)(a + r^{10} - c^1 - c^2)\int_0^\infty e^{-(\rho+\lambda)t} dt - (c^1 - c^2)(2r^{10} - c^1 - c^2)\int_0^\infty e^{-(\rho+2\lambda)t} dt - X_2$

$$= \frac{(c^1 - c^2)(a + r^{10} - c^1 - c^2)}{\rho + \lambda} - \frac{(c^1 - c^2)(2r^{10} - c^1 - c^2)}{\rho + 2\lambda} - X_2.$$

Therefore, $[E(r)]_{r=r^{10}} > 0$ at $t = 10$ if

$$\frac{(c^1 - c^2)(a + r^{10} - c^1 - c^2)}{\rho + \lambda} - \frac{(c^1 - c^2)(2r^{10} - c^1 - c^2)}{\rho + 2\lambda} > X_2.$$

$$\Rightarrow \frac{(c^1 - c^2)[(a - r^{10})\rho + (2a - c^1 - c^2)\lambda]}{(\rho + \lambda)(\rho + 2\lambda)} > X_2. \qquad (13)$$

Further, $E(r)$ at $t = \propto$ is given by

$$[E(r)]_{r=r^\infty} = (c^1 - c^2)(a + r^\infty - c^1 - c^2)\int_0^\infty e^{-(\rho+\lambda)t} dt - (c^1 - c^2)(2r^\infty - c^1 - c^2)\int_0^\infty e^{-(\rho+2\lambda)t} dt - X_2$$

where $r^\infty = e^{-\infty}(r^0 - c^1) + c^1 = c^1$.

Therefore, $[E(r)]_{r=r^\infty} = \frac{(c^1 - c^2)(a + c^1 - c^1 - c^2)}{\rho + \lambda} - \frac{(c^1 - c^2)(2c^1 - c^1 - c^2)}{\rho + 2\lambda} - X_2$

$$= \frac{(c^1 - c^2)(a - c^2)}{\rho + \lambda} - \frac{(c^1 - c^2)^2}{\rho + 2\lambda} - X_2$$

$$= \frac{(c^1 - c^2)[(a - c^1)\rho + (2a - c^1 - c^2)\lambda]}{(\rho + \lambda)(\rho + 2\lambda)} - X_2. \qquad (14)$$

Comparing equations (13) and (14) we get

$$\text{since } r^{10} > r^{\infty} = c^1, \quad \text{therefore, } [E(r)]_{r=r^{10}} < [E(r)]_{r=r^{\infty}=c^1}.$$

Thus, condition (13) is sufficient to ensure that $E(r) > 0$ at $t = \infty$. Therefore, if conditions (12) and (13) are simultaneously satisfied, then the incentive to adopt T_2 (given by the function $E(r)$) will be negative initially (at $t = 0$) but positive at some high value of time (say, $t = 10$), and will remain positive thereafter. Assuming that $E(r)$ is continuous in t, there must be a unique t^* ($0 < t^* < 10$) and a corresponding r^* such that $E(r^*) = 0$. So the leader firm will adopt T_2 at $t = t^*$.

We then establish some conditions under which T_1 will, in fact, be adopted at $t = 0$ If T_1 is adopted at $t = 0$ and T_2 at $t = t^*$, the discounted profit of the leader is

$$\int_0^{t^*} e^{-\rho t} L(r_t^1, c^1)dt - X_1 + \int_{t^*}^{\infty} e^{-\rho t} L(r_t^2, c^2)dt - e^{-\rho t^*} X_2, \qquad (15)$$

$$\text{where } r_t^1 = e^{-\lambda t}(r^0 - c^1) + c^1, \qquad (16)$$

$$r_t^2 = e^{-\lambda(t-t^*)}(r^* - c^2) + c^2, \qquad (17)$$

$$\text{and } r^* = e^{-\lambda t^*}(r^0 - c^1) + c^1.$$

Substituting (16) and (17) in (15) we get

$$\int_0^{t^*} e^{-\rho t}[e^{-\lambda t}(r^0 - c^1)(a - c^1) - e^{-2\lambda t}(r^0 - c^1)^2]dt - X_1$$
$$+\int_{t^*}^{\infty} e^{-\rho t}[e^{-\lambda(t-t^*)}(r^* - c^2)(a - c^2) - e^{-2\lambda(t-t^*)}(r^* - c^2)^2]dt - e^{-\rho t^*}X_2$$

$$= (r^0 - c^1)(a - c^1)\int_0^{t^*} e^{-(\rho+\lambda)t}dt - (r^0 - c^1)^2\int_0^{t^*} e^{-(\rho+2\lambda)t}dt - X_1$$
$$+(r^* - c^2)(a - c^2)e^{\lambda t^*}\int_{t^*}^{\infty} e^{-(\rho+\lambda)t}dt - (r^* - c^2)^2 e^{2\lambda t^*}\int_{t^*}^{\infty} e^{-(\rho+2\lambda)t}dt - e^{-\rho t^*}X_2$$

$$= \frac{(r^0 - c^1)(a - c^1)}{\rho + \lambda}[1 - e^{-(\rho+\lambda)t^*}] - \frac{(r^0 - c^1)^2}{\rho + 2\lambda}[1 - e^{-(\rho+2\lambda)t^*}] - X_1$$
$$+\frac{(r^* - c^2)(a - c^2)}{\rho + \lambda}e^{\lambda t^*}[e^{-(\rho+\lambda)t^*}] - \frac{(r^* - c^2)^2}{\rho + 2\lambda}e^{2\lambda t^*}[e^{-(\rho+2\lambda)t^*}] - e^{-\rho t^*}X_2$$

$$= \frac{(r^0 - c^1)(a - c^1)}{\rho + \lambda}[1 - e^{-(\rho+\lambda)t^*}] - \frac{(r^0 - c^1)^2}{\rho + 2\lambda}[1 - e^{-(\rho+2\lambda)t^*}] - X_1$$
$$+\frac{(r^* - c^2)(a - c^2)}{\rho + \lambda}e^{-\rho t^*} - \frac{(r^0 - c^2)^2}{\rho + 2\lambda}e^{-\rho t^*} - e^{-\rho t^*}X_2. \quad (18)$$

Again, if T_2 is never adopted, the discounted profit of the leader from the adoption of T_1 at $t = 0$ is given by

$$\int_0^{\infty} e^{-\rho t}L(r_t^1, c^1)dt - X_1, \quad (19)$$

So from (19) we get

$$\int_0^{\infty} e^{-\rho t}[e^{-\lambda t}(r^0 - c^1)(a - c^1) - e^{-2\lambda t}(r^0 - c^1)^2]dt - X_1$$

$$= (r^0 - c^1)(a - c^1)\int_0^\infty e^{-(\rho+\lambda)t}dt - (r^0 - c^1)^2\int_0^\infty e^{-(\rho+2\lambda)t}dt - X_1$$

$$= \frac{(r^0 - c^1)(a - c^1)}{\rho + \lambda} - \frac{(r^0 - c^1)^2}{\rho + 2\lambda} - X_1. \tag{20}$$

Difference between (18) and (20) will give us the net gain from the adoption of T_1 :

$$E(r) = \frac{(r^0 - c^1)(a - c^1)}{\rho + \lambda}[1 - e^{-(\rho+\lambda)t^*} - 1] - \frac{(r^0 - c^1)^2}{\rho + \lambda}[1 - e^{-(\rho+2\lambda)t} - 1] - X_1 + X_1$$
$$+ \frac{(r^* - c^2)(a - c^2)}{\rho + \lambda}e^{-\rho t^*} - \frac{(r^* - c^2)^2}{\rho + 2\lambda}e^{-\rho t^*} - e^{-\rho t^*}X_2$$

$$= -\frac{(r^0 - c^1)(a - c^1)}{\rho + \lambda}e^{-(\rho+\lambda)t^*} + \frac{(r^0 - c^1)^2}{\rho + 2\lambda}e^{-(\rho+2\lambda)t^*}$$
$$+ \frac{(r^* - c^2)(a - c^2)}{\rho + \lambda}e^{-\rho t^*} - \frac{(r^* - c^2)^2}{\rho + 2\lambda}e^{-\rho t^*} - e^{-\rho t^*}X_2$$

$$= \frac{e^{-\rho t^*}}{\rho + \lambda}[(r^* - c^2)(a - c^2) - (r^0 - c^1)(a - c^1)e^{-\lambda t^*}]$$
$$- \frac{e^{-\rho t^*}}{\rho + 2\lambda}[(r^* - c^2)^2 - (r^* - c^1)^2 e^{-2\lambda t^*}] - e^{-\rho t^*}X_2.$$

Therefore, $E(r) > 0$ at $t = 0$ if

$$\frac{e^{-\rho t^*}}{\rho + \lambda}[(r^* - c^2)(a - c^2) - (r^0 - c^1)(a - c^1)e^{-\lambda t^*}]$$
$$- \frac{e^{-\rho t^*}}{\rho + 2\lambda}[(r^* - c^2)^2 - (r^0 - c^1)^2 e^{-2\lambda t^*}] > e^{-\rho t^*}X_2.$$

$$\Rightarrow \frac{(r^* - c^2)(a - c^2) - (r^0 - c^1)(a - c^1)e^{-\lambda t^*}}{\rho + \lambda} - \frac{(r^* - c^2)^2 - (r^0 - c^1)^2 e^{-2\lambda t^*}}{\rho + 2\lambda} > X_2. \qquad (21)$$

Thus if conditions (12), (13) and (21) are simultaneously satisfied, T_1 will be adopted at $t = 0$ but T_2 will be adopted at $t = t^*$ where t^* is large. Hence, this is a case of staggered adoption of T_2.

Let us take an example. Let the demand function be $p = 10 - q$. The marginal costs of the leader and the follower are given as follows:

$$c^0 = 8, \quad r^0 = 10, \qquad c^1 = 6, \qquad c^2 = 4.$$

The parameter values are given as follows:

$$\rho = 0.4, \quad \lambda = 0.3, \quad X_2 = 12.$$

Therefore, $r^{10} = 4e^{-3} + 6 = 6.2$ (approx.) and $r^{\alpha} = c^1 = 6$.

Substituting these values in the equation for $E(r^0)$ we get

$E(r^0) = 20/0.7 - 20 - 12 = -3.43$ (approx.) < 0.

Thus the first condition is satisfied.

Next, substituting the given values in the equation for $E(r^{10})$ we get

$E(r^{10}) = 12.4/0.7 - 4.8 - 12 = 0.91 > 0$.

Thus the second condition is satisfied.

Further, $E(r^{\alpha}) = 12/0.7 - 4 - 12 = 1.14$ (approx.) > 0.

Thus $E(r) = 0$ for $0 < t < \alpha$. Calculations shows that if $t^* = 4.63$, $r^* = 7$ (approx.). and

$E(r^*) = 0$ (approx.).

Substituting these values in the equation showing the incentive to adopt T_1 we get

$E(r^0) = 0.01 > 0$.

Thus the third condition is also satisfied. So, we can claim that this is an example of staggered adoption of T_2.

Therefore, under price competition, existing innovations may be adopted in a staggered manner where each adoption is followed by a period of diffusion. Clearly, price competition reveals the cyclical nature of innovation as proposed by **Schumpeter** (1950).

Now, we can examine the third result of **Mookherjee and Ray** (1991) in the simplified framework.

QUANTITY COMPETITION:

Here we have to show that, an increase in the diffusion rate reduces the incentive to adopt for the leader. Given that, $E(r)$ represents the adoption incentive and λ, the constant rate of diffusion, mathematically the proposition implies $\partial E(r)/\partial\lambda \leq 0$.
Let us consider the case where T_1 has already been adopted.

From equation (1) we get

$$E(r,\lambda) = \int_0^{\infty} e^{-\rho t}[L(r_t^2,c^2) - L(r_t^1,c^1)]dt \qquad (22)$$

$$\left.\begin{aligned} \text{where } r_t^2 &= e^{-\lambda t}(r - c^2) + c^2, \\ \text{and } \quad r_t^1 &= e^{-\lambda t}(r - c^1) + c^1. \end{aligned}\right\} \; c^0 > c^1 > c^2$$

Taking the first derivative of (22) w.r.t λ we get

$$\frac{\partial E(r,\lambda)}{\partial \lambda} = -\int_0^\infty t\, e^{-(\rho+\lambda)t}[L_r(r_t^2, c^2)(r - c^2) - L_r(r_t^1, c^1)(r - c^1)]dt. \qquad (23)$$

We know from equation (3)

$$L_r(r_t^2, c^2) - L_r(r_t^1, c^1) > 0.$$

Further $r > c^1 > c^2$. So from equation (23) we can say that $\partial E(r,\lambda)/\ \partial\lambda \leq 0$.
Similarly, for the case of adoption decision of technology T_1.Thus, an increase in the rate of diffusion discourages the incentive to adopt under quantity competition.

The explanation is as follows. Quantity competition is characterised by relative absence of competitive pressure in the market. This is reason why the leader firm should adopt the innovations at the beginning, if it wants to adopt at all. Now, as innovations are bunched together at the beginning of competition, a decrease in the follower's unit cost over time will discourage the leader's incentive to innovate. Therefore, as the diffusion rate increases, it will enable the follower's unit cost to drift down towards the leader's cost faster. Naturally, this will reduce the leader's incentive to adopt.

PRICE COMPETITION:

Here we have to show that an increase in the diffusion rate might enhance the incentive to adopt for the leader firm. Mathematically, it implies that $\partial E(r)/\partial\lambda \geq 0$.

From equation (8) we get

$$E(r,\lambda) = \int_0^{\infty} e^{-\rho t}[L(r_t^2,c^2) - L(r_t^1,c^1)]dt, \tag{24}$$

$$\left.\begin{aligned} \text{where } r_t^2 &= e^{-\lambda t}(r^0 - c^2) + c^2, \\ \text{and } r_t^1 &= e^{-\lambda t}(r^0 - c^1) + c^1. \end{aligned}\right\} \; c^2 > c^1 > c^0$$

Taking the first derivative of (24) w.r.t λ we get

$$\frac{\partial E(r,\lambda)}{\partial \lambda} = -\int_0^{\infty} t\, e^{-(\rho+\lambda)t}[L_r(r_t^2,c^2)(r - c^2) - L_r(r_t^1,c^1)(r - c^1)]dt. \tag{25}$$

From equation (11) we get

$$L_r(r_t^2,c^2) - L_r(r_t^1,c^1)\begin{cases} > \\ \; 0, \quad r > c^2 > c^1. \\ < \end{cases}$$

Hence there might arise a possibility of $\partial E(r,\lambda)/\partial \lambda \geq 0$.

The explanation is as follows. Under price competition, innovations might be adopted in a staggered manner where each innovation is followed by a period of diffusion. Since the innovations are adopted in a phased manner, a decrease in the follower's cost enhances the leader's incentive to innovate. Therefore, an increase in the diffusion rate enables the follower's unit cost to catch up faster the leader's one. This, in turn, creates more competitive pressure and thereby enhances the leader's incentive to adopt the next innovation faster than the earlier ones.

Thus, the adoption behaviour of the leader firm under price and quantity competition may be contrasted under certain circumstances. Under quantity competition, the leader's incentive always lies in quicker and bunched adoption of existing innovations. But under price competition, adoption behaviour of the leader may vary depending upon the fixed cost of adoption, the unit costs of two firms and the rate of diffusion. Somewhere the innovations are instantly adopted and somewhere they are adopted with some time lag. In this sense, "both the **Schumpeterian** carrot and the **Leibensteinian** stick may coexist" in price competition.

Chapter-3

(Cournot Competition with Free Entry)

Cournot Competition with Free Entry

In this chapter, we relax the assumption that the number of firm is exogenously given. In fact, we examine a model of Cournot competition with free entry. The basic purpose behind this exercise is to compare actual versus potential competition. When free entry is allowed in any industry, the incumbent firms in the industry face the competition from potential entrants as well as actual competition from existing firms. On the other hand, when entry is prohibited, existing firms only face actual competition. So, examining the adoption of innovation under Cournot competition with free entry allows us to analyse the effect of potential competition. This exercise is motivated by the **Mookherjee and Ray's** (1991) conjecture that the distinguishing characteristic of their two models of product market competition is actual versus potential competition, rather than the strategic variable (price or quantity) chosen.

We assume, as before, that the first firm is the leader - having sole access to the existing innovations. The other firms, the followers, constitute the "competitive fringe". As before, c denotes the constant marginal cost of the leader, while all firms in the "competitive fringe" face the same constant marginal cost denoted by r ($r > c$). In addition, the followers face a fixed cost also. So, the leader's cost function is given by $C_1 = cq_1$ while that of the n followers is given by $C_j = f^2 + rq_j$; $j = 2, 3, 4, \ldots, n+1$ where f^2 denotes the fixed cost. This fixed cost may be interpreted as a set-up cost, required to adopt the imitated technology that everyone has to incur at the beginning of its establishment. The inclusion of a fixed cost in the follower's cost function will help us to examine how it acts as a barrier to entry for the follower firms.

Now, under Cournot competition with free entry, the leader's profit function is written as

$$\pi_1 = (a - \sum_{1}^{n+1} q_i) q_1 - cq_1. \tag{1}$$

Similarly, the followers' profit function is given by

$$\pi_j = (a - \sum_{1}^{n+1} q_i) q_j - (f^2 + r q_j), \quad j \neq 1. \tag{2}$$

Hence, the first-order conditions for equilibrium are given as follows:

$$\frac{\partial \pi_1}{\partial q_1} = a - 2q_1 - \sum_{2}^{n+1} q_j - c = 0, \tag{3}$$

$$\frac{\partial \pi_j}{\partial q_j} = a - 2q_j - q_1 - \sum_{k \neq j}^{n+1} q_k - r = 0. \tag{4}$$

We then introduce the free entry condition, which requires that, in equilibrium the follower firms have a profit of zero:

$$\pi_j = (a - q_1 - \sum_{2}^{n+1} q_j) q_j - (f^2 + r q_j) = 0. \tag{5}$$

Clearly, the equilibrium with free entry involves a finite number of incumbent firms in the industry.

Now, let us assume that the equilibrium is symmetric so that all the follower firms have the same level of output i.e., $q_j = q, \ \forall j \geq 2$. Hence, from equations (3), (4) and (5) respectively we can write

$$a - 2q_1 - nq - c = 0, \tag{6}$$

$$a - q_1 - (n+1)q - r = 0, \tag{7}$$

$$(a - q_1 - nq - r)q - f^2 = 0. \tag{8}$$

Solving equations (7) and (8) we find that,

$$q = f. \tag{9}$$

Substituting (9) in (6) and (7) we get respectively

$$2q_1 + nf = a - c, \tag{10}$$

$$q_1 + nf = a - c. \tag{11}$$

Solving (10) and (11) simultaneously we get

$$q_1 = r + f - c,$$

$$\text{and, } n = \frac{a + c - 2r - 2f}{f}.$$

Thus, the equilibrium solutions are given by

$$q_1^* = r + f - c,$$

$$q^* = f,$$

$$\text{and, } n^* = \frac{a + c - 2r - 2f}{f}.$$

Substituting the equilibrium values in the leader's profit function we get the leader's equilibrium profit under free entry. Let it be denoted by $L(r,c)$.

$$L(r,c) = (a - q_1^* - n^* q^*)q_1^* - cq_1^*$$

$$= [a - q_1^* - n^* q^* - c]q_1^*$$

$$= [a - r - f + c - \frac{(a + c - 2r - 2f)}{f} f - c]q_1^*$$

$$= (r + f - c)(r + f - c)$$

$$= (r + f - c)^2.$$

We now examine the leader's incentive to adopt the existing innovations under free entry. First consider the case where the technology T_1 has already been adopted. The leader is now deciding upon whether to adopt the technology T_2 or not. The incentive to adopt T_2 is given as follows:

$$E(r) = \int_0^\infty e^{-\rho t}[L(r_t^2, c^2) - L(r_t^1, c^1)]dt - X_2, \tag{12}$$

$$\text{where } r_t^2 = e^{-\lambda t}(r - c^2) + c^2, \tag{13}$$

$$\text{and } r_t^1 = e^{-\lambda t}(r - c^1) + r^1. \tag{14}$$

Substituting (13) and (14) in the leader's profit function we get

$$\begin{aligned} L(r_t^2, c^2) &= (r_t^2 + f - c^2)^2 \\ &= [e^{-\lambda t}(r - c^2) + c^2 + f - c^2]^2 \\ &= [e^{-\lambda t}(r - c^2) + f]^2. \end{aligned} \tag{15}$$

$$\text{Similarly, } L(r_t^1, c^1) = [e^{-\lambda t}(r - c^1) + f]^2. \tag{16}$$

Substituting (15) and (16) in (12) we obtain

$$E(r) = \int_0^\infty e^{-\rho t}[\{e^{-\lambda t}(r - c^2) + f\}^2 - \{e^{-\lambda t}(r - c^1) + f\}^2]dt - X_2$$

$$= \int_0^\infty e^{-\rho t}[\{e^{-\lambda t}(r - c^2) + e^{-\lambda t}(r - c^1) + 2f\}\{e^{-\lambda t}(r - c^2) - e^{-\lambda t}(r - c^1)\}]dt - X_2$$

$$= \int_0^\infty e^{-\rho t}[\{e^{-\lambda t}(r - c^2 + r - c^1) + 2f\}\{e^{-\lambda t}(r - c^2 - r + c^1)\}]dt - X_2$$

$$= \int_0^\infty e^{-\rho t}[\{e^{-\lambda t}(2r - c^1 - c^2) + 2f\}\{e^{-\lambda t}(c^1 - c^2)\}]dt - X_2$$

$$= \int_0^\infty e^{-\rho t}[e^{-2\lambda t}(2r - c^1 - c^2)(c^1 - c^2) + 2fe^{-\lambda t}(c^1 - c^2)]dt - X_2. \quad (17)$$

Next, note that $$E'(r) = 2\int_0^\infty e^{-t(\rho+2\lambda)}(c^1 - c^2)dt. \quad (18)$$

Since $c_1 > c_2$, it follows that $E'(r) > 0$.

Thus the leader's incentive to adopt the exiting innovations is an increasing function of the followers' marginal cost. Hence, the leader will adopt T_2 instantly, if it is to be adopted at all. Because as time elapses, the diffusion will make the follower's cost closer to the cost of the leader. That will reduce the leader's incentive to adopt. Hence if it is not initially profitable for the leader to adopt T_2, it will not be profitable to do so at a later date.

Let us now consider the decision to adopt T_1. First, consider the case where T_2 is never adopted. The leader is deciding upon adoption of T_1 only. In this case the incentive to adopt T_1 is given by:

$$E(r) = \int_0^\infty e^{-\rho t}[L(r_t^1, c^1) - L(r_t^0, c^0)]dt - X_1,$$

where $r_t^1 = e^{-\lambda t}(r^0 - c^1) + c^1$,

and $r_t^0 = e^{-\lambda t}(r^0 - c^0) + c^0$.

Clearly, $$E(r) = \int_0^\infty e^{-\rho t}[\{e^{-\lambda t}(r^0 - c^1) + f\}^2 - \{e^{-\lambda t}(r^0 - c^0) + f\}^2]dt - X_1$$

$$= \int_0^\infty e^{-\rho t}[\{e^{-\lambda t}(2r^0 - c^0 - c^1) + 2f\}\{e^{-\lambda t}(c^0 - c^1)\}]dt - X_1$$

$$= \int_0^\infty e^{-\rho t}[e^{-2\lambda t}(2r^0 - c^0 - c^1)(c^0 - c^1) + 2fe^{-\lambda t}(c^0 - c^1)]dt - X_1.$$

$$\text{Therefore, } E'(r) = 2\int_0^\infty e^{-(\rho+2\lambda)t}(c^0 - c^1)dt.$$

Since $c^0 > c^1$, it follows that $E'(r) > 0$.

We can argue, as before that the leader will adopt the technology T_1 instantly, if it is to be adopted at all.

Lastly, consider the case where, following the adoption of T_1, T_2 is adopted instantaneously. In this case the incentive to adopt is given by:

$$E(r) = \int_0^\infty e^{-\rho t}[L(r_t^2, c^2) - L(r_t^0, c^0)]dt - X_1 - X_2,$$

$$\text{where } r_t^2 = e^{-\lambda t}(r^0 - c^2) + c^2,$$

$$\text{and } r_t^0 = e^{-\lambda t}(r^0 - c^0) + c^0.$$

$$\text{Hence, } E(r) = \int_0^\infty e^{-\rho t}[\{e^{-\lambda t}(r^0 - c^2) + f\}^2 - \{e^{-\lambda t}(r^0 - c^0) + f\}^2]dt - X_1 - X_2$$

$$= \int_0^\infty e^{-\rho t}[\{e^{-\lambda t}(r^0 - c^2) + e^{-\lambda t}(r^0 - c^0) + 2f\}\{e^{-\lambda t}(r^0 - c^2) - e^{-\lambda t}(r^0 - c^0)\}]dt - X_1 - X_2$$

$$= \int_0^\infty e^{-\rho t}[\{e^{-\lambda t}(2r^0 - c^0 - c^2) + 2f\}\{e^{-\lambda t}(c^0 - c^2)\}]dt - X_1 - X_2$$

$$= \int_0^\infty e^{-\rho t}[e^{-2\lambda t}(2r^0 - c^0 - c^2)(c^0 - c^2) + 2fe^{-\lambda t}(c^0 - c^2)]dt - X_1 - X_2.$$

Clearly, $E'(r) = 2\int_0^\infty e^{-(\rho+2\lambda)t}(c^0 - c^2)dt.$

Since $c^0 > c^2$, it follows that $E'(r) > 0$ which, in turn, implies that the leader will adopt the technologies T_1 and T_2 instantly, if they are to be adopted at all.

Let us now see how the leader's incentive for adoption varies with variation in the fixed cost incurred by the "competitive fringe" i.e., what happens if entry becomes more difficult.

For simplicity, we just consider the first case where the technology T_1 has already been adopted. The leader is deciding on the adoption of technology T_2. The incentive for adoption of T_2 is given by the expression in equation (17).

Differentiating equation (17) w.r.t f we get

$$\frac{dE(r)}{df} = \int_0^\infty e^{-\rho t}[2e^{-\lambda t}(c^1 - c^2)]dt$$

$$= \int_0^\infty 2e^{-(\rho+\lambda)t}(c^1 - c^2)dt.$$

Therefore, $\frac{dE(r)}{df} > 0$ as $e^{-(\rho+\lambda)t} > 0$ and $c^1 > c^2$ by assumption.

This implies that as the fixed cost incurred by the competitive fringe increases, the leader's incentive for adoption of existing technologies also increases. The intuition is quite clear. As the fixed cost incurred by the competitive fringe increases, post-entry profit of the follower declines. This in turn, will discourage entry into the industry. Again, as number of existing firms decline, profit earned by the leader will increase. Assuming that adoption cost remains unchanged, this will increase the leader's incentive to innovate. We can make a similar argument in case of incentive to adopt T_1 as well.

Thus we find that the introduction of potential competition does not change the results under quantity competition. Hence we can claim that the conjecture in **Mookherjee and Ray** (1991) does not go through in this framework.

Chapter-4

(Stackelberg Competition)

Stackelberg Competition

In this chapter we again revert to the original model with an exogenously given number of firms (two) having constant but asymmetric unit costs. The difference with the basic model is that we assume that there is Stackelberg competition among the firms in the product market. All other assumptions of the basic model remain unchanged.

Therefore, in this case the follower's problem is given by:

$$\max_{q_2} \ \pi_2 = (a - q)q_2 - rq_2. \tag{1}$$

Accordingly, the first-order condition of the follower is given as follows:

$$\frac{\partial \ \pi_2}{\partial \ q_2} = a - 2q_2 - q_1 - r = 0. \tag{2}$$

Equation (2) is the reaction function of the follower. Since firms are in a Stackelberg competition, the leader knows that the follower will always be on its reaction function. Therefore, the leader will maximise its own profit taking into account the follower's reaction function.

Hence the leader's problem is

$$\max_{q_1} \ \pi_1 = (a - q_2 - q_1)q_1 - cq_1 , \tag{3}$$

where q_2 solves equation (2).

Substituting (2) in (3) we get the leader's problem as

$$\max_{q_1} \pi_1^* = \{a - q_1 - \tfrac{1}{2}(a - q_1 - r)\}q_1 - cq_1. \tag{4}$$

Thus the first-order condition for maximisation for the leader is given by

$$\frac{\partial \pi_1^*}{\partial q_1} = a - 2q_1 - \frac{a-r}{2} + \frac{2q_1}{2} - c = 0$$

$$or, \ \frac{2a - a + r - 2c}{2} = q_1,$$

$$or, \ q_1^* = \frac{a - 2c + r}{2}.$$

$$\text{Therefore, } \ q_2^* = \frac{a - q_1^* - r}{2}$$

$$= \frac{a-r}{2} - \frac{(a - 2c + r)}{4}$$

$$= \frac{2(a-r) - (a - 2c + r)}{4}$$

$$= \frac{a - 3r + 2c}{4}.$$

Substituting q_1^* in (4) we get the leader's profit function as:

$$L(r,c) = \{(a - \frac{a}{2} + \frac{r}{2} - \frac{q_1^*}{2}) - c\}q_1^*$$

$$= \{(\frac{a+r}{2} - \frac{(a - 2c + r)}{4}) - c\}q_1^*$$

$$= \{\frac{2a + 2r - a + 2c - r}{4} - c\} q_1^*$$

$$= \{\frac{a + 2c + r - 4c}{4}\} \frac{(a - 2c + r)}{2}$$

$$= \frac{(a - 2c + r)^2}{8}. \qquad (5)$$

Now, we can examine the adoption behaviour of the leader firm when the firms engage in Stackleberg competition. We are back to our simplified framework. First, consider the case where the technology T_1 has already been adopted. The leader's sole consideration is whether to adopt the technology T_2 or not; and if it is to be adopted, when it will be optimal to adopt.

The net discounted gain from adoption of T_2 is given by:

$$E(r) = \int_0^\infty e^{-\rho t}[L(r_t^2, c^2) - L(r_t^1, c^1)]dt - X_2,$$

where $r_t^2 = e^{-\lambda t}(r - c^2) + c^2$,

and $r_t^1 = e^{-\lambda t}(r - c^1) + c^1$.

Now, if $E(r) > 0$, then T_2 will be adopted instantaneously.

Further, $$E'(r) = \int_0^\infty e^{-\rho t}[L_r(r_t^2, c^2) - L_r(r_t^1, c^1)]dt. \qquad (6)$$

Note that, $L(r_t^2, c^2) = \frac{1}{8}(a - 2c^2 + r_t^2)^2$

$$= \tfrac{1}{8}[a - c^2 + e^{-\lambda t}(r - c^2)]^2.$$

$$\text{Therefore, } L_r(r_t^2, c^2) = \tfrac{1}{4}\{a - c^2 + e^{-\lambda t}(r - c^2)\}e^{-\lambda t}. \tag{7}$$

$$\text{Similarly, } L_r(r_t^1, c^1) = \tfrac{1}{4}\{a - c^1 + e^{-\lambda t}(r - c^1)\}e^{-\lambda t}. \tag{8}$$

$$\text{Therefore, } L_r(r_t^2, c^2) - L_r(r_t^1, c^1) = \tfrac{1}{4}e^{-\lambda t}[a - c^2 + e^{-\lambda t}(r - c^2) - a + c^1 - e^{-\lambda t}(r - c^1)]$$

$$= \tfrac{1}{4}e^{-\lambda t}[c^1 - c^2 + e^{-\lambda t}(r - c^2 - r + c^1)]$$

$$= \tfrac{1}{4}e^{-\lambda t}[(c^1 - c^2)(1 + e^{-\lambda t})]. \tag{9}$$

Substituting (9) in (6) we get

$$E'(r) = \tfrac{1}{4}\int_0^\infty e^{-(\rho+\lambda)t}(c^1 - c^2)(1 + e^{-\lambda t})dt.$$

Since $c^1 > c^2$, it follows that $E'(r) > 0$. Therefore, the optimal strategy for the leader is to adopt T_2 instantly, if it is to be adopted at all.

Next, consider the case where the leader is considering on the adoption of T_1. First consider the case where the technology T_2 is never adopted. The discounted net gain from adoption of the technology T_1 is given by:

$$E(r) = \int_0^\infty e^{-\rho t}[L(r_t^1, c^1) - L(r_t^0, c^0)]dt - X_1,$$

$$\text{where } r_t^1 = e^{-\lambda t}(r^0 - c^1) + c^1,$$

$$\text{and } r_t^0 = e^{-\lambda t}(r^0 - c^0) + c^0.$$

Now, if $E(r)$ is positive, the technology T_1 is profitable to adopt for the leader.

Further, $E'(r) = \int_0^\infty e^{-\rho t}[L_r(r_t^1, c^1) - L_r(r_t^0, c^0)]dt.$ (10)

$$L(r_t^1, c^1) = \tfrac{1}{8}(a - 2c^1 + r_t^1)^2$$

$$= \tfrac{1}{8}[a - c^1 + e^{-\lambda t}(r^0 - c^1)]^2.$$

Therefore, $L_r(r_t^1, c^1) = \tfrac{1}{4}[a - c^1 + e^{-\lambda t}(r^0 - c^1)]e^{-\lambda t}.$ (11)

Similarly, $L_r(r_t^0, c^0) = \tfrac{1}{4}[a - c^0 + e^{-\lambda t}(r^0 - c^0)]e^{-\lambda t}.$ (12)

Therefore, $L_r(r_t^1, c^1) - L_r(r_t^0, c^0) = \tfrac{1}{4}e^{-\lambda t}[(c^0 - c^1)(1 + e^{-\lambda t})].$ (13)

Substituting (13) in (10) we get

$$E'(r) = \tfrac{1}{4}\int_0^\infty e^{-(\rho+\lambda)t}[(c^0 - c^1)(1 + e^{-\lambda t})]dt.$$

Since $c^0 > c^1$, it follows that $E'(r) > 0$. Therefore, the leader will find it optimal to adopt the technology T_1 either instantly or never at all. Because, as time passes on, decrease in the follower's cost due to diffusion will reduce the leader's discounted net gain from adoption. Hence, the technology should be adopted instantly if it is to be adopted at all.

Next, consider the case where, following the adoption of T_1, T_2 is instantaneously adopted. Here, the net discounted gain from the adoption of the technologies are given by:

$$E(r) = \int_0^\infty e^{-\rho t}[L(r_t^2, c^2) - L(r_t^0, c^0)]dt - X_1 - X_2,$$

where $r_t^2 = e^{-\lambda t}(r^0 - c^2) + c^2$,

and $r_t^0 = e^{-\lambda t}(r^0 - c^0) + c^0$.

$$\text{Clearly, } E'(r) = \int_0^{\infty} e^{-\rho t}[L_r(r_t^2, c^2) - L_r(r_t^0, c^0)]dt. \tag{14}$$

$$L(r_t^2, c^2) = \tfrac{1}{8}(a - 2c^2 + r_t^2)^2$$

$$= \tfrac{1}{8}[a - c^2 + e^{-\lambda t}(r^0 - c^2)]^2.$$

$$\text{Hence, } L_r(r_t^2, c^2) = \tfrac{1}{4}[a - c^2 + e^{-\lambda t}(r^0 - c^2)]e^{-\lambda t}. \tag{15}$$

$$\text{Similarly, } L_r(r_t^0, c^0) = \tfrac{1}{4}[a - c^0 + e^{-\lambda t}(r^0 - c^0)]e^{-\lambda t}. \tag{16}$$

$$\text{Therefore, } L_r(r_t^2, c^2) - L_r(r_t^0, c^0) = \tfrac{1}{4}e^{-\lambda t}[a - c^2 + e^{-\lambda t}(r^0 - c^2) - a + c^0 - e^{-\lambda t}(r^0 - c^0)]$$

$$= \tfrac{1}{4}e^{-\lambda t}[c^0 - c^2 + e^{-\lambda t}(c^0 - c^2)]$$

$$= \tfrac{1}{4}e^{-\lambda t}[(c^0 - c^2)(1 + e^{-\lambda t})]. \tag{17}$$

Substituting (17) in (14) we get

$$E'(r) = \tfrac{1}{4}\int_0^{\infty} e^{-(\rho+\lambda)t}[(c^0 - c^2)(1 + e^{-\lambda t})]dt.$$

Since $c^0 > c^2$, it follows that $E'(r) > 0$. Therefore, it is optimal for the leader to adopt both the technologies instantly, if they are to be adopted at all.

Thus, the adoption behaviour of the leader firm does not change if the Cournot competition is replaced by the Stackelberg competition. Although the leader firm gets a higher profit share under the Stackelberg competition compared to that under the Cournot competition, this is not going to affect the leader's incentive. Even under the Stackelberg competition, the leader's optimal decision is to adopt instantaneously or not at all.

Chapter-5

(The Case of Differentiated Product)

The Case of Differentiated Product

In this chapter we relax the assumption that the competing firms are producing homogeneous good. Instead, we assume that the goods produced by the firms are differentiated. All other assumptions of the basic model remain unchanged. Let us assume that firm 1 produces good 1 and firm 2 produces good 2. Thus, each firm faces a separate demand curve. The demand function for the i^{th} firm is given by

$$p_i = a - q_i - \beta\, q_j, \quad i \neq j = 1,2.$$

If $\beta = 0$, the goods are totally differentiated and we are back to the monopoly case. On the other hand, if $\beta = 1$, the goods are perfectly substitute and we are back to the homogeneous good case. If $\beta > 0$, the goods are substitutes, while if $\beta < 0$, the goods are complements. Our purpose is to examine how the adoption behaviour of the leader firm alters under price and quantity competition with differentiated product.

We first consider the case where $0 < \beta < 1$. So, the objective of firm 1 (the leader) is given by:

$$\max_{q_1} \pi_1 = (a - q_1 - \beta\, q_2)q_1 - cq_1.$$

Similarly, the objective of firm 2 (the follower) is given by

$$\max_{q_2} \pi_2 = (a - q_2 - \beta\, q_1)q_2 - rq_2.$$

The first order conditions for maximisation are given as follows:

$$\frac{\partial \pi_1}{\partial q_1} = a - 2q_1 - \beta\, q_2 - c = 0, \tag{1}$$

$$\text{and,} \quad \frac{\partial \pi_2}{\partial q_2} = a - 2q_2 - \beta q_1 - r = 0. \tag{2}$$

Solving equations (1) and (2) simultaneously we get

$$q_1^* = \frac{a(2-\beta) - 2c + \beta r}{4 - \beta^2}, \tag{3}$$

$$\text{and } q_2^* = \frac{a(2-\beta) - 2r + \beta c}{4 - \beta^2}. \tag{4}$$

Substituting equations (3) and (4) in the leader's objective function we get its equilibrium profit as follows:

$$L(r,c) = \frac{[a(2-\beta) - 2c + \beta r]^2}{(4-\beta^2)^2}.$$

To begin with, let us examine the case where the technology T_1 has already been adopted. The leader firm is considering whether to adopt T_2 or not. If T_2 is not adopted, then the leader's discounted profit is given by

$$\int_0^\infty e^{-\rho t} L(r_t^1, c^1)dt,$$

$$\text{where } r_t^1 = e^{-\lambda t}(r - c^1) + c^1.$$

If T_2 is adopted, then the leader's discounted profit is :

$$\int_0^\infty e^{-\rho t} L(r_t^2, c^2)dt - X_2,$$

$$\text{where } r_t^2 = e^{-\lambda t}(r - c^2) + c^2.$$

So, the net discounted gain of the leader firm from adoption of T_2 is given as:

$$E(r) = \int_0^\infty e^{-\rho t}[L(r_t^2, c^2) - L(r_t^1, c^1)]dt - X_2.$$

If $E(r) > 0$, then T_2 will be adopted.

$$\text{Further,} \quad E'(r) = \int_0^\infty e^{-\rho t}\{L_r(r_t^2, c^2) - L_r(r_t^1, c^1)\}dt. \tag{6}$$

To prove that $E'(r) > 0$, we have to show that

$$\{L_r(r_t^2, c^2) - L_r(r_t^1, c^1)\} > 0.$$

Now, under the differentiated product case

$$L(r_t^2, c^2) = \frac{[a(2-\beta) - 2c^2 + \beta r_t^2]^2}{(4-\beta^2)^2}$$

$$= \frac{[a(2-\beta) - 2c^2 + \beta\{e^{-\lambda t}(r - c^2) + c^2\}]^2}{(4-\beta^2)^2}$$

$$= \frac{[a(2-\beta) - 2c^2 + \beta e^{-\lambda t}(r - c^2) + \beta c^2]^2}{(4-\beta^2)^2}$$

$$= \frac{\{a(2-\beta) - c^2(2-\beta) + \beta e^{-\lambda t}(r - c^2)\}^2}{(4-\beta^2)^2}$$

$$= \frac{\{(a - c^2)(2-\beta) + \beta e^{-\lambda t}(r - c^2)\}^2}{(4-\beta^2)^2}.$$

Therefore, $L_r(r_t^2, c^2) = \dfrac{2\{(a-c^2)(2-\beta)+\beta e^{-\lambda t}(r-c^2)\}\beta e^{-\lambda t}}{(4-\beta^2)^2}$.

Similarly, $L_r(r_t^1, c^1) = \dfrac{2\{(a-c^1)(2-\beta)+\beta e^{-\lambda t}(r-c^1)\}\beta e^{-\lambda t}}{(4-\beta^2)^2}$.

Thus, $L_r(r_t^2, c^2) - L_r(r_t^1, c^1) = \dfrac{2\beta e^{-\lambda t}}{(4-\beta^2)^2}[(a-c^2-a+c^1)(2-\beta)+\beta e^{-\lambda t}(r-c^2-r+c^1)]$

$$= \frac{2\beta e^{-\lambda t}}{(4-\beta^2)^2}[(c^1-c^2)(2-\beta+\beta e^{-\lambda t})]. \quad (7)$$

Now, $c^1 > c^2$ by assumption, $2-\beta>0$ as we assumed that $0<\beta<1$ and $\beta e^{-\lambda t}>0$ for $\beta>0$. Hence from equation (7) we can write

$$L_r(r_t^2, c^2) - L_r(r_t^1, c^1) > 0 \text{ provided } 0<\beta<1. \quad (8)$$

$$\text{Therefore, } E'(r) > 0 \text{ for } 0<\beta<1. \quad (9)$$

So, a decrease in the follower's unit cost reduces the leader's adoption incentive when the goods produced by firms are differentiated but substitutes. So the leader firm will choose to adopt the available technology instantly, if it is to be adopted at all -- the same result as in the homogeneous good case.

Let us now consider the adoption decision of the technology T_1. First consider the case where the technology T_2 is never adopted. The net discounted gain from the adoption of T_1 is given by:

$$E(r) = \int_0^\infty e^{-\rho t}[L(r_t^1, c^1) - L(r_t^0, c^0)]dt - X_1,$$

$$\text{where } r_t^1 = e^{-\lambda t}(r^0 - c^1) + c^1,$$

$$\text{and } r_t^0 = e^{-\lambda t}(r^0 - c^0) + c^0.$$

$$\text{Therefore, } E'(r) = \int_0^\infty e^{-\rho t}[L_r(r_t^1, c^1) - L_r(r_t^0, c^0)]dt. \tag{10}$$

Now, under the differentiated product case

$$L(r_t^1, c^1) = \frac{[a(2-\beta) - 2c^1 + \beta r_t^1]^2}{(4-\beta^2)^2}$$

$$= \frac{[a(2-\beta) - 2c^1 + \beta\{e^{-\lambda t}(r^0 - c^1) + c^1\}]^2}{(4-\beta^2)^2}$$

$$= \frac{[a(2-\beta) - 2c^1 + \beta e^{-\lambda t}(r^0 - c^1) + \beta c^1]^2}{(4-\beta^2)^2}$$

$$= \frac{[(2-\beta)(a - c^1) + \beta e^{-\lambda t}(r^0 - c^1)]^2}{(4-\beta^2)^2}.$$

$$\text{Therefore, } L_r(r_t^1, c^1) = \frac{2[(2-\beta)(a - c^1) + \beta e^{-\lambda t}(r^0 - c^1)]\beta e^{-\lambda t}}{(4-\beta^2)^2}.$$

$$\text{Similarly, } L_r(r_t^0, c^0) = \frac{2[(2-\beta)(a - c^0) + \beta e^{-\lambda t}(r^0 - c^0)]\beta e^{-\lambda t}}{(4-\beta^2)^2}.$$

$$\text{Therefore, } L_r(r_t^1, c^1) - L_r(r_t^0, c^0) = \frac{2\beta e^{-\lambda t}}{(4-\beta^2)^2}[(2-\beta)(c^0 - c^1) + \beta e^{-\lambda t}(c^0 - c^1)]. \tag{11}$$

Now, $c^0 > c^1$ by assumption. Further, $2 - \beta > 0$ as we assumed that $0 < \beta < 1$ and $\beta e^{-\lambda t} > 0$ for $\beta > 0$. Hence from equation (11) we can write

$$L_r(r_t^1, c^1) - L_r(r_t^0, c^0) > 0 \ \text{ for } \ 0 < \beta < 1. \tag{12}$$

Substituting equation (12) in equation (11) we get

$$E'(r) > 0 \ \text{ for } \ 0 < \beta < 1. \tag{13}$$

Therefore, the leader will find it optimal to adopt the technology T_1 instantly if it is to be adopted at all.

Lastly, consider the case where T_2 is instantaneously adopted. The net discounted gain of the leader from the adoption of T_1 and T_2 is given by:

$$E(r) = \int_0^\infty e^{-\rho t}[L(r_t^2, c^2) - L(r_t^0, c^0)]dt - X_1 - X_2,$$

$$\text{where } r_t^2 = e^{-\lambda t}(r^0 - c^2) + c^2,$$

$$\text{and } r_t^0 = e^{-\lambda t}(r^0 - c^0) + c^0.$$

$$\text{Therefore, } E'(r) = \int_0^\infty e^{-\rho t}[L_r(r_t^2, c^2) - L_r(r_t^0, c^0)]dt. \tag{14}$$

Now, under the differentiated product we have

$$L(r_t^2, c^2) = \frac{[a(2-\beta) - 2c^2 + \beta r_t^2]^2}{(4-\beta^2)^2}$$

$$= \frac{[a(2-\beta) - 2c^2 + \beta\{e^{-\lambda t}(r^0 - c^2) + c^2\}]^2}{(4-\beta^2)^2}$$

$$= \frac{[(2-\beta)(a-c^2)+\beta e^{-\lambda t}(r^0-c^2)]^2}{(4-\beta^2)^2}.$$

Therefore, $L_r(r_t^2, c^2) = \dfrac{2[(2-\beta)(a-c^2)+\beta e^{-\lambda t}(r^0-c^2)]\beta e^{-\lambda t}}{(4-\beta^2)^2}$.

Similarly, $L_r(r_t^0, c^0) = \dfrac{2[(2-\beta)(a-c^0)+\beta e^{-\lambda t}(r^0-c^0)]\beta e^{-\lambda t}}{(4-\beta^2)^2}$.

Therefore, $L_r(r_t^2, c^2) - L_r(r_t^0, c^0) = \dfrac{2\beta e^{-\lambda t}}{(4-\beta^2)^2}[(2-\beta)(c^0-c^2)+\beta e^{-\lambda t}(c^0-c^2)]$

$$= \frac{2\beta e^{-\lambda t}}{(4-\beta^2)^2}[(c^0-c^2)(2-\beta+\beta e^{-\lambda t})]. \qquad (15)$$

Now, $c^0 > c^2$ by assumption. Further, $2-\beta > 0$ as we assumed that $0 < \beta < 1$ and $\beta e^{-\lambda t} > 0$ for $\beta > 0$. Therefore, we can write from equation (15)

$$L_r(r_t^2, c^2) - L_r(r_t^0, c^0) > 0 \quad \text{provided } 0 < \beta < 1. \qquad (16)$$

Substituting (16) in (14) we get

$$E'(r) > 0 \quad \text{for} \quad 0 < \beta < 1.$$

Therefore, the leader's optimal strategy is to adopt the technologies instantly, if they are to be adopted at all. Thus, there will be bunching of innovations at the beginning of quantity competition if goods are substitute of one another. So it may be concluded that, the basic quantity competition result regarding the adoption behaviour of the leader firm does not change under the differentiated product case, if the goods are substitutes.

Let us now assume that the goods produced by firms are differentiated but complement to each other. In this case, $\beta < 0$. Let us consider the case where the technology T_1 has already been adopted. The leader is considering whether to adopt T_2 or not.

So from equation (7) we get

$$L_r(r_t^2, c^2) - L_r(r_t^1, c^1) = \frac{2\beta e^{-\lambda t}}{(4-\beta^2)^2}[(c^1 - c^2)(2 + \beta(e^{-\lambda t} - 1))]. \tag{17}$$

For $\lambda > 0$, $0 < t < \infty$, $e^{-\lambda t} < 1$. Now if $\beta < 0$, $\beta(e^{-\lambda t} - 1) > 0$. So, $2 + \beta(e^{-\lambda t} - 1) > 0$. Further, $c^1 - c^2 > 0$ by assumption. Hence we get from equation (17)

$$L_r(r_t^2, c^2) - L_r(r_t^1, c^1) < 0. \tag{18}$$

Substituting (18) in equation (6) we get

$$E'(r) < 0 \text{ for } \beta < 0, \lambda > 0, \; 0 < t < \infty. \tag{19}$$

A decrease in the follower's unit cost enhances the adoption incentive of the leader firm. So, in this case there might arise a possibility where the technology T_2 is adopted in a staggered manner. However, this depends on the cost of adoption of T_2. When the adoption cost is too high to reap a positive net gain from the adoption, the leader will wait until the adoption of T_2 becomes profitable.

Let us now consider the case where the technology T_2 is never adopted. Here the leader firm's sole consideration is whether to adopt T_1 or not.

From equation (11) we get

$$L_r(r_t^1, c^1) - L_r(r_t^0, c^0) = \frac{2\beta e^{-\lambda t}}{(4-\beta^2)^2}[(c^0 - c^1)\{2 + \beta(e^{-\lambda t} - 1)\}]. \tag{20}$$

For $\lambda > 0$, $0 < t < \infty$, $e^{-\lambda t} < 1$. Now, if $\beta < 0$, $\beta(e^{-\lambda t} - 1) > 0$. So, $2 + \beta(e^{-\lambda t} - 1) > 0$. Further, $c^0 > c^1$ by assumption. Therefore, we can write from equation (20)

$$L_r(r_t^1, c^1) - L_r(r_t^0, c^0) < 0. \tag{21}$$

Substituting (21) in (10) we get

$$E'(r) < 0 \quad \text{for } \beta < 0, \ \lambda > 0, \quad 0 < t < \infty. \tag{22}$$

Therefore, a decrease in the follower's unit cost due to diffusion enhances the leader's incentive to adopt the technology. So the leader might adopt T_1 with some time lag. However, all this depends on the adoption cost of T_1. If the cost is high enough to make the leader's net discounted gain from instantaneous adoption negative, then the leader will wait until the adoption of T_1 becomes profitable. In that case there will be delayed adoption of T_1.

Thus, when the goods are substitutes, the leader's optimal strategy will be to adopt the available innovations instantly, if they are to be adopted at all. However, if the goods produced by the firms are complements, the leader might adopt the technologies in a staggered manner. Therefore, it may be concluded that the nature of substitutability among the goods determines the nature of adoption of existing innovations.

Chapter-6

(Conclusion)

Conclusion

In this thesis we take up the question of technology adoption in a dynamic framework. While there have been several studies, both theoretical as well as empirical, dealing with the technology adoption in a static framework, much less work is available in a dynamic framework. In particular, we are interested in the question of staggered adoption. Suppose, a technology is available. The question is would it be adopted immediately or would there be a delay in the adoption.

One paper that deals with the issue is **Mookherjee and Ray** (1991). They show that under the Cournot competition, the technologies are bunched and adopted instantly. However, under price competition, the possibility of staggered adoption arises. Our objective in this thesis is to extend these results.

Our first extension is motivated by a conjecture in **Mookherjee and Ray** (1991) itself. They conjecture that what is important is not whether firms compete in prices or quantities, but whether the competition is potential (price) or actual (quantity). In order to test this conjecture, we re-examine the model under the Cournot competition where there is free entry for the follower firms. We find that, this does not alter the result under the Cournot competition. Even in this case there is no staggering of the technologies. So it can be concluded that the threat of potential competition does not change the basic adoption behaviour (bunching of innovations) of the leader firm under quantity competition.

We then examine the model under quantity competition where the nature of competition is of the Stackleberg, rather than the Cournot kind. Again, the results remain unaltered. Therefore, it can be concluded that the adoption behaviour of the leader firm does not depend on the nature of product market competition.

Finally, we consider the case where the product is differentiated. Under quantity competition, we find that with substitute products, there is no staggering of adoption. However, the possibility of staggering may arise if the goods produced by the firms are complements to each other. Thus the nature of substitutability among the goods produced by the competing firms may determine the nature of adoption by the leader firm.

To conclude, we show that the nature of competition, whether actual or potential, does not make much of a difference to the qualitative pattern of adoption. What is important is whether the products are substitutes or complements.

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