THEORY OF INNOVATION AND PATENTS WITH SPECIAL FOCUS ON INDIAN INDUSTRY

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Declaration

This is to certify that the dissertation titled "***THEORY OF INNOVATION AND PATENTS WITH SPECIAL FOCUS ON INDIAN INDUSTRY***" being submitted to the **Centre for Economic Studies and Planning, School of Social Sciences, Jawaharlal Nehru University**, by **Mr. NANDAN KUMAR JHA**, in partial fulfilment of the requirements for the award of **Master of Philosophy** degree has not been previously submitted for any other degree of this or any other University.

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We recommend that this dissertation be placed before the Examiners for evaluation.

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The errors of commissions and omissions are entirely mine.

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CHAPTER 1: Introduction

Overview

From 1950s onwards there has been substantial interest in the phenomenon of technical change. Solow (1957) gave analytical foundations to the proposition that technical advance had been an important source of growth. Another source of interest of technical change came from Schumpeter's (1942) 'Capitalism, Socialism, and Democracy'. He argued that microeconomic analysis, which had come to dominate mainline economics, was missing the point by focusing on competition in a static context. In many industries technical advance was the principal weapon of competition, and that in terms of the social benefits, competition induced innovation was vastly more important than competition induced marginal cost pricing. He further said that a market structure involving large firms with a reasonable amount of market power was both inevitable and desirable, where innovation was potentially important, as against orthodox views about the relationship between market structure and competition. He further stressed that over the long run the gains to society from continuing innovation are vastly greater than those associated with competitive pricing. A market structure involving firms, each with considerable degree of market power, is the price that society must pay for rapid technological advance. Thus, there is a trade off between static efficiency, in the sense of prices close to marginal cost, and dynamic progressiveness.

The academic literature on research and development (R & D) and related issues has focused on Schumpeter's (1942) argument that seller concentration enhances R & D and innovation. According to this argument, a large-scale monopoly firm is to be preferred to many small-scale competitive firms on two grounds. First, the monopoly firm will have greater demand for innovation because its large size increases the ability to profit from any innovation. Second, the monopoly firm will generate a greater supply of innovations because 'there are advantages which though not strictly unattainable on the competitive level of enterprise, are as a matter of fact secured only on the monopoly level' (Schumpeter, 1942, p. 101).

In a recent study on this subject, Baumol (2002) has emphasized the importance of innovation as the vehicle of growth in a capitalist economy. He argues essentially that innovation led growth of capitalist economic systems set them apart from other systems of economy. However, the importance of innovation in an economy notwithstanding, it has also been widely acknowledged that innovation leads to creation of monopoly power, which is the price that a society has to pay to gain dynamic efficiency in the form of rapid growth of its economy.

There is a remarkable consensus amongst economists on the issue of innovation as a means to attain high growth rates of incomes. But there are inherent problems associated with innovation, which have also been analysed with equal importance. Inventions and innovations have properties of public goods and, more often than not, are the source for future inventions. While the latter makes them cumulative in nature and hence makes their valuation very difficult, the former acts as disincentive for firms to undertake R & D spending. This suggests an active role for public policy. To this end, in general, every economy of the world has instituted a patent system to facilitate appropriation of R & D spending by firms undertaking it. The economic literature has emphasized the need for granting temporary monopoly power to firms doing innovations. The argument essentially is that the firms would be able to recoup their R & D spending if they are conferred Intellectual Property Rights in order to correct the market failure arising due to spillover of innovations to other firms. There can be other institutions, such as prizes, contracts etc. in place of a patent system to correct this situation. The other measure discussed in the literature to correct this externality is formation of cooperatives among firms. The magnitude of spillover of an innovation has considerable significance in these studies.

Organisation

The present study is an attempt to survey the literature in the area of research and development which is very important for rapid growth of any economy. We have also looked at the issues related to R & D in Indian industries. We have organised this work into three chapters, each one looking at different issues related to R & D. In the first two chapters we have reviewed the theoretical literature on innovation and patent. In the last chapter we have attempted to look into the scenario of R & D in Indian industries. There is a considerable dearth of theoretical literature on the study of R & D in the context of developing economies like India, where technology has traditionally been adaptive in nature. We have looked into the role of firm size and market structure in determining R & D investments in India based on some of the empirical studies undertaken to analyse these relationships in Indian industries.

Chapter 1 reviews the literature on innovation and related issues. We have divided the chapter into four sections. The section titled 'non-cooperative R & D' is an attempt to analyse the relationship between size, market structure, and R & D spending of firms under the assumption that their behaviour will not affect the behaviour of rivals. We have also reviewed the literature on timing aspect of innovation in much detail. The section titled 'speed of R & D' analyses the date of innovation and related issues in symmetric as well as asymmetric assumptions. This type of analysis, apart from taking the timing aspect of innovations, also investigates the relationships in the Schumpeterian tradition. Finally, the last section of this chapter has investigated the literature on cooperative R & D. The presence of spillovers, where research done by one firm can be used by another at almost no price paid to the former, makes it very difficult for the firms to appropriate their R & D costs. This is one way of providing firms with incentives to undertake R & D investments. Other means of incentives to firms undertaking R & D can be patent systems, prizes, contracts, etc. This is what we have analysed in chapter 2.

The price that the society has to pay to gain dynamic efficiency is to confer monopoly rights to the innovating firms. For this purpose, almost all countries in the world have institutionalised a patent system. In chapter 2, we have looked into the issues related to patents such as its length, broadness, and their relationship with R & D spending of firms. The empirical literature on this area has also been looked at. The chapter has been divided into six sections to render simplicity into our analysis. To balance static welfare losses and dynamic welfare gains, there is a consensus in the literature on this subject that patent protection should last a limited time only. However, there is little consensus among economists on the issue of the scope of patents, i.e. its broadness. If patents are narrow, it makes imitation of products or processes very easy. Thus, the spillovers to rivals become very easy and firms are unable to recoup their R & D costs. Also, innovations are cumulative in nature. This implies that the social value of innovations should include the value of subsequent innovations they inspire in order to rule out discrepancy between the social value and the profit collected by the innovator. This suggests for a public policy to design optimal patent breadth. The literature in this particular area has argued for broad patent protection to overcome the externality that exists between different generations of innovations. We have also looked at some of the empirical findings on this subject. Finally, we have analysed some other alternative incentive mechanisms, such as prizes, contracts, and secrecy to stimulate R & D among firms. The patent system has its pros and cons, and hence other mechanisms to promote R & D investments should also be taken into account. But, the problems associated with these mechanisms make them difficult to implement. Thus, the policy makers across the globe have adopted patent system to provide incentives to firms to undertake R & D.

Finally, we have tried to look at these issues in the context of Indian industries in chapter 3. We have divided the chapter into six sections. First four sections give us an overall picture of R & D in Indian industries and problems associated with it. We have attempted to look into technological capability of India in regulated as well as liberalized regimes. We also take up the issues related to patents in Indian industries. The section titled 'firm size, market structure and R & D activity in India' is an attempt to link Indian industry scenario with relationships investigated in Schumpeterian tradition. We have undertaken two case studies, one from pharmaceutical industry and the other from automobile industry, to look at the behaviour and performance of these firms in terms of R & D spending and their contribution in nation building. The high and unrelenting level of R & D spending of these enterprises have made them technological leaders in their respective fields of operation. The intensity of growth and geographical spread of these companies have the potential of being characterized as models for others to follow.

Concepts Used in the Analysis

Below, we briefly discuss some key concepts to be used in our analysis:

Innovation: Innovation refers to a change in ideas, practices or objects involving some degree of (a) novelty or creation based on human ingenuity and (b) success in application. The concept is used to refer to the new idea, practice or object as well as the process leading to it.

The concept of success can be sub-divided into technical success, commercial success and economic success. Technical success means that technical specifications have been met and / or an invention has been achieved. Commercial success means that the invention has found a first commercial application and economic success means that an acceptable return on the total investment has been achieved.

Invention: An invention is a novelty or creation based on human ingenuity, but the concept of invention does not require success in application. An invention becomes an innovation when it achieves commercial success. However, as both innovation and invention are the outcomes of R & D investments by firms, we have used these concepts interchangeably to analyse the behaviour of firms.

Diffusion: The concept of diffusion refers to the process by which an innovation is adopted by individuals and organizations in a population. This population may consist of potential buyers or users in a market, sellers or producers in an industry, departments in an organization and nations in the world.

Imitation: The concept of imitation refers to close reproduction or near duplication of ideas, practices or objects that were once perceived as inventions or innovations.

CHAPTER 2: R & D and Innovation

Introduction

Research and Development (R & D) makes a significant contribution to the competitive strength of industries, large as well as small, in national as well as international markets. Therefore, R & D and technological innovations play a decisive role in industrial development as they make it possible for industries to bring out new and improved materials, products, processes and systems which are the ultimate source of industrial advancement. Technology and innovation play a crucial role in promoting economic growth of a nation. It is also very important in analysing the differences between nations in economic growth and development. There is, now, a consensus among economists working in the area of economic growth that high investment rates alone in the absence of technological change will not sustain high growth rates in income, because returns to capital will only diminish in the long run. In other words, increase in one of the factors of production, in this case, capital, without corresponding increase in other factors will merely result in a decrease in the return to capital. Hence, only technological change and innovation can sustain high growth.

The above view has emphatically been expressed by one of the notable economists of our time, William J. Baumol in his book "The Free-Market Innovation Machine" (Baumol, 2002). He contends that the capitalist economy can be viewed as an innovating machine whose primary product is economic growth. It is the spectacular and historically unprecedented growth rates of the industrialized economies – the growth rates of their productivity and per-capita incomes – that, above all, set them apart from all alternative economic systems. In the past 150 years, per capita incomes in a typical free-market economy have risen by amounts ranging from several hundred to several thousand percent.[1] This performance can be attributed primarily to competitive pressures, not present in any other types of economy, that force firms in the relevant sectors of the economy to unrelenting investment in innovation. The firms have made innovative activity a regular and even ordinary component of their day-to-day activities, thereby minimizing the uncertainty of the process. It is estimated that some 70 percent of US R & D spending is now done by private industry, much of it incorporated into firms' day-to-day activities.[2]

He further notes that the standard microeconomic analysis contains little on this subject, but fortunately innovation can be integrated into the standard structure of microeconomic analysis. This is made possible by the competitive market pressures that force firms to integrate innovation into their decision processes and activities.[3] It can be noted in this regard that the main focus of the standard neoclassical theory of the firm has been the profit maximizing production processes and quantities of inputs and outputs under different market conditions based on different assumptions regarding time-scale, behavioural perceptions, quality of information etc. In order to incorporate R & D spending by firms as an input and a subsequent change in technology set due to improvements made, this theory needs to be extended.

Considerable work in building up such a generalized theory has been done in recent times by a number of authors. This work has been much inspired by Schumpeter's (1942) ideas about the central role of innovation in modern capitalist economies and the roles of the entrepreneur and market structure in the innovation process. The theoretical literature in this area is concerned primarily with investigations of interrelationships between R & D spending, firm size, and market structure in an attempt to provide a theoretical grounding for Schumpeterian hypothesis. Two broad hypotheses are associated with Schumpeter:

1. There is a positive relationship between innovation and monopoly power, where the firm in question makes monopoly profits.
2. Large firms are relatively more innovative than small firms.

R & D is the act of creating (changing) the production function. It is the basis for the production of knowledge and know-how. It is the monetary equivalent of inputs to the process producing technological advances or invention. R & D spending is an input to both invention and innovation. The R & D expenditure of a firm may lead to process or product improvements. The profits that the firms can obtain from its research process will depend upon the cost of making the advances and the increment in revenue that can be derived from the application or marketing of improvements. The cost side of R & D depends on technological opportunity, efficiency and the speed of development, while the revenue generation from the application and marketing of technological advance depends on how quickly other firms can copy or match the advances made. The innovating firm generates revenue by various means.

- It can incorporate the advances made in its own products and gain market share or can introduce new processes into its production methods which can give it cost advantage.
- Then it can follow a profit-maximizing strategy on the product market. The firm can also raise revenue by licensing the advances made to those who have not developed the technology themselves.

How well the firm will be able to capitalize on any advances made will depend upon the degree to which the firm is able to gain property rights on its inventions, as innovation has many characteristics of a public good. Thus, the returns on R & D depend on the effectiveness of the patent system and on the importance of other mechanisms that can protect technology such as prizes, contracts, secrecy etc. so that the firm is able to earn positive profits on its innovation which in turn will act as stimulant to undertake R & D on a regular basis. We will take up issues related to patents and other policy measures to solve appropriability problem associated with output of R & D in a separate chapter later.

This chapter looks at some of the basic theories in this regard. We shall be looking at some of the basic models showing interrelationship as mentioned above in non-cooperative as well as cooperative settings. We shall also look at the timing aspect of innovation and related issues. We broadly divide this chapter into three sections. The first section looks at some of the early works to investigate R & D expenditure, firm size and market structure interrelationships when firms act non-cooperatively. The second section lists some of the works done on the timing aspect of innovation. This analysis enables one to look at both the R & D expenditures and the timing of innovation. The last section investigates the most recent works triggered after R & D joint ventures were initiated as a policy tool to address appropriability problem of R & D output. The central focus of the literature on cooperative R & D has been to analyse R & D expenditure and output in the product market in the presence of spillovers. Welfare implications of undertaking R & D are also discussed in all the three sections.

Non-Cooperative R & D

Below, we present a model put forth by Arrow (1962). Arrow looks at the incentives to invent by investing in R & D for monopolistic and competitive markets by comparing the two and also compares these two with the social optimum that would exist if the economy were socially managed. He argues essentially that there is a tendency in industry to underinvest in R & D from society's point of view due to problems for a firm to appropriate the economic benefits of its R & D by virtue of it having public good characteristics. Patent protection would be one way of coping with this. Other ways can be prizes, contracts, etc. (See Wright, 1983). The principal way a patent affects innovation is through its effects on the rate of imitation. In the Arrow type of modelling, the innovator's profits dwindle completely by competition when imitation occurs. Thus a delay in imitation through patent protection would be stimulus for firms to invest in R & D, at the expense to society of the possible overpricing of products by the monopolistic patent holder. Arrow's model applies only to process innovation and does not consider product innovation. This approach begins with one innovation having already been made and takes no account of the process leading to that invention.

Arrow (1962):

In the figure below $\mathbf{c_0}$ is the pre-invention unit cost that is brought down to $\mathbf{c_1}$ after innovation. The figure represents the case when the innovation is said to be drastic, i.e. the post invention monopoly price $\mathbf{p_{1M}}$ is less than $\mathbf{c_0}$. We will consider small innovation separately.

It is assumed that R & D expenditure is undertaken at one go which results in instantaneous process innovation for the firm. This fixed R & D cost is then appropriated by the innovating firm through incremental profits that it earns because of reduced unit costs of production. As can be seen from the figure, the monopoly firm's incentive to invest in R & D is given by the incremental profits that it would receive, which is given by the difference between its post-innovation profits (FGHI) and pre-invention profits (ABCE). This is equal to FGHI – ABCE = π_M.

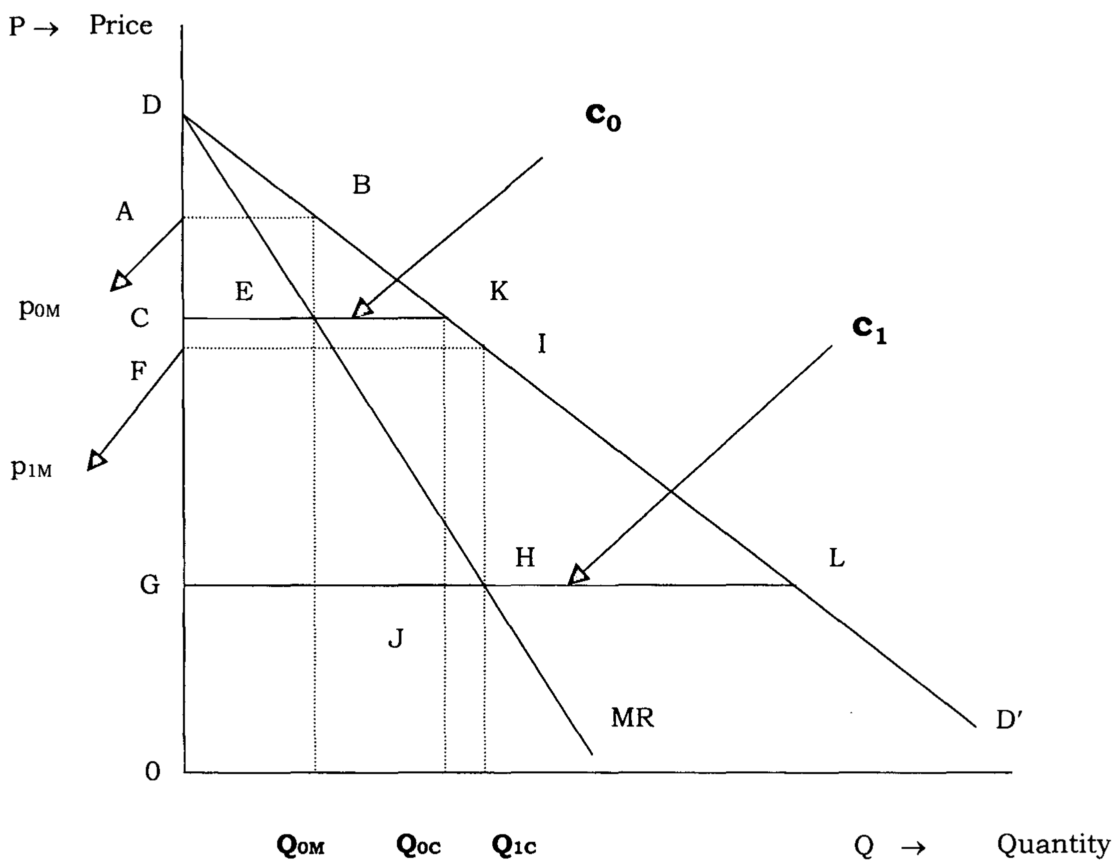

Figure: 1

In case of competitive industry, the innovating firm becomes the monopoly by holding the patent of the new technology. Earlier, it was getting zero profits, but now, it gets an incremental profit of π_C = FGHI. Clearly, the incentive for a competitive firm to undertake R & D investment is greater, i.e. $\pi_C > \pi_M$.

The socially managed market would generate social gains equal to π_S, equal to the area bounded by the region CGLK at new price equal to $\mathbf{c_1}$. Thus, we have $\pi_S > \pi_C > \pi_M$.

Let us consider the case when innovation is small, i.e. $\mathbf{p_{1M}} > \mathbf{c_0}$.

Social Optimum

Let D(c) be the demand curve, set by the social planner at prices equal to marginal cost. The incremental social surplus is the incentive for social planner to innovate. Thus, the present value of this social surplus is given by the following:

$\pi_S = \int_0^{\infty} e^{-rt}\left[\int_{c_1}^{c_0} D(c)\,dc\right]dt = \frac{1}{r}\int_{c_1}^{c_0} D(c)\,dc$, where r is the rate of discounting. ....(1)

Monopoly Firm

Lets look at the monopoly firm's incentives to innovate. From the Envelope Theorem, we have:

$$\frac{d\pi_M(p_M(c))}{dc} = \frac{\partial \pi_M}{\partial c} = -D(p_M(c))$$

The present value of incremental profits that the monopoly firm would receive is thus, given as:

$$\begin{aligned}\pi_M &= \int_0^{\infty} e^{-rt}\left[\int_{c_1}^{c_0}[\pi_M(c_1) - \pi_M(c_0)]\right]dt \\ &= \frac{1}{r}\int_{c_1}^{c_0}\left(-\frac{d\pi_M}{dc}\right)dc \\ &= \frac{1}{r}\int_{c_1}^{c_0} D(p_M(c))\,dc\end{aligned}$$

..................(2)

Now, for any c, $p_M(c) > c$, which in turn implies that $D(p_M(c)) < D(c)$. .... (3)

From (1), (2), and (3) we have: $\pi_S > \pi_M$.

Competitive Framework

In this case, the innovator is constrained to charge a price equal to $\mathbf{c_0}$ because there is a competitive supply from the other firms at $p = \mathbf{c_0}$. Here the present value of the incremental profits is simply given as:

$$\pi_C = \frac{1}{r} \int_{c_1}^{c_0} D\,(c_0)\,dc \qquad \text{....................(4)}$$

Now, from the definition of small innovations, we have $c_0 < p_M(c_1)\ \forall\ c \in [c_1, c_0]$.

$\Rightarrow\ D\,(c_0) > D\,(p_m(c))\ \forall\ c > c_1$.

Also, $D\,(c_0) < D(c)\ \forall\ c < c_0$.

Comparing equations (1), (2), and (4) gives us the following result:

$\pi_S > \pi_C > \pi_M$.

Thus, competition encourages innovation and invention, but in general, the incentives to both competitive and monopoly industries are less than the potential benefit, which suggests that there will be an underinvestment in R & D. The monopolist gains less from innovating than does a competitive firm, because the monopolist replaces himself when he innovates, whereas a competitive firm becomes a monopoly. Arrow called this property as 'replacement effect'.

The above results may seem contrary to Schumpeterian contention that at least some monopoly power was necessary for innovative activity. But Arrow's analysis is not a refutation of Schumpeter's because he refers to the structure of the industry purchasing the innovation rather than to the structure of the industry producing it (See Kamien and Schwartz, 1982).

Nordhaus (1969):

Another seminal work in this area has been put forth by Nordhaus (1969). He considers a firm having two departments, one producing a regular product and the other cost-reducing innovations. The model has two versions. The model is purely static in the sense that only one time period of length τ is considered within which all variables remain unchanged. The first version of the model assumes a perfectly competitive environment with no spillover (externality) effect, i.e. it assumes that due to prohibitive transfer costs, no firm may benefit from research conducted by other firms. These two assumptions are relaxed in the second version of the model. In the second version of the model, the commodity price and the number of firms are endogenously determined. The competitive solution of the second version is then compared with the optimal solution for the socially managed industry. This comparison establishes the result as obtained by Arrow (1962) above, namely that market economy invests less in research than socially optimal.

Version I: Perfect Competition with no Spillover Effect

The production function of the firm is Q = T (R) F (K, L), where T is the level of technology; R, K, L are research expenditure, services of capital and labour respectively. The firm chooses R, K, and L to maximize the value of net profits (denoted as V) generated in the period (0, τ) and discounted at time zero. Thus, we have:

$V = \int_0^{\infty} [pT(R)F(K, L) - qK - wL]e^{-rt}\,dt - R$, where q is the rental on capital, w is the wage rate, and r is the constant discount rate. As all variables remain constant within (0, τ), we have

$$V = [pT(R)F(K, L) - qK - wL]\frac{1 - e^{-rt}}{r} - R$$

Assuming normal neoclassical properties ensures that a positive solution exists. Choosing optimal R leads to the following first order conditions:

$$\frac{\partial V}{\partial R} = pT^{'}(R)F(K, L)\frac{1 - e^{-rt}}{r} - 1 = 0$$

$$\text{Thus, } T^{'}(R) = \frac{r}{1 - e^{-rt}}\frac{T(R)}{pT(R)F(K, L)}$$

$$= \frac{r}{1 - e^{-rt}}\frac{T(R)}{pQ}$$

If returns to research expenditure are diminishing at a decreasing rate then:

- We have a positive association between firm's optimal R and its size, which reflects the proportionality of cost savings to output.
- Optimal R is negatively related to r, which captures the fact that a higher discount rate reduces the present value of future marginal benefits.

Version II: Oligopoly with Free Entry and Spillover

Firms are assumed to be symmetric and they maximize profits non-cooperatively. Entry and exit in the market is free. The technology function has a convenient additive form, given by:

$$T^j = \sum_{i=1}^{N} \lambda_{ij} R_j^{\alpha}; \; 0 < \lambda_{ij} < 1 \text{ and } 0 < \alpha < 1$$

Here, λ is the spillover parameter. Symmetry of the firms implies that

$$\lambda_{ij} = \lambda \text{ for all } i \neq j \text{ and } \lambda_{ij} = 1 \text{ for } i = j$$

Input-output coefficients are fixed, i.e.

$F(K_j, L_j) = \min(aK_j, L_j) \text{ for } L_j \leq \overline{L_j}$

Since firms are identical, we have

$L_j = \overline{L} \text{ and } R_j = R$.

In this set up we have the following production function:

$Q = T(R)F(K, L) = [(N-1)\lambda + 1]R^{\alpha}\overline{L}$.

Nordhaus denotes $[(N - 1)\lambda + 1]$ as μ and shows that it represents social to private marginal benefits for undertaking R & D expenditure. He treats μ as a given constant parameter, specific for a particular industry. He takes industry demand to be fixed, i.e. price elasticity of industry demand is zero. Below we define the various variables that Nordhaus looked at.

1. $\frac{R}{pQ}$ is the measure for research intensity.

2. $\frac{1}{N}$ is the index of concentration.

3. Unit prime cost of production, 'c' measures technical efficiency.

4. $\frac{p-c}{c}$ represents 'monopoly power'.

Nordhaus concludes that given the zero price elasticity of demand, an increase in the size of spillover effect would raise the degree of concentration, reduce research intensity, increase technical efficiency of the industry, and reduce the mark-up over production cost. Thus, all other things remaining unchanged, the degree of concentration and technical efficiency would be positively related in an inter-industry comparison with μ varying. The monopoly power and research intensity would also be related. On comparing these results with social optimum that would exist in this situation Nordhaus found that the level of research under oligopoly might be significantly less than the socially optimal level, thereby reinforcing Arrow's claim.

An important aspect of the Nordhaus' model is the simplifying assumption of an infinitely inelastic demand function. This assumption is relaxed by Dasgupta and Stiglitz (1980a,b). They however, maintain the assumption of constant unit cost of conventional inputs, as done by Nordhaus. The price elasticity of Demand becomes an exogenously given key parameter of the environment in which firms operate, taking decisions that affect both innovation rate and market structure at the same time. They also assume away the spillover effect present in Nordhaus model. The spillover parameter λ is equal to zero and μ is identically equal to unity in this model.

Dasgupta and Stiglitz (1980a):

Dasgupta and Stiglitz take the approach that there is a continuum of advances that can be made, and the amount spent on current R & D determines the extent of the advances produced. The firm is assumed to generate reductions in unit costs by spending on R & D. If R & D spending is R, then unit cost of production **c**, is related to R by:

$$c = c(R); c'(R) < 0.$$

We note that the R & D spending itself yields reductions in unit costs. Once the technological advance is made, no further costs are involved in introducing and using that technology. Product innovations are not considered here. The new technology generated is exploited on the market by production using the new technology.

Consider firm i in an oligopoly industry. It will choose R & D spending R_i and its output Q_i to maximize profits π_i, where π_i is given by

$\pi_i = [p(Q_i + Q_r) - c(R_i)]Q_i - R_i$; where Q_r is the output of rivals. Thus, industry output is $Q \equiv Q_i + Q_r$.

Assuming Cournot competition, we have first order conditions as:

$$-c'(R_i)Q_i = 1 \qquad (1)$$

$$Q_i \frac{\partial p}{\partial Q} + p(Q) - c(R_i) = 0 \qquad (2)$$

Manipulating the equations algebraically, we get

$$p\left(1 - \frac{\epsilon(Q)Q_i}{Q}\right) = c(R_i);$$

where $\epsilon(Q) = -\frac{\partial p}{\partial Q}\frac{Q}{p}$ is the inverse elasticity of demand. (3)

Combining (1) and (3) we get

$$\frac{R_i}{pQ_i} = \alpha(R_i)\left[1 - \frac{\epsilon(Q)Q_i}{Q}\right]$$

where $\alpha(R_i) = -\frac{R_i c'(R_i)}{c(R_i)}$ is the elasticity of unit cost reduction with respect to R & D.

It can be noted here that α (R_i) is positive. Thus, high R & D to sales ratios for the firm is associated with smaller market shares. A greater effectiveness of R & D, i.e. a larger value for α (R_i) is associated with an R & D to sales ratio that is higher.

Considering innovation at the industry level, the Dasgupta and Stiglitz (1980a) model explores market equilibria that are symmetric. Let the number of firms in the equilibrium be N^*, which is endogenous. Then denoting N^*, Q^*, R^* as the symmetric equilibria, we have

$$p(Q^*)\left(1 - \frac{\epsilon(Q^*)}{N^*}\right) = c(R^*);$$

and $-c'(R^*)Q^* = N^*$

where Q^* is total output in equilibrium and Q^*/N^* is output per firm. Assuming free entry and zero profit condition, we have $[p(Q^*) - c(R^*)]\,Q^* = N^* R^*$. We can now solve for N^*, Q^*, and R^*. We have

$$\frac{\epsilon(Q^*)}{N^*} = \frac{N^* R^*}{p(Q^*)Q^*}$$

The above result shows that the ratio of industry R & D to industry sales equals the inverse of the elasticity of demand divided by the number of firms. Considering $1 / N^*$ as the measure of concentration, then, ceteris paribus, the R & D to sales ratio is linearly related to concentration. Further manipulation gives us

$$\frac{N^* R^*}{p(Q^*)Q^*} = \frac{\alpha(R^*)}{1 + \alpha(R^*)}$$

This equation implies that the R & D to sales ratio is the same in different industries if $\alpha(R^*)$ is the same. We also have

$$N^* = \in(Q^*)\,\frac{1 + \alpha(R^*)}{\alpha(R^*)}$$

Which implies that the greater is the elasticity of demand ($1 / \in$), the smaller is the equilibrium number of firms. Another useful result that we have is

$$\frac{p(Q^*)}{c(R^*)} = 1 + \alpha(R^*)$$

We may argue that the price cost margin or the degree of monopoly power is a positive function of $\alpha(R^*)$. Thus, we may say that high R & D to sales ratio is associated with high price-cost margins. Also, that N^* is inversely related to $\alpha(R^*)$, we have positive association between R & D per firm and unit cost reduction and thus with monopoly power.

It can be noted here that in this symmetric equilibrium all firms undertake the same amount of R & D and each independently discovers the same reduction in unit costs. There is no licensing by one firm to another. Also, the Cournot conjectures imply that each firm makes its own decisions in the belief that its behaviour will not affect the behaviour of rivals. To proceed further, we will assume that the demand and unit cost functions take the forms as:

$$p(Q) = \sigma Q^{-\epsilon} \text{ and } c(R) = \beta R^{-\alpha} \; ; (\alpha, \beta > 0)$$

With these specific functions, one can show that in equilibrium the greater is the size of the market (σ), the greater is R & D expenditure per firm and thus the greater is unit cost reduction. Greater β makes the R & D process costlier and in equilibrium, the greater is β, the smaller is R & D per firm if the demand is elastic and opposite is the case when demand is inelastic.

However, the main reason for introducing these particular cost and demand functions is to enable us to make welfare comparisons, and thus to generate some results comparable to those of Arrow (1962). With these specific functions Dasgupta and Stiglitz show that the net social return to innovation is maximized if R is determined such that

$$R = R^S = \left(\alpha^{\epsilon} \sigma \beta^{\epsilon - 1}\right)^{\frac{1}{\epsilon - \alpha(1 - \epsilon)}} \text{ holds and}$$

$$Q = Q^S = (\alpha\beta)^{-1} \left(\sigma \alpha^{\epsilon - 1}\right)^{\frac{(1+\alpha)}{[\alpha - \epsilon(1 - \epsilon)]}} .$$

With these specific functions, it can be shown that $Q^S > Q^*$ and $R^S > R^*$. However, if ϵ is large then $N^*R^* > R^S$. Thus, compared with the socially optimal solution, it will generally be the case that the rate of unit cost reduction will be too low ($R^S > R^*$), but if ϵ is large, there will be excessive expenditures on R & D because of too much repetition.

Speed of R & D

The above models described the extent of innovation aspect of technological change in the context of cost reduction. The other strand in the literature is one that considers that money is spent on R & D to achieve a given pre-determined technological advance, and the greater is the R & D expenditure, the earlier is the date at which the advance is made. This enables one to analyse both the expenditure on R & D and the date of innovation. This approach is perhaps best detailed in the work of Kamien and Schwartz (1982).

Kamien and Schwartz (1982):

The analysis considers one firm faced by rivals in the innovation process. They construct profit schedule of firm undertaking R & D expenditure based on the following:

1. Stream of profits prior to any innovation is introduced by any firm.
2. The firm in question happens to be the first to introduce innovation.
3. Post innovation stream of profits in case the rivals imitate.
4. Rivals introducing innovations first.
5. The stream of profits after the firm makes its own innovation in case rivals were the first to introduce a new product.

The firm's problem is to determine the optimal timing of introduction of its new product. It holds expectations regarding rival's innovation date. For this purpose Kamien and Schwartz (1982) introduce a hazard parameter in their model and show that an increase in the hazard parameter will hasten the expected date of rival entry. The main conclusions of their model are:

- High profits on an existing product slow down innovation if the innovation is a substitute for the existing product. A firm may thus have greater incentive to develop diversified products.
- Rivalry will have a definite influence on the date of innovation.
- The firm's introduction date may be premature or late relative to the social optimum time at which development costs just balance expected benefits.
- As rivalry increases, innovations with expected modest returns will be introduced rapidly up to some level of rivalry, after which the innovation date starts to slip back.

Kamien and Schwartz (1982) concentrated their analysis on one firm only. A similar analysis at the level of the market has been done by Dasgupta and Stiglitz (1980b). In their analysis the firm determines its date of innovation rather than the extent of innovation.

Dasgupta and Stiglitz (1980b):

The basic assumption is that there is only one innovation to be made which will reduce unit costs from c_0 to c_1. The time to make the innovation T is related to R & D expenditure, R by T = T (R). If we have an industry with a monopolist supplier protected by entry barriers, the incremental profits of the monopoly firm will be π^M per period for t > T, where π^M can be defined as ABCE in figure 1. If r is the discount rate, the present value of this incremental profits is given as:

$$V^M = \pi^M / r.$$

In a socially managed market, the gain in net social surplus per period after innovation will be π^S which can be defined as CGLK in figure 1 and its present discounted value is given as:

$V^S = \pi^S / r.$

In the socially managed market, R will be determined to maximize $V^S e^{-r T(R)} - R$ and in the monopoly market R will be determined to maximize $V^M e^{-r T(R)} - R$. As noted earlier, it follows from figure 1 that $\pi^S > \pi^M$ and thus $V^S > V^M$. The volume of R & D expenditures and thus the speed of innovation undertaken by the monopolist is less than is socially optimal.

If we have a competitive market, we may think of a number of firms who can undertake R & D in order to invent the new technology. If one assumes that a patent system will prevent any imitation, then the inventor of the new technology will get a gain in profits from the invention of π^C = FGHI for a large invention or CGJK (in figure 1) for a small one. Thus, we have $V^S > V^C > V^M$ as shown earlier.

If the innovating firm is granted a patent having a life of T' years, the present value of the profit flow may be defined as $V^C = \pi^C (1 - e^{-rT'}) / r$. In a competitive market with free entry, it is argued that any potential monopoly rents will be dissipated in the R & D process in the absence of uncertainty. Thus, R will be determined to make the net return to R & D equal to zero. Thus, we have

$R^C = V^C e^{-rT[R^C]}$ and in the equilibrium only one firm will be undertaking R & D.

Based on these arguments Dasgupta and Stiglitz (1980b) argue that more elastic demand curves are likely to be associated with excessive research in the competitive market while there will be inadequate research for 'big innovations'. The R & D expenditure in the market economy is not an outcome of a duplication of research effort, but rather arises from the presence of competition. Competition forces the single firm to innovate earlier than is socially desirable.

By introducing uncertainty in their model regarding the date at which the innovation will be made, for a given expenditure, R on R & D at time $t = 0$, Dasgupta and Stiglitz show that the possibility that the invention is made at or before t is $1 - e^{-\lambda (R) t}$, where $\lambda (R) \Delta t$ represents the probability of making invention in the interval $(t, t + \Delta t)$.

In such a world they show that the entry-protected monopolist always delays innovation relative to the socially managed market and this parallels the certainty result. In the competitive market it is argued that

- ❖ For small inventions the market always provides inadequate research.
- ❖ For sufficiently long patent lives the market spends too much on research.

Reingnaum (1989):

Reingnaum (1989) provides a comprehensive survey of literature on the timing of innovation. She investigates the various issues pertaining to the timing of innovation in two basic paradigms.

1. A deterministic 'auction model', which can be traced to Barzel (1968) and Scherer (1967) and appears subsequently in Dasgupta and Stiglitz (1980b) as outlined above. Gilbert and Newbery (1982) and Katz and Shapiro (1985b) also look at these issues within this paradigm.
2. Second paradigm is that of a stochastic 'racing model', which was analysed for the single-firm case by Lucas (1971), and Kamien and Schwartz (1971), and

subsequently was generalized by Fethke and Birch (1982) and Grossman and Shapiro (1986). Kamien and Schwartz (1972) generalized the single-firm model to include a partial account of the effects of rivalry, and the stochastic racing appears as a full equilibrium model in Loury (1979), Dasgupta and Stiglitz (1980b), Lee and Wilde (1980) and Reingnaum (1981a, 1982a).

Reingnaum identifies a third paradigm for examining investment in R & D used by Futia (1980), Hartwick (1982) and Rogerson (1982). The game in the model is not one of timing, it is rather a "contest model". However, it does predict that firms overinvest in R & D and that each invests more the better is the patent protection.

Reingnaum (1989) addresses the problems of innovation timing and related issues using the above two mentioned paradigms for the case of symmetric games of research and development in a non-cooperative setting. She also investigates the issues related to timing of innovation when the assumption of symmetry is relaxed.

In case of symmetric models the issues addressed are:

- Aggregate non-cooperative investment in R & D and its distribution across firms and across time.
- Number of firms entering the race and the resulting equilibrium date of innovation.
- The answers to these questions are then compared with various benchmarks, such as their cooperative or surplus-maximizing counterparts.

The outcome of these comparisons is the following:

1. Aggregate expenditure on R & D is too high relative to the cooperative optimum.

2. There are too many firms and each invests too much when compared to the cooperative optimum.
3. In the absence of entry barriers, whether or not entry results in increased or decreased investment by a given firm can depend critically upon the extent to which the rewards are appropriable. When rewards are sufficiently appropriable, firms will overinvest relative to the cooperative optimum and opposite is the case when rewards are sufficiently inappropriable.

Reingnaum argues that these problems can be attributed to two types of market failures. At each date, each firm considers only its own marginal benefit from investment and does not take into account the reduction it imposes on the expected value of the other firms' investment and hence each firm invests too much. Also, since there is no entry barrier into the race, entry of firms in the market will continue until all expected profits are competed away. The entering firms do not take into account the loss of intertemporal efficiencies by rival firms when they decide to enter. Thus, due to symmetry the firms collectively forgo intertemporal efficiencies which could be realized by investing at a lower rate over a longer time period. Thus, by analogy to the problem of the commons (See Gibbons, 1992), one can say that there is "over-grazing" in the industry.

Reingnaum (1981a) notes that the existence of spillovers need not affect the timing of innovation under non-cooperative play. While it is true that each firm invests at a lower rate in the presence of spillovers, each also benefits from the investment of the others. For some parameter value, the existence of spillovers may result in stochastically earlier innovation.

Asymmetric models in Reingnaum (1989) look into the issues such as the effects on investment incentives provided by current market power, anticipated future innovation, and the possession of a technological advantage. Results in this area seem particularly sensitive to the presence or absence of technological uncertainty in the production of the innovation. When innovation is uncertain, a firm which currently enjoys a large market share will invest at a lower rate than a potential entrant, for an innovation which promises the winner a large share of market. When innovation is deterministic, the opposite is true. In the former case, the role of technological leader tends to switch from one firm to another in the industry, while deterministic innovation results in a single, persistent technological leader.

The effect of anticipated future innovation will also differ in these two cases. When the innovation is stochastic, it reduces the value of winning the current race, since today's winner is likely to lose the new race, while in case of deterministic innovation, winning today is all important, since today's winner also wins all future races.

In a multistage game, the technological lead increases the firm's likelihood of winning the overall race, everything else remaining equal. If however, all else is not equal, i.e. one firm anticipates greater benefits or faces lower costs, then an absolute disadvantage in terms of distance from completion will be overcome by the increased investment by the lagging firm which has greater desire or effectiveness. When innovation is stochastic, although firms with a technological lead invest at a higher rate than their lagging rivals, a lucky lagging rival may still win the race.

Cooperative R & D

While the market gives private firms incentives to engage in research and development, competition for potential rents may result in firms doing less R & D than is socially optimal. Such competition is a feature of the non-tournament model of R & D which has been used widely in the literature to analyse R & D competition. We have seen in our discussion of non-cooperative R & D above that while the market economy may be characterized by excessive expenditure in aggregate R & D, each firm may spend too little with the result that the degree of cost reduction is less than is socially desirable. This situation is further complicated when there is presence of spillovers. In the presence of spillovers, research done by one firm can be used by another at almost no price paid to the former. This puts the firm undertaking research at a disadvantage which may adversely affect its R & D investment. Also, R & D output (cost reduction or introduction of a new product) has many features of a public good. These are all examples of the types of market failure that can occur in non-cooperative market equilibrium. Research in joint ventures which can be defined as an entity set by the partner firms simply to conduct research appropriately in a coordinated way, have been proposed as a way to overcome the market failures as enumerated above.

By now policy makers have recognized firm's need to join innovative activity. In Europe, the United States and Japan firms are allowed to form R & D cooperatives. This relaxation of antitrust policies, initiated in the 1980s, triggered the establishment of a substantial body of literature dealing with the economics of strategic R & D.

Setting up of cooperative R & D could have both beneficial and adverse effects. If the firms are allowed to share their research output, it will increase the efficiency of R & D spending by eliminating any needless duplication. The second reason is that cost sharing will lower the effective cost of R & D and encourage firms to do more of it. Also, cooperative R & D acts as a barrier to entry. Vickers (1985) has shown how cooperative R & D can help restore the asymmetry of incentives in favour of the incumbent. In games of timing, the effect of a cooperative R & D can be to delay the date of innovation (Ordover and Willing, 1985).

d'Aspremount and Jacquemin (1988):

The basic model of R & D, spillovers and cooperative R & D on which most of the work has been built up in this area is that of d'Aspremount and Jacquemin (1988). Before we proceed any further we shall go through their model in detail. Their model is a non-tournament one and there are diminishing returns in terms of cost reduction to R & D spending. As we will see, they found that for large spillovers cooperation in R & D results in greater technological advance. d'Aspremont and Jacquemin argue that in many situations, firms compete in some fields and cooperate in others. An important example is the case of cooperative research efforts bringing fierce competitors together.

Two types of agreement can be observed among the firms. First, R & D cooperation can take place at the 'pre-competitive' stage. In this case the firms share basic information and efforts in the R & D stage but remain rivals in the final product market. Secondly, the firms have an extended collusion between partners, creating common policies at the product level. The usual justifications of this extension are the difficulties of protecting intellectual property rights. One can expect that due to these agreements there can be reduction in R & D expenditures, because of less duplication and a reduction of total production because of more monopoly power.

Using a two-stage approach, this model provides an example that does not fulfil these expectations and that allows a social welfare comparison between the corresponding games. They take spillovers in R & D as an important factor in their analysis.

The Model

- The industry is a duopoly having inverse market demand curve $D^{-1}(Q) = a - bQ$, with $Q = Q_1 + Q_2$; $a, b > 0$ and $Q < a / b$. Firms are symmetric.
- Each firm's cost of production is given by $C^i = [A - R_i - \beta R_j] Q_i$; $i = 1, 2, i \neq j$ with $0 < A < a$, $0 < \beta < 1$, and $R_i + \beta R_j \leq A$.
- The cost of R & D is assumed to be quadratic, $\gamma R_i^2 / 2$, implying diminishing returns to R & D expenditure. This assumption is based on the argument given by Dasgupta (1986, p. 523) that " the technological possibilities linking R & D inputs and innovative outputs do not display any economies of scale with respect to the size of the firm in which R & D is taken.
- Firm's strategies consist of a level of research in the first stage and production strategy based on their R & D choice in the second stage.

Case I: Firms act non-cooperatively in both output and R & D markets

The profit of firm i at the second stage for given level of R_1 and R_2 is

$\pi_i = [a - bQ]Q_i - [A - R_i - \beta R_j]Q_i - \gamma \frac{R_i^2}{2}$; $j \neq i$ and $i = 1, 2$. The Nash – Cournot Equilibrium is given as $Q_i = [(a - A) + (2 - \beta) R_i + (2\beta - 1) R_j] / 3$.

Folding the game backwards we have

$\pi_1^* = \{[(a - A) + (2 - \beta) R_i + (2\beta - 1) R_j]^2 / 9b\} - \gamma R_i^2 / 2$; $j \neq i$ and $i = 1, 2$.

The unique symmetric solution is $R^* = 2 [(a - A) (2 - \beta)] / [9 b \gamma - 2 (2 - \beta) (1 + \beta)]$; $i = 1,2$ and $Q^* = Q_1^* + Q_2^* = 18 [(a - A) b \gamma] / [27 b^2 \gamma - 6 b (2 - \beta) (1 + \beta)]$.

Case II: Firms are non-cooperative in output market and act cooperatively in R & D market.

For the second stage we have the same solutions as above. In the first stage firms maximize joint profits:

$\pi^{CN} = \pi^*_1 + \pi^*_2 =$

$$\frac{1}{9b} \sum_{i=1}^{2} \left\{[(a - A) + (2 - \beta) R_i + (2\beta - 1) R_j]^2 - \gamma \frac{R_i^2}{2}\right\} \quad ; j \neq i.$$

Symmetry gives us the following unique optimal solutions:

$R^{CN} = 2 [(1 + \beta) (a - A)] / [9 b \gamma - 2(1 + \beta)^2$ and

$Q^{CN} = 18 [(a - A) b \gamma] / [27 b^2 \gamma - 6 b (1 + \beta)^2]$.

Comparing the results of the above two case we note that for $1 + \beta > 2 - \beta$ i.e. $\beta > 0.5$, we have $R^{CN} > R_i^*$. Thus, for large spillovers captured by $\beta > 0.5$, the level of R & D increases when firms cooperate in R & D. Also, the amount of production is higher with cooperation in R & D.

Case III: Firms cooperate in both output market and R & D market.

Here the firms cooperate in both stages of the game. At the second stage the joint profits conditional on R_1 and R_2 is given by

$$\pi = [a - bQ]Q - AQ + (R_1 + \beta R_2)Q_1 + (R_2 + \beta R_1)Q_2 - \gamma \sum_{i=1}^{2} \frac{R_i^2}{2}$$

Assuming symmetry and solving for Q, we obtain $Q = [(a - A) + (1 + \beta) R] / 2b$. Now, solving for the first stage, we have

$\pi^{CC} = \{[a - A + (1 + \beta) R]^2 / 2b\} - \gamma R^2$. The unique solution is given by

$R^{CC} = [(a - A)(1 + \beta)] / [4 b \gamma - (1 + \beta)^2]$ and $Q^{CC} = [(a - A) 4 b \gamma] / [8 b^2 \gamma - (1 + \beta)^2]$.

We can see that $Q^{CC} < Q^*$ iff $5\beta^2 + 4\beta + 1 < 3 b \gamma$. For $\beta = 1$, $Q^{CC} < Q^*$ would require that $b\gamma > 8/3$. It can be noted here that $R^{CC} > R^{CN}$ for reasonably large spillovers. Also, $Q^{CC} < Q^{CN}$, whenever $b\gamma > (1 + \beta)^2 / 3$.

Welfare Implications

Social welfare W (Q) is defined as the sum of the consumer's surplus V (Q) and producer's surplus. Assuming $R_1 = R_2 = R$;

$W(Q) = V(Q) - AQ + (1 + \beta) RQ - \gamma R^2$.

At the second stage, the efficient output is given as Q, for any given R by the following:

$Q = [a - A + (1 + \beta) R] / b$. Solving the game now at first stage by putting the value of Q in the first stage social welfare function and solving for optimal R and Q, we get

$R^{**} = [(a - A)(1 + \beta)] / [2 b \gamma - (1 + \beta)^2]$ and $Q^{**} = (a - A) 2 b \gamma / [b \{2 b \gamma - (1 + \beta)^2\}]$.

Thus, for large spillovers such that $\beta > 0.5$, we have

$R^{**} > R^{CC} > R^{CN} > R^*$ and $Q^{**} > Q^{CN} > Q^* > Q^{CC}$.

d'Aspremont and Jacquemin thus conclude that for large spillovers the amount of research which is closest to the social optimum is the one achieved by firms cooperating in both output and research, while non-cooperative research is the most distant from social optimum. In case of output, the nearest to the social optimum is the one when firms cooperate in research and compete in output market. Fully cooperative output is the least in this case. Making some corrections in this model, d'Aspremont and Jacquemin (1990) note that for some spillovers such that $\beta \leq 0.4$, the following holds:

$R^{**} > R^{*} \geq R^{CC} > R^{CN}$ and $Q^{**} > Q^{*} > Q^{CN} > Q^{CC}$. Thus, the 'second – best' for R & D is obtained by a noncooperative behaviour in both stages for $\beta \leq 0.4$. Henriques (1990) investigates the stability properties of this model and note that the model is unstable for $\beta < 0.17$ and stable for $0.17 < \beta < 1$. These instabilities can lead to corner solutions. They also point out that for $\beta > 0.6$, an equilibrium cannot be determined in the fully cooperative model. In case $\beta < 0.17$, the second order conditions are satisfied, but stability is not assured in the non-cooperative two stage model.

Among studies incorporating imperfectly appropriable R & D, we just saw one way of modelling where leakages in technological know-how take place in the final outcomes. Each firm's final cost reduction is the sum of its autonomously acquired part and a fraction (equal to the spillover parameter) of all other firms' parts. The other way of modelling is to incorporate the presence of spillover effect on R & D expenditures. Here, each firm's final R & D investment is the sum of its own expenditure and a fixed fraction given by the spillover parameter of other firms' expenditures. This type of modelling appears in Spence (1984), and Kamien et al. (1992).

Kamien et al. (1992) present an n – firm oligopoly model with spillovers, where firms engage in either Cournot or Bertrand competition in the product market and examine R & D performance and welfare in four different scenarios.

- The firms behave non-cooperatively in choosing R & D levels in the first stage.
- The firms choose equal R & D levels to maximize the sum of their payoffs.

- The firms choose equal R & D levels to maximize the sum of their payoffs by setting spillover parameter equal to 1.
- The fourth case is when the firms behave non-cooperatively in choosing R & D levels in the first stage by setting the spillover parameter equal to 1.

Suzumura (1992) and Suzumura and Yanagawa (1993) use general demand and cost functions and extend the results of d'Aspremont and Jacquemin (1988) in the case of either Cournot or Bertrand competition. De Bondt and Veugelers (1991) consider strategic investment with spillovers while De Bondt et al. (1992) examine the number of rival firms necessary for effective R & D. Vonortas (1994) addresses the question of industry performance and welfare by considering a three-stage game where in the first stage firms spend on generic R & D, in the second stage they spend on development and finally in the third stage they compete in quantities. Beath et al. (1998) investigate the process by which R & D spending is transformed into the knowledge that can be used to produce cost reduction.

Choi (1993) examines the private and social incentives for cooperative R & D in the presence of product market competition. The key assumption here is that spillover rate increases with cooperation in R & D and total industry profits decreases as the spillover rate increases due to intensified post-innovation competition. They show that private firms prefer a cooperative R & D to noncooperative R & D when spillover rates are high and that the private incentive for cooperative R & D is less than the social incentive.

Hinloopen (2003) examines that cooperative R & D efforts exceed non-cooperative R & D efforts if the technological spillover rate is relatively high, under the assumption of an increasing spillover rate due to cooperation in R & D. He argues that for small pre-cooperative technological spillovers, it is not their size that dictates the comparison of cooperative and non-cooperative R & D levels, but their increase due to cooperation. Even if the pre-cooperative technological spillovers are small, an agreement to cooperate in R & D raises effective R & D efforts if the post-cooperative technological spillover rate is high enough. Cooperatives can also be socially desirable if the pre-cooperative technological spillovers are small, provided that the cooperative induces an increase in technological spillover rate that is "high enough".

As noted earlier, the presence of spillovers make it difficult for the firms to fully appropriate its R & D output. This puts them at a disadvantage and can affect their R & D investment. Also, the public good nature of R & D output leads to market failures. We analysed that one way of correcting this market failure is to allow firms to undertake joint R & D. Other ways can be to establish an effective patent system so that firms have incentives to undertake R & D. We shall analyse this aspect of R & D in detail in the next chapter. We shall also compare the patent system with some other less prevalent measures such as prizes, contracts, etc. with regard to their effect on R & D expenditures, outputs and social welfare.

CHAPTER 3: Incentives for Innovation: Contracts, Patents, Prizes and Secrecy

Introduction

Patent policy is the centrepiece of many nations' attempts to encourage innovation by granting a property right to an inventor. In the language of modern economic theory, an inventor is given the right to exclude others from producing over a part of the product space. One element of the protection is the length of time for which the protection lasts. Another is the set of products that at any given time may be prevented by the patent holder: in other words, the patent's breadth. Patent protection is costly because it generates market power for the innovator; it is necessary because inventions are costly to produce but may be non-rival (costless to reproduce) after their invention, leaving the inventor without a means of benefiting without some protection.

In principle, the grant of patent is a transaction between the rights holder and the state. This transaction means that the rights holder is rewarded for disclosing the information to the public by receiving the transferable, temporary and exclusive legal right to prevent others from commercially exploiting the invention. Furthermore, the rights holder can use legal means, which can enjoin the infringer and disgorge his or her profits, as a means to stop any further exploitation by an infringer who has been found guilty by a court.

The traditional interpretation of this among economists is that the inventor / rights holder enters voluntarily into a binding contract with society, which grants a temporary monopoly right in return for information about the invention. There is, of course, a cost in setting up and running a system with legislation, patent offices and courts (with any patent policing costs deferred to the rights holder). The fixed system costs are mostly tax-financed while operating costs are mostly fee-financed. The cost for third parties to access patent information is rather low, although it may be costly to absorb it.

For a society that wants to stimulate the generation and diffusion of technical information and technical innovations, a patent system is one way.[4] More specifically, the major rationale for the patent system from a traditional economist's point of view is as follows:

- To stimulate invention and investments in R & D.
- To stimulate commercial exploitation of inventions through direct investments in production and marketing and / or through technology trade (licensing in and out).
- To stimulate public disclosure of technical information.
- Patent protection assures orderly development of inventions which are cumulative.
- Without patent protection, lack of appropriation of full benefits of innovation leads to free-rider problem. Patent protection internalises this externality.
- Patents encourage licensing rather than relying on secrecy to obtain innovation rewards. Licensing both increases the rewards to innovation and leads to wider dissemination

Thus, the patent system is intended to be a stimulus not only to investments in R & D but also to production and marketing. In this respect, the patent system differs from and inventor prize system such as the one practiced in the former USSR (with 'inventors' certificates').[5] Public disclosure of an innovation is also thought of as stimulating technological progress and competition after the patent protection has ceased. The economic benefits to society have to be weighted against economic losses due to any monopolistic behaviour of the inventor/right holder, plus the net administrative cost of setting up and running the patent system.

In addition, three things must be kept in mind when discussing the patent system as a system of incentives. First, there are different pros and cons concerning the patent system for different levels or actors in the economy. For example, apart from the rationale for a patent system as listed above, there may be many disadvantages, such as risk of monopolistic inefficiencies, risk of over-investment in duplicative R & D and / or substitute inventions, administrative costs for setting up and running the system, to name a few. Second, there are a number of alternative policy measures for government wanting to stimulate R & D and innovation, such as secrecy alternative, prize system, etc. In this context, it may be argued that the patent system is a demand-side rather than supply-side measure, since it affects the output markets of a firm through its supposed benefits through reduced factor costs. Third, there are numerous possibilities for modifying existing patent laws and practices, and the strengths and weaknesses of their effects as incentives depend very much on the detailed design of the patent system.

The present chapter is an attempt to look at various issues related to patents as an incentive for firms to undertake R & D investment. We also discuss some of the alternative incentive mechanisms, such as secrecy alternative, award system, contracts, etc. in this regard briefly. We have divided the chapter in five sections: patent length, patent breadth, cumulative innovation, empirical studies, and alternatives to patent system to look at the various issues by taking up one issue at a time.

Patent Length

A pervasive obstacle in seeking the optimal technology policy is the public good aspect of intellectual property. On the one hand, intellectual property does not wear out and it is thus wasteful to restrict its use. On the other hand, without the protection of intellectual property, inventors cannot fully appropriate the return on their work, and, in consequence, there is too little innovation in the economy. Accepting that market failure in creating intellectual property rights justifies government intervention raises the question of how intellectual property should be protected and how long. The principal policy tool both in theory and practice has traditionally been patent institution.

William Nordhaus (1969) was the first to offer a rigorous model explaining the fundamental trade-off between static and dynamic considerations in designing patent policy: if one wants to spur innovative activity, it is possible only at the expense of the competition. Since Nordhaus's seminal works (1969) and (1972) there has been extensive research on patent protection and its consequences for social welfare.

In his seminal work, Nordhaus (1969) simply shows that the policy-makers' problem is to fine-tune the term of patent protection in order to balance static welfare losses and dynamic welfare gains optimally. As a result, the patent monopoly should last a limited time only. Nordhaus's model thus deals with *patent life* or *patent lengt*h, i.e. the number of years that the patent is in force. His model provides a simple description of the patent system in its original purpose, that is, when a patent confers temporary but complete protection over an invention.

The Model: Nordhaus (1969)

There are three stages in the model. Stage I is the time period before the new product is introduced in the market. Stage II represents the time horizon for which patent is granted on the product. Stage III starts when the patent protection on a product or process ceases to exist. For all practical purposes, we can think of stage I as time interval $[0, t_1)$, stage II as time interval $[t_1, t_2)$ and stage III as time interval $[t_2, \infty)$, where t_1 is the time point when the new product or process is introduced, t_2 is the time point when patent protection ceases. We can think of time period $[t_1, t_2)$ as $[0, L)$ for all practical purposes, as L is the length of patent protection.

Let the profits of an innovator is constant over time, denoted by π. Then innovator's total discounted value V derived from a new product or process innovation in $[0, L)$ is given by

$$V = \int_0^L \pi e^{-rt} dt - R; \text{ where R is R \& D spending of the firm.}$$

$$\text{Thus, } V = \pi \times \frac{1}{r}\left(1 - e^{-rL}\right) - R.$$

Now, to be able to aid R & D investment decisions in principle, the dependence of π upon R must be specified. For this purpose Nordhaus (1969) introduces an 'invention possibility function' for constant unit costs c, being reduced from c_0 to c_1 by a cost-reducing patented invention derived from spending in total R on cost-reducing R & D, according to:

$c_1 = c_0 (1 - k R^{\alpha})$; $k > 0$; $\alpha \in (0, 1)$, $R \geq 0$, $c_1 > 0$.

Assuming that the patent offers a perfect monopoly on the product market during a period of length L (stage II) and perfect competition before (stage I) and after (stage III) this period, Nordhaus derived conditions for the innovator's optimal spending on R, regardless of whether the innovator chooses to license out the innovation fully or chooses to go alone.[6]

Assume further that the invention is sufficiently minor so that the pre-invention price $p = c_0$ and output q_0 remain the same during stages I and II. In stage III competition forces the price to fall to post-invention cost c_1 with a corresponding expansion of output from $q(c_0) = q_0$ to $q(c_1) = q_1$. Then, we have

$\pi(\mathrm{I}) = \pi(\mathrm{III}) = 0$

$\pi(\mathrm{II}) = q_0 (c_0 - c_1)$ for $t \in \mathrm{II} = [t_1, t_2)$.

$$V = \pi \times \frac{1}{r}(e^{-rt_1} - e^{-rt_2}) - R.$$

Thus, over the whole time horizon, we have the present discounted stream of profits of an innovator as:

$$V = q_0 c_0 k R^{\alpha} \frac{1}{r}(e^{-rt_1} - e^{-rt_2}) - R.$$

Putting $\partial V / \partial R = 0$ gives the necessary condition for any optimal R & D investment $R^* > 0$:

$$R^* = \left(\alpha q_0 c_0 k \left(1 - e^{-rL}\right) / r\right)^{1/(1-\alpha)}$$

Since $\alpha \in (0, 1)$ implies $\partial^2 V / \partial R^2 < 0$ for $R > 0$, R^* is in fact optimal and maximizes V if $V(R^*) > 0$. This means that the length of patent protection cannot be too short in order to generate positive optimal investments in R & D.[7]

Optimal Length of a Patent

In order to illustrate how the optimal L^* can be calculated in a simple case, assume first a general (but declining) demand function $p(q)$ and that the innovation reduces a constant marginal cost from c_0 to c_1. The innovation is minor in the sense that pre-invention marginal cost is lower than the monopolistic price for the innovation. Assuming $t_1 = 0$ and $t_2 = L$, i.e., R occurs instantaneously at $t = 0$, the benefit to society of the innovation is then equal to the producer's net surplus, which is realized as the innovator's discounted value V (R^*) of the profit stream in stage II plus the additional consumer surplus V^c generated in stage III by the cost savings from innovation. Assuming same discount rate, we have then

$$V^c = \int_L^{\infty} q_0 (c_0 - c_1) e^{-rt} dt + \int_L^{\infty} \left(\int_{q_0}^{q_1} (p(q) - c_1) dq \right) e^{-rt} dt$$; where q_1 is the output in stage III.

The second term corresponds to the dead-weight loss in stage II being turned into consumer surplus in stage III when competition forces price down to c_1 and output expands from q_0 to q_1.

Now, for q (p) linear in p, we have $V^c = (c_0 - c_1)(q_0 + q_1) e^{-rL} / 2r$.

The producer's net surplus is:

$$V^P = q_0 c_0 k R^{*\alpha} (1 - e^{-rL}) / r - R^*$$; where R^* is given by

$$R^* = (\alpha q_0 c_0 k (e^{-rt_1} - e^{-rt_2}) / r)^{1/(1-\alpha)}.$$

After some simplification, we have

$$V^P = [\alpha q_0 c_0 k (1 - e^{-rL}) / r]^{1/(1-\alpha)} (\alpha^{-1} - 1)$$

$$= R^* (\alpha^{-1} - 1).$$

Thus, total net surplus or welfare to society $V^s = V^p + V^c$ is a function in L explicitly. The first-order necessary condition for any $L^* > 0$ to maximize V^s gives us a marginal change of L^* giving equal but opposing changes in discounted consumer and producer net surplus, that is, at L^*, a balancing trade-off is made between the innovator and the rest of society. Taking p = - a q + b, we have

$$L^* = -\frac{1}{r}\ln\left(1 - \left[\frac{c_0 k R^* (L^*)^{\alpha} + a q_0}{c_0 k R^* (L^*)^{\alpha} * (\alpha + 1) / 2\alpha + a q_0}\right]\right)$$

Using this expression one can analyse how L^* varies with the relevant parameters.

The pertinence of this view is, however, much in doubt. Since the pioneering study by Mansfield (1961), researchers have reported overwhelming evidence of the inability of patent protection to prevent imitation with a few exceptions such as the pharmaceutical industry.[8] Nordhaus (1972) thus extends his model to allow imperfect patent protection. In other words, Nordhaus (1972) formalizes the concept of *patent breadth* or *patent width*.

Patent Breadth

While the notion of patent length is indisputable, the meaning of patent breadth, or patent width, is relatively vague. The width of the patent grant measures the degree of the patent protection. If patents are narrow, a patent is easy to 'invent around', that is, it is easy to produce a non-infringing substitute for the patented invention. An extremely narrow patent does not protect even against trivial changes such as changes in colour. This kind of description is too loose to provide an unambiguous ground for the modelling attempts, and the definition of patent breadth in the literature varies from one author to another.

Nordhaus's (1972) pioneering model deals with process innovations, and he measures patent breadth by the fraction of the cost reduction not freely spilling over to competitors. In Klemperer's (1990) and Waterson's (1990) product innovation models, patent breadth reflects the distance in the product space between the patented product and the nearest non-infringing substitute. Klemperer (1990) concludes, in a differentiated product model, that either broad or narrow patents could be optimal depending on characteristics of substitution.

The simplest definitions of patent width are provided in Gilbert and Shapiro (1990) and Gallini (1992). Gilbert and Shapiro conclude, in the context of a homogeneous product model, that long-lived patents of narrow breadth are likely to be optimal. In Gallini (1992), the width of the patent is equivalent to an increase in imitation costs caused by patent protection.

Such a view is supported by the much-cited queries by Mansfield, Schwartz and Wagner (1981) and Levin, Klevorick, Nelson and Winter (1987). Gilbert and Shapiro (1990) simply identify the patent breadth with the innovator's profit while the patent is in force. In doing so, their analysis also encompasses Tandon's (1982) investigation of the compulsory licensing of patented innovations, because compulsory licensing simply reduces the patentee's profits by facilitating imitation. The compulsory royalty rate, the patent holder's profit with compulsory licensing, can thus be equated with the patent width. Tandon (1982), Gilbert and Shapiro (1990), Klemperer (1990), Gallini (1992), and Denicolo (1996) have addressed optimal patent breadth in the context of one-time innovation, where broader patents permit a shorter patent life.

Sometimes the optimal patent has maximum length and minimum breadth, as in Tandon (1982) and Gilbert and Shapiro (1990), sometimes the result is the reverse, as in Gallini (1992), and sometimes the length-breadth mix makes no difference, as in Nordhaus (1972). Klemperer (1990) provides examples of all these results.

In an excellent article Denicolo (1996) reconciles these seemingly contradictory findings. He demonstrates within a unified framework that the difference in the results reported in the literature is caused by the dissimilar influences of patent breadth on post-innovation profits and social welfare in these models. To be more precise, Denicolo's (1996) theorem predicts that the optimal patent has maximum breadth and minimum length, when both the incentive to innovate and the post-innovation social welfare are convex functions of the patent breadth, the reverse being true if they are concave. Whilst Denicolo's theorem is convenient, it fails to provide policy advice when the second derivatives of these functions take the opposite signs. Takalo (2001) advance the theory by deriving a rule for the optimal patent policy that includes also these cases ignored by Denicolo (1996).

Takalo (2001) shows that optimal patent policy is determined by three conditions. If the marginal rate of substitution of patent life for breadth is larger on the incentive to innovate than on social welfare, the optimal patent has maximum breadth and minimum length. If the same marginal rate of substitution is smaller on the incentive to innovate than on social welfare, the optimal patent has minimum breadth and maximum life. For the special case when patent life and breadth have equal impacts on the incentive to innovate and social welfare, the mix of policy variables does not matter. Broader patents increase static inefficiencies, but with a shorter life the inefficiencies terminate sooner. In contrast, when innovation is cumulative the patent breadth and patent life must work together to achieve an adequate effective patent life, which is an additional consideration.

Cumulative Innovations

Recent developments in the economic theories of innovation have challenged the notion that innovations are isolated events and emphasised the cumulative nature of innovation. The cumulative nature of innovation implies that the social value of innovations should include the value of subsequent innovations they inspire. This has significant implications for optimal patent design, especially optimal patent breadth. Hence, one of the main issues addressed in the cumulative innovation literature is how patent policy can be designed so as to divide the profits between sequential innovators in a way that provides them with optimal incentives to invest. Several papers have argued for broad patent protection in order to overcome the externality that exists between different generations of innovators.[9] One exception is Denicolo (2000). In a two-stage patent race framework, he shows that having broad protection may not always be optimal.

When technology grows cumulatively, there may be a large discrepancy between the social value of an innovation and the profit collected by the innovator. On one hand, the innovation may be very valuable because it has spillover benefits for future innovators. On the other hand, future innovators are a competitive threat. Each innovator fears that his profit flow will be terminated by invention of an even better product. When innovation is cumulative, optimal patent policy must provide adequate incentives to develop the primary invention as well as incentives for follow-on inventive activities. Kitch (1980) argues that granting broad patent rights to a pioneering inventor (with subsequent licensing) will assure orderly development. More recent work by Scotchmer and Green (1990) and others confirms Kitch's view that broad protection ought to be given to the initial invention in a cumulative series of inventions. These results depend on a known trajectory of innovation and a strong ex ante incentive to license. If licensing breaks down, broad patents could slow second-generation invention due to heightened fear of infringement. Hopenhayn and Mitchell (2001) suggest that offering a menu of patent breadths for innovations of different types may be superior to "one size fits all".

In cumulative innovations the statutory life of a patent may be irrelevant. O'Donoghue *et al* (1998) introduce the notion of *effective patent life,* which is the expected time until a patented product is replaced in the market. They argue that effective patent life depends on patent breadth as well as on statutory patent life, since patent breadth determines which products can replace the patented product. They investigate the optimal design of patents, given that breadth helps determine effective life. They conclude that patent breadth-in particular, leading breadth-can increase the rate of innovation by increasing the effective patent life, and without it, the rate of innovation may be seriously sub optimal. A specified rate of innovation can be achieved with either (1) a patent of infinite length and modest leading breadth, or (2) a patent with infinite leading breadth and modest length. The former is more efficient in minimizing R&D costs, but the latter is more efficient in minimizing the costs of delayed diffusion.

In the theoretical literature on cumulative innovation, it is generally assumed that all innovations are patented. Erkal (2003) challenges this assumption. He shows that having broad patent protection may not always be optimal if one takes into account the fact that innovators choose between several mechanisms, including patents and trade secrecy, to protect their innovations. In fact, studies such as Cohen et al. (2000) and Levin et al. (1987) report that firms frequently rely on secrecy to protect their discoveries. Specifically, Cohen et al. (2000) find that patents tend to be the least preferred protection mechanism by firms while secrecy and lead-time tend to be the most heavily used ones.[10]

Moreover, by comparing their results with those of Levin et al. (1987), Cohen et al. (2000) conclude that there is an apparent growth in the importance of secrecy as an appropriability mechanism and a decline in the importance of patents. The importance of secrecy is further supported by Lerner (1994) who finds that 43% of all intellectual property litigation cases involve trade secrets.

The cumulative nature of innovation implies that early innovators may have significant incentives to keep their innovations secret to get a head start in subsequent R&D races. In an environment where firms compete to come up with improved versions of current products, the profits of early innovators can be significantly reduced if the following race is won by one of the rival firms. This is especially true under a policy of narrow patent protection. When early innovators prefer secrecy to patenting, the dynamics of subsequent R&D races change substantially since non-disclosure of early innovations can severely affect the investment incentives of rival firms in subsequent R&D races. Therefore, the analysis of optimal intellectual property policy should take into account the possibility that early innovators may hinder the pace of innovation by delaying the disclosure of their innovations.

Empirical Literature on the Subject

Empirical work has tended to look whether patents last their stipulated life and aid innovation through increasing appropriability. Interview / survey studies by Mansfield (1986), Levin et al (1987) and Cohen *et al* (1996) indicate that patents are important inducement to innovation in only a few industries (e.g., pharmaceuticals) Kortum and Lerner (1998) and Sakakibara and Brandsetter (1999) find little evidence that changes in patent scope have lead to increased R&D or patent output in the US or Japan. Hall and

Zionidis (2001) find no evidence that increased patent scope in the US is driving innovation effort or output in the semiconductor industry. Merges and Nelson (1990) find that in the historical development of several industries, strong patent rights inhibited the broad development of the technologies.

There is at least some evidence that effective patent lives are short. Mansfield (1985) reports from survey evidence that in some industries 60% of patents are effectively terminated within 4 years, which is considerably less than the statutory life of 17 years. This finding was corroborated by Levin et al. (1987), who reported that almost all patents are duplicated within five years. Further evidence of short effective patent lives comes from patent renewal data. Schankerman and Pakes (1986) conclude that European patents lose on the order of 20% of their value per year, and Pakes (1986) reports that only 7 percent of French patents and 11 percent of German patents are maintained until the patent expires (See also Pakes and Schankerman (1984)). Lanjouw (1993) presents a more disaggregated model of how German patents become obsolete, and concludes that fewer than 50% are maintained more than ten years.

The empirical studies of patents have grown rapidly since the 1980s. Several factors have contributed towards this growth. The increased availability of large, electronic databases concerning patents and R & D and the availability of computers have enabled and lowered the cost of many types of analyses. Moreover, increased international technology-based competition and the emergence of a pro-patent era in the 1980s have generally spurred the interest in patents among both practitioners and scholars.

Alternatives to Patent System

Patents are not necessary for producing appropriability, and therefore they are not necessary to induce R & D. In general, unpatented innovations still yield gains to their inventors, at least for a short period of time. Imitators may observe an innovation with a lag, or may not have the know-how to copy it immediately. Indeed, patents play a minor role in some industries (e.g., computers). Still, many economists agree with Schumpeter that patents, and the concomitant static inefficiency associated with monopoly power, are required to give firms proper incentives to innovate, and that patents promote dynamic efficiency. But there are other methods of encouraging innovation, such as the award or prize system, secrecy alternative, contractual mechanism, etc.

The Award System

The award system, in its extreme form, consists in designing a well-defined project and then granting a fixed sum of money (the "prize") to the first firm that completes the project. After the prize is awarded, the innovation falls into public domain.

Like the patent system, this method has very ancient origins; however, it is used much less frequently than the patent system. An important advantage over the patent system is that it does not produce a monopoly. Wright (1983) argues that prizes may mitigate problems associated with patent races. It is well understood that, when information is complete, it is optimal to choose a prize as the reward, since it does not result in any of the distortions that may accompany market power. When the principal charged with rewarding innovators does not have complete information about the benefits of an invention, however, it has been shown, for instance in Scotchmer (1999), that it may be optimal to grant a patent, since the value of the reward is then tied to the innovation's value through its potential profits in the market.

The award system is difficult to implement. First, the government must be highly knowledgeable about the feasibility of various inventions and the demand for them. Information about demand is crucial for determining the size of the award, which, in turn, influences the research incentives. Generally, firms are better informed than the government on these matters, so a less centralized solution such as the patent system is preferable. Indeed, one advantage of the patent system is that monopoly profits are correlated with the social value of an invention.

In practice, the prize in the award system is likely to be determined after the innovation takes place. Because the inventor's investment is sunk at that stage, the inventor is subject to delay in appropriating R & D expenditure. The administrative and judicial bodies in charge of prizes generally estimate the values of innovations very conservatively.

Another drawback of the award system in comparison with the patent system is that with the latter it is not necessary to transmit technological information which can be tricky when the technological know-how acquired by the innovating team is difficult to transmit or even to define.

Last, the award system implies competition at the research level. As in the case of a patent system, there is no reason why this competition should yield the optimal amount of innovative activity.

Contractual Mechanism

A more serious rival to the patent system is a centralized solution known as the procurement or contractual mechanism. Although somewhat similar to the award system, the contractual mechanism differs in that the government controls access to the research market. More precisely, the government chooses a certain number of firms and signs a contract with these firms. The contract usually contains more details than are specified when an award is offered. For instance, it often specifies that a certain portion of the research costs will be borne by the government.[11] Contracts of this sort may prevent excessive duplication of research costs. However, there are incentive problems linked to limited yardstick competition. The compromise sought between these two factors depends on the research technology and the ease with which the contracting firms can be controlled.[12] As with the award system, the government must know the value of the innovation. Obviously, this is facilitated when the main customer for the innovation is the agency. This explains why the procurement system is often used in connection with space and defence projects.

The Secrecy Alternative

The other alternative open to firms to appropriate indigenous technology is through secrecy operations. Secrecy protection is substantially more effective for production technology than for product technology, since products may more easily be 'reverse engineered'. Thus, secrecy protection may to some extent substitute for patent protection regarding process inventions but less so for product inventions.

To operate within secrecy agreements would also make technology trade more cumbersome. It is well recognized in economics that any market for information works imperfectly. The moment one has to disclose a piece of information in order to sell it, one is running the risk of being cheated.[13] It would be quite possible, at least in principle, to replace a patent with secrecy agreements in business negotiations over a piece of technological information. However, the enforcement of such agreements might become very difficult since the licensor would have to show that the secret information was divulged by the licensee. Thus, the seller has to prove *ex post* that his or her invention or know-how was uniquely new and unknown to others at the time the secrecy agreement was signed. This is a formidable burden of proof. Alternatively, the seller might try to establish *ex ante* that the invention is new. However, this would also be a formidable task to perform without disclosing too much. Hence, enforcement of a secrecy agreement leads to the necessity of establishing novelty and unique proprietorship of the information passed under the agreement. The difficulty of doing so without disclosure leads one to conceive of some kind of system where novelty and unique proprietorship are established *ex ante* through public disclosure. In effect, some kind of patent system would likely result as a consequence of difficulties in enforcing secrecy agreements, as well as difficulties in disseminating information in a secrecy regime. In summary, the transaction costs for conducting technology trade purely under secrecy agreements would be too high, and technology trade would shrink.

CHAPTER 4: Research and Development in Indian Industry

Introduction

It has long been recognized that investment in science and technology makes a vital contribution to economic growth in terms of higher growth rate of the economy's productivity (See, for instance, Shultz (1953), Abramowitz (1956), Solow (1957), Denison (1962), Griliches (1958 and 1986), among others). In addition to direct returns, the externalities associated with investment in science and technology have also been found to be huge (Abramovitz, 1989).

Realizing the importance of technology, most developing countries adopted R & D policies in the early phases of their development. The evidence however suggests that the historical gap in technology generation between developed and developing countries has not narrowed down over the years. According to an estimate (Kumar, 1998), the three most developed countries namely, US, Japan and Germany alone accounted for 65 per cent of the total R & D expenditure in 1993. Their share in US patents over 1977-1996 was 83 per cent and they controlled 71 per cent of global royalties and technology fees. It has also been observed that in most developed countries technology generation got increasingly concentrated within a few large transnational corporations (TNCs) (Tulder and June, 1988). This resulted in an increasing dependence of developing countries' firms on TNCs for the transfer of new and advanced technologies. Recognizing the role of TNCs in technology transfer, developing countries started liberalizing their policies towards FDI in the mid- 1980s. The process was further accelerated in the early 1990s. However, there are indications that though FDI has been increasing since then[14], technology transfers have actually been declining (Kumar, 1998). Besides, there is little evidence of the transfer of sophisticated technologies by TNCs to developing countries (Urata, 1998). The adoption of the Agreement on Trade Related Intellectual Property Rights (TRIPs) under WTO at the same time is likely to restrict the imitative and adaptive R & D that most firms in developing countries carry out (See Kumar and Siddharthan, 1997 on R&D activities in developing countries). Under such conditions, the neglect of R & D in developing countries will have serious repercussion on firms' ability to absorb and evolve new technologies and participate in their development. This may have long-term implication for the developmental efforts of these countries.

Technology in Indian Industries

India's development effort, beginning with the first Plan, has emphasized raising the domestic savings and investment rate in order to achieve higher growth and faster industrialization. The second Plan provided the requisite elements of industrialization for this strategy, stressing the increased domestic manufacture of capital goods through the development of 'basic' industries. Given India's ample natural resources, it was recognized that the key to industrialization lay, first, in establishing a manufacturing capacity in heavy machinery, heavy electrical equipment and machine tools. As this machinery became available it would be possible, gradually, to manufacture everything else. The next four stages of the logic of development were: steel to make machinery and electricity to drive the machinery; engineers, technologists, technicians and skilled workers to convert raw material resources into machinery and power; the expansion of applied S & T research to solve practical development problems and also to expand the S & T knowledge stock through fundamental or basic research; and a sufficient number of persons with S & T capabilities to undertake the above tasks. Increasing the supply of S & T manpower came to be considered "the only secret" of fast development for a big country like India.[15]

The above logic of development is reflected in the structural changes envisaged in the second and subsequent Five-Year Plans in favour of relatively more growth in the basic and capital goods industry, emphasis on import substitution in steel, fertilizers and oil, the high priority given to higher and technical education, and an increasing allocation of resources to R & D in government institutions.

The strategy aimed at faster growth and self-reliance was characterized by an investment pattern in favour of the development of basic industries and physical infrastructure. The public sector played a significant role in their development, increasing the allocation to higher and technical education and the development of central institutions; this was accompanied by a host of policies and measures for the promotion of indigenous industry and technology, the growth of domestic savings and investment, the diversification of industry and trade in favour of manufactures and high value-adding products, and self- sufficiency in essential items like food. The basic thrust of the strategy was the acceleration of the process of domestic capital and technological accumulation. It was also oriented to strategic and security considerations.

The initial plans emphasized the creation of an institutional infrastructure in S & T. The government's emphasis was on the pure, applied, and educational aspects of S&T, on creating conditions that would lead to an increase in the supply of quality scientists, and on ensuring that the benefits derived from the acquisition and application of scientific knowledge would be enjoyed by the people.

The industrial infrastructure built after independence in 1947 covers almost all sector; mining, extraction, power, road transport, aircraft, chemical, pharmaceutical, mechanical engineering, electrical and electronic goods. There is a vast array of small and tiny industries catering to various consumer goods and also providing supplies of ancillaries to bigger industries. In biotechnology and advanced materials area, there are a few good world-class industries, in the private and public sectors. There is now an emerging vibrant business in the IT sector, with Bangalore in India being called 'Silicon Valley' and with several other cities following with speed. Almost all the essential drugs and vaccines are manufactured in India. There are also exports. But India's total export of commodities is only about 0.6 per cent of the world trade.

Nature of Technological Sophistication

A closer look at the industrial sectors would, however, show an uneven state of technological sophistication. The slow process of liberalisation which began in 1985 did not expose Indian Industry to foreign competition. Most of them were used to import of mature and standardized technologies, often as turn key plants and equipments (both in the private and public sectors). They were not keen to add incremental innovations or to do further R & D for a new generation of products, processes or services. The protected economy along with high customs barriers for imports provided them with exceptionally safe environment. The quality movements of the mid-eighties and even now were / are concentrating more on the mechanics of organising the production lines and documentations within the company, rather than on doing research into basic reliability of the systems, components, processes etc. aiming at better performance specifications.

Pre-Liberalisation Era

The process of industrialization had little connection with the building up of R & D capabilities. While industrialization proceeded on the basis of foreign technologies, R & D promotion policies focused on creating a scientific and research base. As early as 1948, the Ministry of Scientific Research and Cultural Affairs was created. In 1958, the Scientific Policy Resolution was announced that served as a basis for the government policy on domestic R & D. The Resolution considered the creation of a scientific base as a pre-requisite for developing domestic R & D capacity on the premise that technology grows out of the study of science and its application. The policy aimed at ensuring an adequate supply of research scientists and promoting scientific research for expanding the scientific base within the country. This required establishing and supporting educational and R & D infrastructure. The university and professional education institutions were expanded to generate scientific, engineering and technical manpower. From about 25 universities in 1947, the number increased to 80 in 1969 (Krishna, 2001). The number of engineering colleges increased from 38 (with 2940 seats) to 138 in 1970 with a capacity of 25000 seats. Indian Institutes of Technology (IITs) modelled on MIT were set up to provide high-quality engineering education to gifted students (Krishna, 2001). Besides, there was a rapid expansion of the science base through agencies, such as Council for Scientific and Industrial Research (CSIR), Department of Atomic Energy and Defence Research and Development Organisation (DRDO). The CSIR had no independent lab in 1942, by the late 1950s, 15 such labs were created (See Krishna, 2001 for details). Between 1950 and 1970, Rs1500 million were invested in the Council for Scientific and Industrial Research (CSIR) laboratories. The S & T infrastructure scenario during this phase also included the establishment of consulting, engineering and design organisations. There were 42 such organisations in the private sector and eight in the public sector by 1970. These efforts resulted in a four-fold increase in science and engineering personnel per million of population between 1950-70. The R & D policies thus focused on expanding scientific base and research capabilities by creating an R & D infrastructure. As a result, this phase is termed 'Infrastructure Phase' (Jain et al. 1989). Though R & D expenditure increased significantly both in the private and public sectors in India during this period, the accent was on R & D with a short pay-off (Desai 1980). R & D activities centred on: (a) scaling down of plants based on foreign technology to suit small Indian markets; (b) adapting foreign processes to Indian conditions and local materials; and (c) tackling on-the-spot production problems and quality control. The expansion and diversification in the industrial base achieved during this period was mainly owing to increasing factor inputs, particularly increasing public investment; factor productivity, which grew at a negligible rate of 0.2 per cent did not contribute significantly to industrial growth (Ahluwalia 1991).

The Technology Policy Statement (TPS) of 1983 placed emphasis on reducing technological dependence in key areas. Technology acquisition from abroad was not to be at the expense of the national interest, and due recognition and support was to be given to indigenous initiatives. The TPS contemplated the preparation and periodic updating of lists of technologies that had been adequately developed locally; normally no import of these would be permitted. The onus to demonstrate the necessity of that import was on the seeker. The TPS put a firm commitment on absorption, adaptation, and subsequent development of imported know-how through adequate investment in R & D, to which importers of technology were expected to contribute. The initiatives taken as a follow-up to the TPS included a Technology Absorption and Adaptation Scheme (TAAS), which aimed at providing catalytic support for the accelerated absorption and adaptation of imported technologies. It was made mandatory for all importing firms to highlight steps taken towards the absorption of technology imports.[16]

The technology import policy that evolved over the years has the following features. First, it is selective and seeks to provide protection to local technology where available. Local sources of all individual components of technology - consultancy, know-how, skills, and capital goods - receive protection from their foreign counterparts. Second, it seeks to reduce the direct and indirect costs of technology imports by regulating royalty and other payments. Third, it discourages packaged imports of technology. Technology import through foreign direct investments (foreign financial collaboration) is restricted only to select, relatively complex technology industries. Approvals of foreign financial collaboration are also subject to more stringent screening and attract ceilings on ownership. On the other hand, imports of designs / drawings / capital goods are less restricted. Finally, there is emphasis on rapid absorption, indigenisation, and updating of the acquired technology.

Post-Liberalisation Era

During 1991, the pace of liberalisation was more. Practically the licensing controls on expansion or opening of new industries, in most industrial categories, were removed. Foreigners were allowed to invest in most sectors. Many of the existing traditional and mature industries which were profitable in the controlled economy with nearly administered or protected prices, started feeling the pressures of competition. Most of the companies which could afford, went in for modernisation through further import of new equipment. Some found it difficult because the exporting companies placed various restrictions on the importing Indian Company in terms of its export marketing and even on its domestic marketing, as these foreign companies themselves had an eye on the opening Indian markets and possible future investments in India. They wanted to safeguard themselves from the competition that may emerge from the importing Indian company. There are a number of cases where joint ventures of Indian companies arrived at during this period to get better management technology, have broken up and foreign companies have established direct 100% owned subsidiaries in the same product lines. The established and powerful Indian industry leaders started raising the question of "level playing field" against such foreign investment.

During the pre-reform period licensing or purchase of technology from foreign firms was difficult. Besides, there were several restrictions on the royalty rates to be charged, period of the contract, etc. Consequently, the 'price' of technology (including trans-action costs) was high. Besides, import substitution policies induced local (mainly adaptive) research. Economic liberalization in recent years has reduced the 'relative price' of foreign technology purchase vis-a-vis making one's own technology. Consequently, more options are available to the Indian corporate sector in the make/ buy decision. The number of approved foreign collaborations has increased significantly in recent years. Apparently, the Indian corporate sector is actively seeking technology from foreign companies. Significantly, the share of pure technology licensing collaborations, in the total approved collaborations has declined dramatically in the 1990s.[17] Indian firms are apparently opting for equity linked technology transfer [Subrahmanian et al. 1996]. The data on actuals for such alliances is not readily available. Besides, technology is not acquired only through licenses; other types of alliances can also contribute to technology flows. Moreover, many other inputs may be required to effectively implement newly acquired technologies. Basant (2000) compiled information from the Centre for Monitoring Indian Economy (CMIE) publications on the recent non-equity alliances, including domestic and foreign. Information on a total of 190 such alliances was collected for the period 1995-97. A significant proportion of alliances are designed to access critical complementary assets like marketing and manufacturing.[18] Together these two objectives account for about two-thirds of the alliances. About 20 per cent of these arrangements are for licensing technology. Interestingly, in about 5 per cent of the cases, firms have decided to come together to develop new technologies or products. This is an encouraging development which needs to be supported.

What has been the impact of these strategies on R & D investments of the Indian corporate sector? The real R & D expenditures in the private sector grew at about 7 per cent in the 1990s, a rate slightly lower than what was achieved in the late 1980s. There were, however, significant differences across industry groups. In a large number of industries (12 out of 28 in Table 1) real R & D expenditures declined. In six out of 28 industry groups (metallurgical industries, Transportation, fertilizers, sugar, food Processing and rubber goods), the rate of growth of real R & D expenditures was positive in the 1990s but lower than in the Late 1980s. Only in nine out of 28 industries did it grow at a rate faster than in the Late 1980s. These industries were telecom, agricultural machinery, chemicals, dyestuff, drugs and pharmaceuticals, textiles, soaps and cosmetics, glass and cement. In almost all these industries (except textiles) competition has increased through entry of multinationals and other domestic firms. Firms in chemicals and drugs and pharmaceutical Industries may be gearing up for the new intellectual property rights regime. Dyestuff industry may be conducting research to grapple with environmental regulation.

Table 1: Growth Rates of Real Private Sector R & D Expenditure by Major Industry Group (1980-81 Prices)

Industry Group	1974 - 80	1980 - 86	1986 - 91	1991- 95	1974 - 95
Metallurgical industries	21.5	1.5	4.9	3.7	5.1
Fuels	17.9	–6.8	6.5	–16.4	–0.4
Boilers and steam generating plants	–29.5	21.3	53.3	–19.0	10.4
Prime movers	6.5	–6.0	14.9	–24.1	6.6
Electrical and electronics equipments	12.6	5.0	5.8	–1.5	5.5
Telecommunications	23.7	–8.3	–0.7	14.4	8.4
Transportation	27.5	–2.6	28.6	12.0	10.6
Industrial machinery	26.8	12.5	3.9	–4.1	5.3
Machine tools	28.5	9.4	26.3	–16.6	9.3
Agricultural machinery	15.2	–4.3	–0.3	33.9	2.0
Misc mechanical, engg Industries	–37.3	–4.1	57.6	–6.8	13.3
Commercial offices, household equipments	16.1	12.4	39.6	–15.2	10.8
Industrial equipment	28.8	5.6	–32.6	32.3	9.2
Scientific instruments	44.1	25.8	-4.2	–40.5	6.3
Fertilisers	–12.3	–10.0	42.5	7.4	6.9
Chemicals (other than fertilizers)	20.2	-0.2	–10.2	11.7	5.3
Dye-stuffs	10.4	–10.5	5.5	11.4	2.2
Drugs and pharmaceuticals	7.6	8.2	0.0	14.0	7.2
Textiles (dyed, printed and processed	19.9	4.3	–11.9	11.4	4.4
Paper and pulp	17.2	7.6	–30.6	–7.7	–2.4
Sugar	40.9	19.2	16.3	4.4	11.9
Food processing industries	19.5	24.9	29.1	7.2	12.7
Soaps, cosmetics, toilet preparations	9.9	2.3	–7.1	12.3	3.8
Rubber goods	31.9	6.9	32.8	0.4	9.6
Leather and leather goods and pickers	NA	1.7	100.0	–11.7	20.8
Glass	13.0	–15.0	9.3	12.4	2.5
Ceramics	23.7	2.0	7.2	–2.8	1.7
Cement and gypsum	27.8	0.6	2.0	2.3	1.6
Total	17.1	4.0	7.6	7.4	6.7

Source: Basant (2000)

Even in industries where real R & D expenditures have risen, the R & D / sales ratios have either stagnated or declined (See Table 2 below). The only exceptions are telecom, machine tools, scientific instruments and transportation. One observes a relative stagnancy even in industries where real R & D expenditures in the 1990s grew faster than in the late 1980s (See Table 2 below).

Table 2: Trends in R & D to Sales Ratio by Industry Groups for Private Sector Industries

Industry	1974-77	1980-83	1984-87	1988-91	1991-92	1992-93	1993-94	1994-95
Metallurgical industries	0.33	0.48	0.32	0.29	0.25	0.36	0.41	0.33
Fuels	0.71	0.17	0.46	0.52	0.79	0.37	0.34	0.35
Boilers and steam generating plants	1.81	0.40	0.78	0.63	0.82	1.43	0.51	0.67
Prime moovers	1.15	1.28	1.25	1.51	1.26	0.79	0.75	0.52
Electrical and electronics	0.91	0.80	1.06	0.94	0.66	0.85	0.84	0.78
Telecommunications	0.64	1.86	1.33	1.23	2.14	1.61	2.29	1.96
Transportation	0.84	1.07	0.57	0.65	0.77	0.86	1.32	1.09
Industrial machinery	0.80	1.13	0.97	0.74	0.69	0.87	0.69	0.67
Machine tools	0.40	3.92	1.53	1.37	1.42	2.32	1.91	1.67
Agricultural machinery	1.59	0.62	0.33	0.85	0.35	0.62	0.47	0.63
Misc mechanical, engg	0.74	1.07	0.63	1.09	0.67	0.47	0.44	0.43
Offices and household equipments	0.28	0.57	0.46	0.54	0.56	0.39	0.37	0.4
Industrial equipment	1.46	1.02	0.94	1.96	0.54	0.54	1.1	0.96
Scientific instruments	0.00	4.69	1.40	2.65	9.35	2.12	2.07	3.46
Fertilizers	0.29	0.49	0.27	0.21	0.27	0.33	0.33	0.38
Chemicals (other than fertilizers)	1.07	0.95	1.01	0.69	0.57	0.66	0.64	0.65
Dye-stuffs	1.01	1.06	0.80	0.74	0.72	0.87	0.96	0.92
Drugs and pharmaceuticals	2.10	1.93	2.02	1.40	1.35	1.37	1.37	1.58
Textiles (dyed, printed and processed	0.44	0.45	0.34	0.25	0.2	0.28	0.29	0.26
Paper and pulp	0.21	0.49	0.53	0.23	0.19	0.14	0.13	0.12
Sugar	0.25	0.44	0.52	0.77	0.67	0.39	0.36	0.47
Food processing industries	0.22	0.29	7.77	4.25	0.96	1.05	0.99	1.2
Soaps, cosmetics, toilet preparations	0.48	0.37	0.63	0.42	0.39	0.55	0.51	0.53
Rubber goods	0.17	0.51	0.31	0.58	0.5	0.57	0.47	0.44
Glass	0.73	1.11	0.68	0.51	0.45	0.46	0.51	0.5
Ceramics	1.36	1.39	1.06	1.27	0.67	1.23	0.87	0.69
Cement and gypsum	0.94	0.68	0.38	0.45	0.3	0.6	0.38	0.44
Total	0.76	0.74	0.74	0.73	0.60	0.67	0.71	0.70

Source: Basant (2000)

Manufacturing strategies

Manufacturing related initiatives in the post-reform era are not restricted to alliances of the type mentioned above. Several initiatives to improve manufacturing capabilities within the firm have also been taken. A recent study, based on survey of firms sought to make an assessment of these initiatives (Chandra and Sastry, 1998). The survey results suggest that Indian firms will give the highest priority to quality improvements in the next five years, seeking to improve conformance to specifications and standards, product reliability and durability.

The other priorities, in descending order, are operations (e.g. improving distribution network and performance, delivery time, flexibility in handling different volumes of production, after sales service, etc); structural changes (to develop capabilities for fast delivery, rapid product mix changes and low prices); and innovation and R and D (to develop new products and designs and broaden product line). Chandra and Sastry (1998) argue that while these priorities are appropriate, the synergies among initiatives to achieve better quality, operational performance, structural changes and innovation will have to be reaped in order to get their full benefits. According to them, the Indian corporate sector is yet to fully recognize the links between these priorities.

Patenting Activity

Patent policies in all countries involve finding a balance between protecting the rights of innovators and ensuring access to resources at reasonable prices. India's patent policy, which emphasized public interest over monopoly rights, is in the process of shifting this balance towards greater protection of intellectual property rights. The recent surge in patent applications in India in the post-1995 period, which has not received attention in policy analysis, provides important data for evaluating the potential for domestic actors to adjust to the new patent regime. The number of patent applications filed in the Indian Patent Office has risen approximately 150% in 1997-98 from 1993-94, crossing the 10,000 mark for the first time in 1997-98.[19]

The emergence of TRIPs (Trade Related Intellectual Property Rights Agreement) in the WTO is the catalyst that led to changes in India's policy on patents. Policy shift in relation to patents did not occur immediately after India signed the TRIPs Agreement, but took place only after a domestic constituency emerged that supported patent reform. In spite of bilateral and multilateral trade pressure, India did not revise its patent laws according to TRIPs from 1994-1998 due to opposition from actors that benefited from the existing patent structure. A domestic policy shift enabled India to revise its patent laws in 1998-99, which laid the foundations for redefining the balance towards the rights of patent holders, and led to a strategy aimed at raising the patent activity of domestic actors.

The pharmaceutical industry has benefited the most from India's Patent Act of 1970. One of the main provisions of the act was that only process and not product patents could be granted in pharmaceutical, food and chemicals. Indian research institutes utilized this provision to reverse engineer technologies, build indigenous capabilities in them, and disseminate them cheaply to industry.[20] Domestic industry used this clause to introduce imitated products to the Indian market, and in the case of drugs, this took place just four or five years after their appearance in the world market.[21] As one analyst points out, the Indian Patent's structure has enabled India to achieve self-sufficiency in the production of bulk drugs and prices of most drugs in India are lower than other countries.[22] India's patent policy allowed very little scope for patents in the field of agriculture. Agricultural resources operated under the "common heritage" regime where agricultural goods were freely exchanged. The debate on the implications of TRIPs on agriculture in India has focused more on plant variety protection, another form of IPR, rather than patents, as TRIPs allows India to exclude plant varieties from patent protection. However, the new patent regime will affect India's agriculture policy. Firstly, although TRIPs does exclude plant varieties, there is confusion internationally on what would require patent protection, for example, plant parts. Secondly, India has revised its patent law to allow applications for product patents in agro-chemicals, opening up an important field to patent protection. Thirdly, several multinational firms have begun filing patent applications in various areas related to agriculture and agricultural biotechnology in India. The lack of capability of domestic actors to acquire patents in this field would have enormous implications that have so far not been widely recognized.

The Patent Amendment 1999 reframed the clause in the Patent Act of 1970 that only process and not product patents could be granted in food, chemicals, and drugs. The amendment allowed for:

1) Applications for product patents in agro-chemical and pharmaceutical fields which would be examined in 2004 and granted (if it meets the stipulations) in 2005.

2) Exclusive marketing rights for these products. The patent amendment act revised one of the main provisions of the Patent Act of 1970 that aimed to balance public interest with patent rights in India.

The policy shift towards greater protection of the rights of patent holders is leading to a greater emphasis on domestic patent activity. The draft of the Science and Technology Policy Statement 2001 points out that, "The Government will encourage and promote R & D projects capable of generating competitive IPR and also their effective protection. The development of skills and competence to manage IPR and leveraging its influence will be given a major focus".[23] The argument is no longer that Indian companies don't have the capacity to file applications, but rather that they could do so if incentives were provided through breaking down legal barriers. This strategy is aimed at raising the patent activity of domestic actors in various ways.

The first of these measures involves establishing offices to provide assistance to domestic actors to increase their patent activity. Patent cells have been established in various public sector institutions to enable them to increase their patent holdings. The Council for Scientific and Industrial Research (CSIR) has established a patent cell. The Department of Biotechnology established a Biotechnology Patent Facilitating Cell in July 1999. A Patent Facilitating Cell was created by the Department of Science and Technology in 1995.

A second effort to ensure increased patent activity is on modernization of the Patent Offices in India. Funds have been allocated by the government to computerize the Patent offices and recruit more specialized manpower to cater to increasing demands for information relating to patents.

Thirdly, emphasis is being placed on providing training and education on patents in India. Patent seminars, training by WIPO (World Intellectual Property Organization) and various other programmes are being organized to educate industry and scientists on patents. WIPO initiated a program to train and advise Indian users of the Patent Cooperation Treaty of 1998, and completed a major project that led to the creation of a nation-wide patent information system.

The shift in patent policy is leading to a strategy aimed at raising domestic patent activity. This marks a significant departure from India's policy on patents that emphasized public interest over monopoly rights. The effectiveness of the revised policy strategy will be determined by the capacity of domestic actors to make the transition towards the new patent regime.

Table 3: Ratio of Foreign to Domestic Patent Applications

Year	Ratio
1970-71	3.6
1975-76	1.7
1980-81	1.5
1984-85	2.3
1985-86	2.5
1986-87	2.5
1987-88	2.7
1988-89	2.3
1989-90	2.5
1990-91	2.3
1991-92	1.7
1992-93	1.8
1993-94	2.1
1994-95	2.1
1995-96	3.4
1996-97	4.2
1997-98	4.3
1998-99	3.0

Source: Ramanna (2002).

Patent applications declined from 5100 patents filed in 1970-71 to an average of about 3500 applications filed annually between 1985-1992. In the post-1995 period patent applications are more than double than those of previous years. The provision in India's Patent Act of 1970 that no product patents on food and drugs could be granted in India had discouraged foreign applicants from filing in India.[24] India has now revised its law to allow applications on product patents. The increase in patent applications in this period represents, to some extent, the interest of firms in filing patents in India in fields that were not patentable under the 1970 Act. Applications under the revised Patent Amendment Act of 1999 are designated as 'WTO applications' by the Indian Patent Office and are being listed in the Gazette as regular patent applications. Although no public figures are available on the number of applications that have come into India through this route, unofficial estimates put the figure at over 3,000[25]. The Mumbai office alone has received over 300 such applications to date[26].

The first aspect of this rise in patent applications is that there is a significant increase in the ratio of foreign to domestic applications in the post-1995 period as compared to previous years (See Table 3 above).

In a study by the Technology Information and Forecasting Assessment Council (TIFAC), an autonomous body under the Department of Science and Technology, confirms that few firms account for the rise in domestic patent applications. In a study of 1117 R & D units (excluding public sector undertakings) recognized under the Directory of Recognized in-house R & D units by the Department of Scientific and Industrial Research, TIFAC found that 153 units held all the 1127 patent applications filed by these units[27]. Approximately 13.7% of the R & D units have filed patent applications with the rest of the 86.3% not having shown much interest in patenting.[28]

Firm Size, Market Structure and R & D Activity in India

The role of firm size and market structure in determining innovative activity has been one of the most extensively debated issues in the theoretical and empirical literature on economics of innovation (See, among others, Kamien and Schwartz, 1982; Dosi, 1988; Cohen and Levin, 1989; Cohen, 1995, for reviews of the literature). It also happens to be one of the issues that is yet to be satisfactorily resolved because of conflicting findings in the empirical studies. One of the possible reasons for the conflicting results relating to the relationship between firm size, market structure and innovative activity could be the diverging measurements used to denote innovative activity used by different studies. Another factor that may have contributed to the conflicting results could be the changing nature of technological development. Finally, the diverging results could also be due to specification errors and sample selection biases in the models employed by these studies.

Not many studies have analysed the relationship between firm size and technological activities in the developing countries' context such as India, given the relatively little importance attached to enterprise-level technological activities in most of these countries. Those that pursued this link for Indian industry report varying results. Lall (1983) found R & D intensity to increase with firm size more than proportionately for a cross-section sample of Indian engineering firms. He attributed this result to the fact that the larger firms tended to be more diversified, technologically more complex, better aware of technological opportunities, and able to afford more investment in R & D activities. Katrak (1985) postulated R & D expenditure to increase with firm size less than proportionately in view of scale economies. His results for a cross-section of Indian industries confirmed his hypothesis that the elasticity of R & D expenditures with regard to firm size was less than one.

In view of the non-linearities in the relationship observed by industrialized country studies[29], Siddharthan (1988) postulated and found a non-linear 'U'-shaped relationship between R & D intensity and firm size for a cross-section sample of 166

Indian firms. Thus, for the smaller firms, R & D expenditures increased more slowly than the increase in firm size, but for the very large firms they increased more rapidly than the increase in size. This result was attributed to the differences in the nature of R & D activity undertaken by large and small firms. In addition to estimating regression equations for all the 166 firms in the sample, that included both public and private sector firms, the study also estimated equations for the private sector firms separately to analyse the differential behaviour of these two groups of firms. Furthermore, these equations were also estimated for firms belonging to different industrial groups like chemicals, electrical and electronics, industrial machinery, and textiles. In addition to the size variable, the equations also had other determinants, such as technology imports and age of the R & D units. The 'U"-shaped relationship between size and R & D intensity held good for all the equations, irrespective of the ownership group or the industrial sector.

In general, firms in developing countries spend very little on R & D. Expenditures relating to import of technology, in the form of lump sum, technical fee and royalty payments, dominate their expenditures on technology. Hence, it may be useful to analyse the role of firm size in influencing this expenditure. Studies using Indian data showed that the size of the firm was an important determinant of the ratio of technological imports to sales (Siddharthan and Krishna, 1994).

Almost all the above studies, however, concentrated on samples of R & D reporting firms. Hence, their findings could be subject to sample selection bias. Siddharthan and Agarwal (1992) and Kumar and Saqib (1996) used more complete samples for Indian enterprises and analysed the probability of a firm undertaking R & D and its intensity. These studies generally found a positive influence of the size on the probability and intensity of R & D.

Siddharthan and Agarwal (1992) considered a sample of Indian manufacturing firms drawn from the top 500 firms quoted on stock exchanges. Of the 384 firms included in the sample, only 164 firms reported R & D units. They found that the firm size variable had a statistically significant positive coefficient in the model explaining R & D expenditures and significantly negative coefficient in the model explaining R & D intensity. Therefore, firm size influenced the probability of a firm having R & D activity favourably, but not its intensity.

Kumar and Saqib (1996) studied the R & D behaviour of a sample of 291 firms having foreign collaborations in India. Their sample also covered both firms that had R & D units and that did not. They employed two different models to explain R & D decisions. The first, a probit model where the dependent variable took values of either zero or one, and the second, a tobit model where firms without R & D units had zero values and those with R & D units took the actual R & D intensity. Controlling for other determinants of R & D activity, the coefficient of size was positive and that of its quadratic term was negative in the probit model. They concluded that the probability of undertaking R & D activity increased with firm size up to a point, beyond which it declined. In the tobit model, where the actual R & D intensities were considered as a dependent variable, they concluded that once a firm had decided to set up an R & D unit, the intensity of R & D expenditures increased with size in a linear fashion. In other words, larger firms spent more on R & D compared to smaller firms. This second result contradicted the findings of earlier works that found evidence in favour of economies of scale advantages.

Among the developing country studies on market structure and innovation, Desai (1983), on the basis of an examination of the relationship between market structure and technological activities in Indian industries and also several industry case studies, concluded that market structures with few firms – between two and half dozen – were more conducive to adoption of new technology by firms. He added further that 'the long tailed market structures common in India are not especially conducive to technological progress; nor are the monopoly firms set up by the government in high-technology industries'. Kumar (1987b), in a study of forty-three Indian manufacturing industries, found a negative influence of four-firm concentration ratio on R & D intensity. He explained this finding in terms of government policy factors which deterred entry to industry in addition to the structural barriers to entry. The entry to Indian industries until recently had been regulated by the government through its industrial licensing policy. Tariffs, non-tariff barriers and exchange controls had shielded the competition from abroad. The existing firms, therefore, faced hardly any threat or potential competition. The principal motivation for firms to pursue innovative activity is to acquire monopoly power with the accompanying quasi rents. He therefore argued that in the absence of any threat of potential competition high concentration does not provide any motivation for innovation.

In developing countries where much of the R & D activity is of an adaptive nature, tighter intellectual property rights might choke the innovative activity by reducing the knowledge from spillovers available to the R & D of foreign firms. A number of studies have empirically demonstrated the ability of rather weaker intellectual property rights in stimulating domestic innovative activity in developing countries to absorb spillovers of foreign R & D. Fikkert (1993), in a study of Indian enterprises, found evidence of their R & D activity absorbing considerable foreign R & D spillovers facilitated by the weak Indian patent regime, and concluded that a stronger patent regime was 'not optimal from either short or long-term perspectives'. Similarly, Kumar and Saqib (1996) found Indian chemical industry enterprises to be among the more innovative ones in Indian industry. They attributed this to the weak patent laws, i.e. the absence of product patents in India which enabled Indian enterprises to undertake alternative process development.

Thus, it can be argued from the above discussion that firm size is more likely to determine the likelihood of a firm's tendency to undertake R & D activity rather than the scale of that activity in Indian Industries. The scale or intensity of R & D may depend on other factors, including industry characteristics and size profile of the sample firms. It is also becoming quite clear that the relationships vary across industry groups depending upon the extent of scale economies involved in R & D activity in different industries. Also, market concentration in the absence of any threat of potential competition does not provide any motivation for innovation. Market structure's effect on innovation may be dependent upon other factors, such as technological opportunities, appropriability conditions, and entry conditions. The tightening of intellectual property protection is likely to affect innovative activity if Indian industries adversely by stifling the spillovers of foreign firms' R & D, because their technological activity is largely adaptive in nature.

Case Studies From Selected Industrial Enterprises

Pharmaceutical Industry

The evolution of the Indian domestic pharmaceutical industry constitutes one of success stories of the Indian economy. From being an import dependent industry in the 1950s, the Indian pharmaceutical has today achieved global recognition as a low-cost producer of high-quality pharmaceutical products and its annual exports turnover is in excess of $1.5 billion. Leading Indian companies have established manufacturing and marketing activities in over 60 countries including USA and in Europe. The industry today is poised to become a powerhouse in pharmaceutical research and development, and a significant player in the international generics market.

The rapid strides that the Indian pharmaceutical industry has taken is the result of many factors-the vision of some of the leaders of the industry; the culture of excellence fostered in some companies; the skill and expertise of Indian scientists; the low-cost advantage of the Indian economy; and above all, a policy environment which gave Indian pharmaceutical companies breathing space to become competitive. Today, India has a TRIPS compliant patent regime. More importantly, it has an industry, which possesses the capabilities to not only compete, but also flourish under a TRIPS compliant patent regime.

In this section, we will seek to briefly trace the evolution of the Indian pharmaceutical industry, the policy regime that regulated intellectual property rights and the flow of investment and technology, and the impact of these policy initiatives on the development of the Indian pharmaceutical sector. Mainly we will focus attention on the development of India's largest pharmaceutical company, Ranbaxy Laboratories, and how visionary leadership, relentless pursuit of excellence, and determination to create world-class R & D capabilities has combined, to create a truly Indian multinational corporation.

Prior to the mid-1970s, the Indian pharmaceutical industry was relatively small and dominated by MNCs. In 1974-75, the total production of the Indian pharmaceutical industry amounted to $605 million with formulations accounting for $494 million and bulk drugs contributing $111 million. MNCs had a disproportionately large share of the total production and 43 multinationals accounted for more than 40 per cent of total production in the country. The total market share of foreign companies, including imports was around 75% (OPPI).

The landscape of the pharmaceutical sector was however transformed in the 1975 to 1990 period, largely as a result of some important policy initiatives undertaken by the government. Total pharmaceutical production grew from $605 million in 1974-75 to $2.5 billion in 1989-90. During the same period, bulk drug production grew from $111 million to $394 million and formulation production grew from $494 million to $1526 million. This period also witnessed the rise of home grown pharmaceutical companies as well as the waning influence of pharma MNCs in the domestic market (OPPI).

The most rapid growth in the pharmaceutical sector has taken place post-1990, with domestic industry truly coming of age in this period. Indian companies have been able to leverage their skills in reverse engineering and low-cost production capabilities to successfully penetrate the profitable export market. While the Drug Price Control Order, which regulates drug prices in India, imposes a check on the profitability of pharmaceutical companies, Indian pharma companies have been able to grow profitably largely, because of their success in overseas markets. The pharmaceutical industry has grown to $4.7 billion in 2001-02, with exports accounting for around 38 per cent of total production. The industry is a net foreign exchange earner with imports amounting to just $608 million. The market share of MNCs in the domestic market has fallen to around 35 per cent and only three of the top ten pharmaceutical companies in India (in sales turnover terms) are Indian.

To sum up the current status of the Indian pharmaceutical industry, India is one of top five manufacturers of bulk drugs in the world and the 14th largest pharmaceutical exporter in the world. The industry manufactures almost the entire range of therapeutic products and is capable of producing raw materials for manufacturing a wide range of bulk drugs from the basic stage. The industry has practically achieved self-sufficiency and has attained global recognition as a low cost producer of high quality bulk drugs and formulations.

In a country where research and innovation have traditionally been neglected by domestic industry, the pharmaceutical industry is realising the importance of R & D. The successes enjoyed by a few companies such as Ranbaxy and Dr Reddy's in the R & D field have shown the way for others. Several Indian pharmaceutical companies including Cipla, Lupin, Wockhardt, Nicholas Piramal and Torrent are today engaged in R & D activities. Investment in pharmaceutical R & D has been rising steadily. From Rs.220 crores in 1997-98, R & D expenditure rose to Rs.260 crores in 1998-99 and to Rs.320 crores in 1999-2000. This figure is projected to jump up to Rs.1500 crores by 2005. At present, R & D spending accounts for two per cent of the pharmaceutical industry's turnover. This is estimated to rise to five per cent by 2005.

Table 4: R & D Expenditure of Pharmaceutical Industry

Year	Expenditure in Rs. Mn.
1976-77	105.0
1978-79	120
1979-80	147.5
1981-82	293.0
1983-84	400
1986-87	500
1993-94	1,250
1994-95	1,400
1995-96	1,600
1996-97	1,850
1997-98	2,200
1998-99	2,600
1999-00	3,200
2000-01	3.700

Source: OPPI (Organisation of Pharmaceutical Producers of India).

Ranbaxy Laboratories- An Illustrative Study

Ranbaxy Laboratories Limited is India's largest pharmaceutical Company. It manufactures unbranded market drug products, branded generic pharmaceuticals and active pharmaceutical ingredients. It stands amongst the top ten generic companies worldwide. It has employed diverse strategies, including exports, alliances, partnerships and acquisitions to gain the flexibility needed for viable and profitable business operations worldwide.

Founded in 1961 as a distributor of antibiotics, vitamins and anti-tuberculosis drugs, Ranbaxy set up its first manufacturing facility in 1965. Its first real breakthrough came in 1969 with the launch of 'Calmpose' - a generic version of Roche's patented 'Valium' tranquilizer. Ranbaxy achieved further success in 1971 with Roscillin, India's first Ampicillin, and 'Gramoneg', a Nalidixic Acid formulation (the first fluroquionolone) launched in 1974.

By 1973, Ranbaxy had gained a strong position in the anti-infectives market and went public to raise finances for a bulk drug facility. It was, thus, ideally poised to take advantage of the developments that took place in the 1970s. The Patent Act 1970 allowed Indian companies to reproduce patented drugs as long through a different process. Ranbaxy, with its focus on chemical synthesis R & D, took full advantage of this flexibility. Some of its major successes in process engineering included a new process for manufacturing Doxycycline in 1978 as well as a new process to manufacture Ranitidine in 1985, which at that time was the world's largest selling drug.

Table 5: Products Launched by Ranbaxy

Products	Molecules	Countries
Keflor MR	Cefaclor	India, SA, Poland, Hungary, Singapore, Malaysia (Total 18 countries)
Sporidex AF	Cephalexin	India, USA, SA
Coriem XL	Diltiazem Hcl	India, Malaysia
Difnal DR	Diclofenac Sod.	Malaysia, Singapore
Difnal OD	Diclofenac Sod.	Malaysia, Singapore
Roletra D	Loratadine Pseudoephedrine	India
Altiva D	Fexofenadine Pseudoephedrine	India
Romesec DR	Omeprazole	Malaysia, Singapore
Cifran OD	Ciprofloxacin	India; Licensed to Bayer AG for further development
Zanocin OD	Ofloxacin	India

Source: Company Website

In 1992, Ranbaxy developed a non-patent infringing process for Cefaclor. This was a landmark event in the life of the company. It paved the way for a relationship with Eli Lilly, the originator of Cefaclor, and also established Ranbaxy's credentials in the international pharmaceutical industry. More importantly, it gave Ranbaxy the belief that it possessed the capabilities to move up the R & D value chain.

The DPCO (Drug Price Control Order) of 1979 also played an important role in Ranbaxy's growth. By controlling drug prices, and hence profits in the Indian market, it forced Ranbaxy to scout for export opportunities. The company initially targeted developing countries and between 1986 and 1996, exports grew at an annual rate of 34 per cent. The major markets that contributed to this growth included China, SE Asia, Africa as well as Europe. By the mid 1990s, exports contributed 40 per cent of the company's total turnover. In addition to exporting bulk drugs, the company also entered into a large number of joint ventures with foreign partners with the objective of establishing a manufacturing and marketing presence abroad.

It became clear by the end of the Uruguay Round of negotiations (1991) that India would become a member of the World Trade Organization and agree to a Product Patent regime. The Ranbaxy management, led by its visionary Chairman and Managing Director, late Dr. Parvinder Singh, realized that this would have profound implications, both for the Industry and the Company. Instead of resisting change, Ranbaxy initiated the process of restructuring the Company, redefining its product offering and developing a range of new capabilities. In 1993, it clearly enunciated its mission statement: **"to become an international, research based company"**. And indeed, it is this twin engines of internationalisation and research that have powered the company over the last one-decade.

In April 1993, Ranbaxy restructured its worldwide operations into four regions (Middle East and India; CIS and Western Europe; China, Southeast Asia; and USA, Central / South America) with four headquarters based in New Delhi, London, Hong Kong and Raleigh, USA. Today, out of global, consolidated sales of $600 million, international sales account for 60% of the sales. The company is selling its products in over 100 countries and has an expanding international portfolio of affiliates, joint ventures and alliances, ground operations in 25 countries and manufacturing operations in

7 countries. Ranbaxy's internationalisation drive has been accompanied by a relentless focus on upgrading R & D capabilities. The company has the largest R & D spent in the Indian pharmaceutical sector and accounts for nearly 27 per cent of the total Pharmaceutical R & D expenditure in the country. It employs 608 trained R & D personnel, including 474 scientists at its R & D Centre in Gurgaon, India. The therapeutic focus at R & D is on Urology, Respiratory, Anti-infectives, Anti-inflammatory and metabolic disorders segments. The Research networking across the globe is a key growth driver for the company. It is also investing in new areas of Biotechnology and Herbal Research.

Table 6: Unaudited Financial Results (Provisional) for three months ended 30th September 2003 (Rs. Millions)

	Three Months Ended 30/09/2003	Three Months Ended 30/09/2002	Nine Months Ended 30/09/2003	Nine Months Ended 30/09/2002	Year Ended 31/12/2002 Audited
Sales	9,247	8,044	28,320	20,717	28,894
Exports	6,028	5,210	19,847	12,885	18,503
R & D Expenditure	622	490	1,727	1,141	1,686
Profit after Tax	2,051	1,594	6,817	3,927	6,236

Source: Company financial booklets.

It has well-defined programs in the areas of: Chemical Research (Synthetic Chemistry); Pharmaceutical Research (Dosage forms); Novel Drug Delivery System (NDDS); New Drug Discovery Research (NDDR); and Fermentation Research.

The overall research endeavours are amenably supported by world class infrastructure comprising: Analytical Research; Clinical Research; International Regulatory Affairs; Intellectual Property Cell; and Corporate Quality Assurance.

The emphasis on reverse engineering has now given way to a focus on innovative research with focused initiatives in New Drug Discovery Research (NDDR) and Novel Drug Delivery System (NDDS). The company's New Chemical Entity Pipeline currently includes five molecules, of which one-RBx 2258 is in Phase II clinical trials. Recently, Ranbaxy has entered into a licensing arrangement with Schwarz Pharma AG of Germany for the development of RBx2258. Ranbaxy's NDDR program works with a mandate to deliver one Investigational New Drug (IND) within a period of 12 to 18 months.

The satisfactory progress of Ranbaxy's NDDR and NDDS programs testify to Ranbaxy's shift towards innovation and higher value addition. Moreover, in the future, Ranbaxy's export income will come not just from the sale of products but also from licensing of intellectual property rights and technology platforms.

Pharma Research: Over 40 products launched in India in 2002.

Chemical Research: Development activity undertaken for synthesis of 24 APIs in 2002, process know-how developed & commercialised for 12 APIs.

IDRA: IDRA achieved filing of 980 new registrations across 102 countries in 2002. Ranbaxy also received regulatory approvals for 455 products across 74 countries.

R & D Activities: With over 550 scientists working diligently to make Ranbaxy the true pharma pilot of the new Millennium, Ranbaxy's Research and Development wing is all set to lay undivided focus on it's all areas of activity. Taking the company a step further in establishing itself as a research-based pharmaceutical company, Ranbaxy has developed a promising NCE pipeline.

In the next few years, Ranbaxy will attempt to move further up the value chain. In the words of the company's CEO and managing director D.S Brar: "Till now in the first wave of our development we have drawn significant competitive strengths from our moorings in India. In the next wave, advanced markets led by USA, would play the key role. While we will continue to pursue growth in Generics based on our strengths of cost effective development and international reach, our direction shall be to explore and move increasingly into the branded pharmaceutical space. Our coordinated efforts in R & D, international operations, marketing and global networking would see us evolve to a research oriented specialty / branded pharmaceutical company''.

Automobile Industry

The automotive industry anywhere in the world has been a key indicator of economic development. Mobility is something, which every individual craves for and people seek access to convenient modes of transportation, and it is here that the automotive industry plays a meaningful role. India is now the ninth country in the world to design a vehicle on its own. In fact, the Indian auto industry is fast becoming an outsourcing hub for automobile companies worldwide, as zooming automobile exports from the country indicate. Surinder Kapur, the chairman of Sona Koyo Steering, which exports car steering assemblies, says, "Car makers over the world have realized that India can design a car on its own and make it globally acceptable". Passenger car exports have nearly trebled in four years, from 28,122 units in 1998-99 to 71,653 vehicles in 2002-3. The industry expects this to gather steam further ahead because car exports in the first quarter of 2003-4 leapt by 87 percent over the same period in 2002-3. The two-wheeler segment is booming, too, with exports zooming from 100,004 units last year to 179,000 units in 2002-3. By 2005, the industry expects 400,000 two-wheelers on foreign shores. The Indian-made sports utility vehicle Scorpio received a singular response in Detroit early this year, not just for its design but also because of its cheaper price tag. Tata Motors, the country's second-largest carmaker's small Indica convinced MG Rover of the UK to sell it to the UK market as the City Rover. Others like Ford's mid-sized car model Ikon, Maruti's Altos and Toyota's Indian-made multi-utility vehicle have found ready buyers in a number of American, European and neighbouring countries. According to industry analysts, the Indian auto industry has finally come of age, having upgraded itself in the past few years to meet global standards.

Until the mid 1990s, the Indian auto sector consisted of just a handful of local companies. However, after the sector opened to foreign direct investment in 1996, global majors moved in. By 2002, Hyundai, Honda, Toyota, GM, Ford and Mitsubishi had set up their manufacturing bases here. These companies first had to focus on issues like quality, vendors and marketing before they could think big. Thus, in the past four to five years, these companies have not only fine-tuned their operations but forced transformation on the rest of the industry as well. Consequently, India has not only emerged as a low-cost base but also a source for producing quality products. The sector also received an unintended boost from stringent government auto emission regulations over the past few years. This ensured that vehicles produced in India conformed to the standards of the developed world. It also drew technology infusion and investment. India is also set to become a preferred R & D centre. Nevertheless, according to managing director Jagdish Khattar of Maruti Udyog Ltd. India's largest carmaker and a Suzuki joint venture, India still has a long way to go to become a global force. "Indian companies need to first grow the Indian market to acquire economies of scale," he says. China, for instance, consumes four times India's 700,000 annual car sales. Moreover, if Indian companies hope to corner a big chunk of the global market they need to show global presence considerably. Still, Joginder Singh of Ford feels that India's auto industry will continue to make its presence felt, primarily because it is one of the few countries the global auto industry cannot ignore. "Two-thirds of a car is built from suppliers. That's a big cost item and companies can cut costs to a large extent in places like India and China," he says. With the increasing emphasis on quality, India is fast moving towards becoming a sourcing hub for global automobile makers.

Table 7: The Indian Utility Vehicles Market: Sales of Major Players (units)

Company	1997-98	1998-99	1999-00
Bajaj Tempo (Trax)	8,843	5,379	6,133
Hindustan Motors (Trekker)	3,476	2,938	2,649
Mahindra & Mahindra (Armada, Voyager)	69,836	64,820	70,433
MUL (Gypsy)	7,785	7,250	8,705
TELCO (Sumo, Sierra, Safari)	43,716	31,349	31,983
Toyota (Qualis)	0	0	3,519
Total	133,656	111,736	123,422

Source: Business World, August 14, 2000.

Table 8: The Indian Car Market: Sales of Major Players (units)

Manufacturer	Model	June 2000	June 1999	% Change	June- July 1999-00	June- July 1998-99	% Change
Economy Segment Cars							
Maruti	800	2598	12107	-56	173721	168260	3
Maruti	Zen	3972	6731	-41	80372	67960	18
Maruti	Omni	3270	5353	-39	77896	64538	21
Maruti	WagonR	1180	-	-	11665	-	-
Hyundai	Santro	5011	4634	8	73240	31128	-
Tata	Indica	4085	3576	-58	61505	9787	-
Daewoo	Matiz	4484	2231	101	47336	10385	-
HM	Ambassador	1346	1319	2	18258	16054	14
Fiat	Uno	675	1272	-47	14637	12855	14
PAL	Padmini	0	10	-	16	1766	-99
PAL-Peugeot	118 NE	0	20	-	6	121	-95
Total		29.321	37.253	-21	558.652	382.854	46
Mid-size and luxury cars							
Maruti	Esteem	756	1330	-43	14937	16248	-8
Maruti	Baleno	239	0	-	3256	0	-
Honda	City	801	750	7	10136	8968	13
Mitsubishi	Lancer	750	629	19	8457	4769	77
Fiat	Siena	153	497	-	4565	751	-
Daewoo	Cielo	218	200	9	2621	3550	-26
Ford	Escort	-	288	-	1102	3022	-64
Ford	Ikon	1728	0	-	11299	0	-
Opel	Astra	202	230	-12	2772	3000	-8
Opel	Corsa	401	0	-	1392	0	-
Hyundai	Accent	1105	0	-	10727	0	-
Maruti	1000	0	38	-100	343	495	-31
M-Benz	E-class	46	37	24	593	430	38
HM	Contessa	28	26	8	228	395	-42
Tata	Estate	0	2	-	15	79	-81
Total		6427	4,027	60	72,443	41,708	74

Source: Autocar India, August 2000, p. 188.

Tata Motors: An Illustrative Study

Tata Motors is India's foremost and only fully integrated, automobile manufacturer. Established in 1945, as the Tata Engineering and Locomotive Company (Telco) to manufacture locomotive and other engineering products, the company is today among the world's top ten producers of commercial vehicles. Tata Motors, previously known as Tata Engineering, is one of the biggest and most prominent companies in the Tata Group, with an annual turnover of USD 18 billion in 2001-02. It is India's largest private sector company. It is also India's largest commercial vehicle manufacturer with a market share of 31.2% in the multi-utility vehicles segment and 6.4% in the luxury car segment. Worldwide it is ranked among the top ten in the manufacture of vehicles in the range of 5-15 tonnes. The company enjoys a significant demand in export markets such as Europe, Australia, South East Asia, Middle East and Africa. Tata Motors Vehicles currently sell over 70 countries. It manufactures heavy commercial vehicles (HCV), light commercial vehicles (LCV), passenger cars and multi-utility vehicles. 7 out of the 10 medium and heavy commercial vehicles in India bear the trusted Tata mark.

In its early years, Telco manufactured only commercial vehicles, through a technical collaboration with Mercedes Benz of Germany. Starting with the 1980s, Telco moved into light commercial vehicles, pick-up trucks, multi-utility vehicles, large cars and finally, small cars. The Tata Mobile pick-up truck launched in 1988 was probably a turning point in Telco's history. The model failed to build volumes, but gave Telco engineers confidence in their design capabilities. Telco then launched its big cars, Tata Sierra (1991) and Tata Estate (1992). Both these cars have been more or less phased out, as Telco decided to take a plunge into the mass-market small car segment. The challenge before Telco now is to make its newly introduced passenger car 'Indica', as popular as its other models. The IndicaV2, India's first indigenously designed and manufactured passenger car- has been a phenomenal success, standing testimony to the company's research and engineering expertise. Tata Motors followed this up with the launch in 2002 of the Indigo-a sedan.

The star in Tata Motor's portfolio today is the small car, Indica, designed in Italy, but manufactured in India as an almost completely indigenous effort. The car has a distinctive look and sufficient space but its engines can probably be improved. At the time of launch, the Indica was plagued by quality problems. Telco engineers, however, ironed these out in quick time. Priced at just over Rs. 3 lakhs, the Indica offers value for money and has catapulted Telco to a position in which it is one of the few serious challengers to Maruti Udyog Limited (MUL). In the Rs 3 - 4.5 lakh price segment consisting of the Santro, the Zen, the Matiz, the Wagon R and the Uno, Indica has a market share of 21%.

The passenger car division of Tata Motors was born out of a vision to offer the Indian customer all the comfort of a big car, at the price of a small car. The Indica was formally launched in 1998, and has rewritten the rules of Indian car industry since then. The latest addition to the Tata Motors family is Indigo which is designed to deliver never -before levels of luxury, safety, power and comfort on Indian roads is the new Indica V2.

Tata Motors seems to be well ahead of the other players in the industry in its e-business initiatives. It has created a portal, vcm.com, where business partners can log in with their unique passwords. Enquiries can be floated electronically to qualified vendors, quotations received and orders processed through the Internet. As soon as a vendor supplies goods, Tata Motor's systems and the vendor's books are updated. Information regarding acceptance of a consignment is also conveyed electronically. Telco is attempting to integrate its internal ERP system with the web so that production schedules can be given online to different vendors.

***Research and Development*:**

World-class automotive research and development are key factors that contribute to the leadership of the Company. Tata Motors invests up to 1.3 percent of its annual sales turnover on research and development. It has set up two in-house engineering research centre, including India's only certified crash-test facility. The company has been implementing environmentally sensitive technologies in manufacturing processes, and uses some of the world's most advanced equipment for emission checking and control. Tata Motors has led the Indian Automobile industry's anti pollution efforts by introducing cleaner engines. It is the first Indian company to introduce vehicles with Euro I and Euro II norms. Its joint venture with Cummins Engineering Company, USA in 1992 was a pioneering effort to introduce emission control technology in India.

***Facilities*:**

The Engineering Research Centre (ERC) at Jamshedpur regularly upgrades components and aggregates. A well-equipped torture track enables rigorous and exhaustive testing of modifications before they are used as regular fitments. The Engineering Research Centre in Pune was set up in 1966 and is among the finest in the country.

***Awards*:**

The technology Development board of the department of Science and Technology, Government of India, recognised the indigenous development and successful commercialisation of the Indica car by awarding Tata Motors 'The National

Award for Successful Commercialisation of Indigenous Technology by an Industrial Concern, 2000'. Tata Motors also received 'The DSIR National Award for R & D efforts in Industry' in 1999. It was also awarded the EEPC regional top exporters award trophy.

CHAPTER 5: Conclusion

In our discussion on technological activity of firms, we analysed the role of firm size, market structure and appropriability incentives in determining its innovative activity. The theoretical literature of the neo-Schumpeterian tradition has emphasized the role of firm size to favour innovative activity.

However, findings from a rather large body of empirical literature for industrialized countries have been quite divergent. The studies for developing countries generally suggest that larger firms are more likely to have an R & D unit or formal technological activity than smaller firms, although the intensity of R & D activity might not always be affected positively by firm size, given the economies of scale in technological activity. Given the economies of scale in R & D, the productivity of the technological effort of larger firms may be higher because of the larger scale of their R & D. Therefore, the policies that encourage larger national enterprises to take a greater role in building the technological capabilities of the nation should be encouraged.

With regard to discussion on market structure influencing the R & D spending of firms, market concentration has been expected to favour innovative activity rather than perfectly competitive market structures in the Schumpeterian tradition. The empirical literature, however, has found that the market structure's effect on innovation may be dependent upon other factors, such as technological opportunities, appropriability conditions, and entry conditions. Under certain conditions, a market structure consisting of few sellers could be more conducive for innovations. The role of threat of entry or potential competition as a major factor in determining R & D activities of a firm has also been highlighted. The innovative activity of existing firms may raise barriers to entry of new firms. Besides, the patent system also grants temporary monopolies to the firms that introduce innovation. This suggests a role for policy. National competition or anti-trust policies are needed to prevent the build-up of excessive monopoly power of certain enterprises and to ensure a constant threat of entry of new firms. The competition policy could also deal with possible abuse of monopoly power emanating from patent protection.

The role of appropriability conditions in encouraging innovative activity has assumed importance in recent times with the attempt by industrialized countries to strengthen the intellectual property protection system world-wide through multilateral trade negotiations incorporating both the length and breadth of patents. One of the arguments in favour of a stronger regime of intellectual property is based on the premise that expenditures on R & D were significantly determined by appropriability conditions. Hence, ensuring adequate appropriability with more stringent protection of the intellectual property is deemed to be necessary condition for sustaining the pace of innovation in the global economy. The empirical literature, however, does not support this presumption, as patent protection is found to be instrumental for only small proportion of innovations.

On the other hand, studies show the spillover effects of the R & D activity of other firms to be a lot more important than appropriability in inducing firms to undertake R & D. The R & D outputs of other firms form valuable inputs for the R & D efforts of these firms to undertake R & D. Hence, tightening of intellectual property protection is likely to affect innovative activity adversely by stifling these spillovers. However, forming cooperatives to tap spillovers can be one solution. But, stronger patent protection is likely to affect innovative activity of developing country enterprises adversely, which is largely of an adaptive in nature. For instance, the process innovations which form an important part of the innovative activity of developing country enterprises in the chemical industry, for known bulk drugs and chemicals covered by product patents, would be prevented by the new regime established by TRIPs under the World Trade Organisation.

With regard to R & D activities in India, it can be said that the country adopted well-defined development strategies and technology development approaches. Growth with rapid industrialisation had been the major objective after independence. In the initial phase it adopted an unbalanced growth strategy and initiated their development with foreign technologies. India followed a more traditional approach of promoting science first. However, there is little evidence that the mode of technology acquisition has significant implication for the growth process. In case of the technology acquisition in developing countries, the mix of channels through which an economy obtains technology from foreign sources is less important than the overall efforts to exploit and master these technologies. The weakness of the Indian policies lies in its failure to evolve a right mix of different policy strands that impacted on the performance of the national innovation system. Thus, the overall problem relates to the lack of appropriate linkages between different actors of the national innovation system. Though various policy measures were adopted during the 1990s to correct the imbalance in the approach, these efforts did not succeed significantly owing to the half-hearted approach. No innovation policy has been announced. After the Technology Policy 1983, the Draft Policy 1993 was announced. However, it was never translated into a policy. Schemes and policies are announced in a discretionary manner without any concrete approach. Their implementation and performance are left to the market forces. No serious evaluation is ever made of these policies and little is done to ensure their effective use. Under such a policy environment no major change is perceptible in the near future.

In this era of liberalisation, when technology has emerged as the most crucial factor determining competitiveness and growth, it is important to adopt a highly focused approach. A package of well formulated policies needs to be introduced that take care of different aspects of technological development.

Given limited resources, it is important to identify the sectors or specific activities across sectors where the country may build comparative advantages. These activities should have significant technological potential and generate beneficial externalities for other activities. Biotechnology and information technology for instance are two sectors where India has potential and which cut across various sectors. Once the priorities have been decided, policies need to be formulated at the sector / activity level. In each case, it is important to identify an innovation chain which includes both technical and economic interfaces for example, stages of innovation, skills required, institutions involved, financing of research, marketing of products and market feedback. Having identified the innovation chains, a package of direct and indirect policies needs to be developed to promote R & D in these areas. These measures include, direct intervention in forging links between institutions and industry, between industry and universities and among firms; strengthening of the existing infrastructure and creation of new institutions that may have important links in the innovation chains. Successful restructuring of the technical institutions is important in this context. This requires reorientation of the incentive schemes and funding patterns. The Government of India did take certain measures to improve the accountability of these institutions in the post-1991 period and the National Chemical Laboratory is an excellent example of the structural transformation. However, the results in the case of other institutions are modest and call for more stringent steps. University-industry linkages also need to be developed. Patenting by universities is almost absent in India. It is important to harness the skills of the higher education institutions by forging links between industry-institutions and universities. Promotion of industrial clusters is another area that may be given priority to internalise deficient markets for capital, skills, information and entrepreneurship. All these measures may be supplemented with fiscal incentives, research grants and R & D subsidies. Fiscal incentives should be given not only on R & D expenditures but also on the products developed in the process. Human skill is a crucial aspect of the process of technological development. It needs to be treated as human capital investment and not as social service expenditure as in India.

At the higher education level, emphasis should be on forging proper links between industry and technical institutions for improving the relevance of technical education, for reducing manpower imbalances and for financing of technical education in the country. It also requires periodic analysis of manpower requirements for better planning in human capital investment. AICTE (1994) recommended the formation of an Education Development Bank for better financing technical education in India. Such policy measures may improve the access to technical education.

Finally, the supply side policies need to be matched by appropriate demand side policies. On the demand side, competitive pressures may be maintained by adopting a well-formulated competition policy and intellectual property protection.

In sum, in the changing global scenario, the concept of science and technology policy needs to be replaced by 'innovation policy'. The innovation policy aims at establishing and strengthening the Techno-Economic network rather than supporting science and technology activities *per se*. While Korea and other OECD countries are increasingly focusing on innovation policy, India is still in the regime of S & T policy. The country needs a transition from an S & T policy regime to an innovation policy regime and the Department of Science and Technology has to take a major step forward in this direction.

Notes

[1] See Baumol, Blackman, and Wolff (1989).

[2] See Baumol (2002, pp: 4-5).

[3] See Baumol (2002, pp: 6-7).

[4] There are other ways as well, for example, through prizes and contracts (see Wright, 1983 for a theoretical analysis), or through tax deduction schemes (see Mansfield, 1985 for an empirical analysis). Each way has a particular set of advantages and disadvantages and there is no way that is clearly recognized as superior overall. Usually, several ways are used at the same time in the hope that they complement each other.

[5] See Granstrand (2000; page-83).

[6] This latter alternative typically requires more investment in production and marketing. Nordhaus disregards these; as long as they are independent of the optimising variable R, it is not essential for the way the analysis is done.

[7] It might off course happen, depending upon the coefficients k and α, that it does not pay at all to do research, that is, V is negative for any positive R, in which case the optimal solution is $R = V = 0$.

[8] Other empirical studies on the rate of imitation include Mansfield, Schwartz, and Wagner (1981), Mansfield (1985, 1986, 1993), Levin, Klevorick, Nelson and Winter (1987), Harabi (1995), and Arundal and Kabla (1998).

[9] See Scotchmer (1991 and 1996), Green and Scotchmer (1995), Chang (1995), and Matutes, Regibeau and Rockett (1996). Gallini and Scotchmer (2001) contains an excellent survey of the different approaches to the problem of optimal patent breadth.

[10] According to their study, especially in case of product innovations, firms report that they use secrecy to protect just over 50% of their innovations.

[11] Here we assume that the customer is the government. The customer might also be a private firm needing a particular technology or some particular machine tools.

[12] See Ponssard (1981) for a discussion of how French government agencies trade off these two factors.

[13] This is the so-called 'information paradox' (Arrow, 1962).

[14] See Jain (1998).

[15] See Mahalanobis (1961).

[16] DSIR, Annual Report 1985-86, New Delhi: Gov. of India, Department of Scientific and Industrial Research, 1986.

[17] See Table 7 in Basant (2000).

[18] See Table 8 in Basant (2000).

[19] TIFAC (February 1999), p. 6.

[20] Jolly (2001), p. 297.

[21] Lanjouw (1998).

[22] Alam (1996), p. 19-20.

[23] Government of India, Department of Science and Technology, "Action Plan / Implementation Strategy for STP-2001", http://mst.nic.in/dst/policy/snt.htm

[24] Rajeshwari (1996), p.110.

[25] Iyer et al (1998), p. 25.

[26] Ramanna (2002), p. 2069

[27] TIFAC (September 2000), p.1.

[28] Ibid.

[29] The 'U'-shaped nature of firm size-R & D relationship, i.e. higher R & D intensity for both very small and very large firms, has been reported by a number of recent studies (see, for example, Bound *et al.*, 1984; Acs and Audretsch, 1987, 1988; and Pavitt *et al.*, 1987).

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