TRIPS Agreement and the Emerging In-house R&D Activity of the Indian Pharmaceutical Companies: A Panel Data Analysis of the Firm Level Data

Mainak Majumder & Meenakshi Rajeev

Abstract

Under the WTO agreement on the Trade Related Aspects of Intellectual Property Rights (TRIPS), India amended its Patent law and recognized Product Patent from 1st January 2005. The recognition of the product patent is a big challenge for the Indian generic pharmaceutical companies, which has always relied on the imitation of the patent product of the innovative firms for its growth and development. Realizing the increasing importance of R&D among the pharmaceutical companies in the face of the current challenges, this paper examines the evolving R&D scenario in the Indian pharmaceutical sector and also identifies the factors that induce the firms to do more of R&D utilizing the panel data of about 288 firms for the time period 1991 to 2005. The empirical findings suggests that the probability of undertaking R&D and also the intensity of R&D is largely influenced by a number of firm specific factors like firm size, age, internal resources, outward orientation of the firms, firm structure, diversification strategies, competitive pressure, ownership pattern and the spillover-effects in the industry.

Keywords: *Product Patent, Firm -Size, R&D, R&D Intensity, MNC, Spillover effect, Firm Structure, Imitative R&D*

Introduction

Research and development (R&D) is a recent phenomenon for the pharmaceutical companies of India, which has gained momentum only after 1995. Historically, the low level of R&D activities among the Indian pharmaceutical companies is an outcome of the existing institutional set up under which the sector has developed. If we look back, we find that the Indian pharmaceutical industry has evolved through three distinct phases. The first phase was the period of early seventies when the British Patent law of 1911 was in force. A distinguishing feature of this period is the recognition of product patent in the existing patent law, lack of technology among the domestic players and a significant share of the multinational companies (MNC, about 70%) in the domestic market. The MNC operating in India were however, not keen in establishing the production unit in the country and imported most of the drugs from their home country. Thus, the very purpose of conferring product patent to encourage the MNC to establish their production unit for basic drugs and medicines by safeguarding their product was not fulfilled. Concerned by the lack of domestic manufacturing facilities for drugs and medicine in the country the government of India amended the Patent law of 1960 and the Patent law of 1970 that recognizes only process patent with limited scope of application was enforced. This marked the second stage of development of the Indian pharmaceutical industry, which spans from late 70s to 80s. Taking advantage of the flexible provision of the Patent Act of 1970, the Indian companies started imitating the patented products of the foreign companies, master the technique of reverse engineering, and could eventually come out with better process technology for the same product. This resulted in the decline in the

MNC's share in the domestic market by about 30 percent in 1990 and a spectacular growth and development of the sector (see Table No.1 Appendix A and Figure 1 and 2 Appendix B). The third phase of development of the sector stems from 90's onward during which, the pharmaceutical industry had experienced a stable growth rate of around 16 percent and a further consolidation of the Indian companies in the domestic market from 60 percent in 1991 to 77 percent in 2003.

Currently, the Indian pharmaceutical sector produces over 90 percent of the medicine consumed in India and manufactures almost the entire range of therapeutic products from its basic stage. It accounts for about 8 percent of world's production by volume, placing it in 4th place in the international market[1]. It is the largest producer in the global generic market and one of the top 20 exporters of bulk drugs and dosage forms. Its exports are destined to around 175 countries around the globe including the highly regulated markets of US, Europe, Japan, and Australia. The country can supply drug at a very low price in the international market and an important source of supplier of essential drugs to World Health Organization (WHO) and other under developed countries. We therefore find that the impressive growth and the existing strength acquired by the Indian pharmaceutical companies is an outcome of the ***Patent law of 1970,*** which has enabled the Indian companies to master the process technology and reverse engineering. However, in spite of all its strength a major complaint against the Indian pharmaceutical companies is their low level of R&D activities. We find that the existing institutional framework was not conducive for the pharmaceutical companies to do R&D. But in the recent years, the pharmaceutical companies of India have also ventured into R&D activities. This is evident from the rising aggregate expenditure for R&D by the pharmaceutical sector and also from rising proportion of firms with a R&D unit (see figure 3 and 4, Appendix B). Three major changes have prompted the Indian companies to do R&D. Firstly, the biotechnology revolution has revolutionized the drug discovery process that requires increasing expenditure in R&D. Secondly, due to the intense competition and the near stagnation in the domestic market, many Indian companies have decided to explore the global regulated market of US, Europe and Australia with their competency in process engineering. This requires increased R&D expenditure to invent newly improved product and cost effective process to compete with the MNCs. Thirdly, the recently amended patent law under the TRIPS agreement of the WTO have also compelled the Indian companies to think beyond reverse engineering and do more of innovative R&D. Thus, the increasing R&D activities of the Indian pharmaceutical companies is an outcome of the interaction of three distinct phenomenon viz; a) the change in the technological paradigm leading to a new trajectory of drug discovery b) the change in the institutional set up under which the firms were operating and c) the change in the R&D strategies of the firms due to the changes in the technological and institutional set up.

It is at this point, the paper attempts to explain the evolving R&D scenario in the Indian pharmaceutical sector and identifies the emerging R&D trends of the Indian pharmaceutical companies. Keeping in mind the distinctive features of the pharmaceutical companies, the paper also identifies some important firm specific factors like firm size, age of the firm, knowledge acquisition from abroad, export orientation, extent of diversification etc that encourages firms to undertake more of R&D. Thus in the context of the current policy changes this study locates some crucial factors that assist to maintain the competitiveness of the Indian generic companies by increased R&D spending. In the process, the study also highlights the need on the part of the

government to implement appropriate policies for enriching the R&D environment of the sector to enhance the R&D propensity of the Indian pharmaceutical companies.

Given this brief background, the paper is structured in the following sections. Section A explains the importance of R&D in the context of the pharmaceutical industry. Section B traces the nature of R&D pursued by the Indian pharmaceutical companies. The importance of different firm specific factors that encourages firms to undertake more of R&D is identified by appropriate empirical model in Section C. A concluding section follows thereafter.

Section A: Research and Development in the pharmaceutical Industry

The pharmaceutical companies produce products which are an outcome of the research and development (R&D) undertaken by the companies. Firms conduct R&D to find cures for new disease emerging and also because there is always a scope for the improvement of the existing products. R&D undertaken by the pharmaceutical companies are primarily of three distinct varieties- *i) innovative product R&D ii) incremental or imitative product R&D and iii)process R&D.*

Innovative research forms the "core" research of the drug industry. It tries to identify the basic cause of the disease, and invent novel product to cure the diseases. The process of basic research is complex and there are several steps involved in it. Basic or innovative R&D is a also a costly endeavor The Tufts centre for drug development (Philadelphia) estimated the cost of invention for a new drug to be about US$ 802 million and this figure is rising over the years. The success rate for inventing a new drug is also low – out of 100 drugs that go for clinical trial, only 3 are considered as successful, while only 1 turns out to be commercially lucrative. Further, the time span required for the marketing approval of a new drug is about 14.5 years[2].

Incremental or imitative innovation does not involve any major technological breakthrough and the chemical entities of the products do not entail genuine therapeutic progress. They are also known as "me-too" drugs, developed as result of the great deal of emulation of the successful drugs undertaken by rival companies. This type of innovation is motivated by the commercial benefit that entails the innovation process. The advantages of this type of drugs lies in improved efficiency, better patient's satisfaction, and compliance.

Process R&D is distinct from product R&D and refers to the new manufacturing method of producing the same set of drugs. Generally, drugs are produced through the complex combinations of different chemicals and ingredients. Process R&D then refers to the alternative forms of synthesizing the chemicals for producing the drugs and focuses mainly on the cost component of the product invented. Superior process R&D then refers to the alternative way of producing drugs at low cost.

The ability of a country to produce each of these categories of drug depends largely on the degree of industrialization, infrastructural development, and technological capability and also on the availability of technical skill and resources in the country. Until recently, the R&D in India is predominantly of the last three varieties. The practice of process R&D as opposed to product R&D by the Indian companies is largely an outcome of the technological evolution in the Indian pharmaceutical industry, which has eventually shaped the R&D behavior of the firms. The following section therefore explains the technological evolution of the Indian pharmaceutical sector in some details.

Section B: Technological evolution and the nature of R&D pursued by the Indian pharmaceutical industry

As already mentioned, during the early seventies the Indian pharmaceutical

companies lacked the necessary technology to produce the essential drug for the country. Concerned by the lack of the domestic manufacturing facilities the government of India established two public sector units – the Hindustan Antibiotics Ltd (HAL) in 1954 and the Indian Drugs and Pharmaceuticals Ltd (IDPL) in 1961 to start the production of drugs from the basic stage. HAL was established to produce antibiotic under the assistant of WHO and UNICEF. It is the first company in India to manufacture a number of antibiotic drugs.. The technology required to produce these drugs were imported from a large number of foreign companies from time to time which was then adapted to the local condition assisted by the in-house R&D wings of the company. In the process the in-house R&D endeavor of HAL has also resulted in the discovery of two very useful antifungal antibiotics-Hamycin and Aureofungin which has been licensed to a US company.

The IDPL was established with the support and assistant of Soviet Union to produce antibiotics, synthetic drugs, and surgical instruments. The technology required for the production of the drugs were transferred to IDPL by the Soviet Government and was upgraded and adapted to the local conditions by the Indian scientists. IDPL has three major plants - the Rishikesh plant, which was established to produce majority of the basic drugs and their product mix. The Hyderabad unit was established to produce synthetic vitamins, analgesics, antipyretics and other varieties of drugs, and the Madras unit produced the surgical instruments. Subsequently, two more plants were established at Gugaoan and Muzaffarpur.

For both HAL and IDPL the manufacturing plants were established with the help of the imported foreign technologies obtained either through the licensing scheme or through direct purchase. But subsequently the in-house R&D wings of the companies played a pivotal role to upgrade the technologies to the local conditions. In fact, the Soviet technology transferred to IDPL was not even adequate to start the production. It is the research centre of IDPL at Hyderabad, which started an extensive program to improve the imported technologies and increase its economic viabilities and profitability. A noteworthy achievement of IDPL is the development of 24 basic drugs including vitamin B-6, methldopa and ampicilin trihydrate for the first time in India by the process of reverse engineering. Furthermore, it also entered into joint ventures with a number of state government units, which resulted in the horizontal transfer of technologies among the domestic firms (Smith, 2000). Moreover, the presence of production plant of the company in different parts of India particular in the Southern and Western India had a remarkable and significant geographical spillover effect in the form of accumulation of skilled labor, specialized capital and other technical services, which has resulted in the conglomeration of large number of firms in those areas. The high concentration of bulk drug manufacturing facilities in and around Hyderabad bears testimony to this fact. We thus find that the pattern of technological transfer in the context of Indian pharmaceutical industry was technology purchase adapted to local condition through the in-house R&D efforts of the firms. Thus, the basic trust of R&D from the very beginning was in the adaptive type of R&D, the tradition of which is even followed by a large number of Indian companies.

Apart from the PSUs, the public funded research institute also played a pivotal role in determining the technological behavior of the firms. Realizing the fact that the private sector is incapable of doing any fundamental R&D the government created a number of research institutes under the guidance of Indian Council of Medical Research (ICMR) and Council of Scientific and Industrial Research (CSIR) to promote the R&D environment of the country. Some of the CSIR institutes, which have played a significant role in

boosting up the knowledge base in the pharmaceutical sector of India, are Central Drug Research Institutes (CDRI) Lucknow, Indian Institute of Chemical Technology (IICT) Hyderabad, National Chemical Laboratory (NCL) Pune and Regional Research Laboratories of Jammu and Jorhat. Among the few innovative drugs developed in India, the CDRI has the major contribution (see Table No. 2, Appendix A). But in spite of its achievement, what is really missing is the lack of commercial orientation and therefore most of the new drugs developed could not be profitably introduced in the market. However, CDRI[3] have inventing more than 100 new process technologies, which has also been successfully commercialized. Besides CDRI, the technologies developed by NCL and other RRLs were also transferred effectively from the laboratories to the industries. The success of the CSIR laboratories in fostering the technological environment of the Indian pharmaceutical sector is also evident when we find that almost all the top pharmaceutical companies like Lupin, Ranbaxy, Cipla, Nicholas Primal, Wockhardt, Uichem, Torrent, J.B chemical, Nicholas Primal, Neuland, Sun Pharmaceutical, Orchid, S O L Pharmaceuticals Ltd and Aurobindo Pharma Ltd have benefited from the services of the research institutes in India in some way or other (Chaudhuri 2005, pp 35-36).

The establishment of the large-scale public sector units and the contribution of CSIR then sparked the R&D environment of the country in a big way. However, the thrust of R&D was mainly in process technology and adaptive R&D of the foreign technology transferred through direct purchase of technology. The CSIR laboratories, however, have employed a different route to unveil the technology incorporated in the drugs of the foreign companies. Taking the flexible provision of the Patent Law of 1970, it disintegrated the chemical composition of the drugs and synthesis the product through an alternative route, which turned out to be more effective than the original product developed by the MNCs. The excellent infrastructural facilities and the human capital endowment have assisted the research laboratories to achieve the same. The product was then transferred to the private companies for marketing. Since product patent was not recognized in India during that time, the companies did not face any charge of infringement while marketing the product.

Last but not the least, the in-house R&D wings of the companies have also helped them to further upgrade the technology transferred from the research laboratories and also to develop their own competency in the process engineering. We thus find that the public sector units, the government funded research institutes coupled with the in-house R&D wings of the companies have played a major role in promoting the technological capacity of the country. However, in spite of the remarkable achievement what was really missing is adequate R&D. The total thrusts of R&D by the Indian pharmaceutical companies were substantially low and were mostly done by the large companies. For most of the medium and small sized firms, what went on in the name of R&D in most of the cases were quality control works. Low level of R&D by the Indian pharmaceutical companies is mainly due to the adaptive nature of R&D pursued by them. Since the cost of adaptive R&D is substantially low than the original R&D (Mansfield, 1961) the total R&D expenditure of the pharmaceutical sector of India is low. We can then summarize from the above discussion that the nature of technology transfer from the public research institutes and the policy regimes adopted by the government to boost the domestic pharmaceutical production have largely shaped the R&D behavior of the firms, which is mainly of the adaptive type.

Section C: Post TRIPS R&D Scenario in India

The R&D scenario in India has however, changed after the enforcement of the TRIPS agreement in India in the mid half of nineties.

This is evident from the increased aggregative R&D spending by the Indian pharmaceutical companies (Figure 3, Appendix B). Increasing importance of R&D by the pharmaceutical companies is also evident from the cross comparison of the R&D spending by the Indian pharmaceutical sector with respect to the other industry groups. Figure 5 (Appendix B), which bears testimony to this fact indicates two noticeable trends (i) the pharmaceutical industry is one of the major contributor of R&D in the chemical and manufacturing sector (ii) share of pharmaceutical R&D in the total manufacturing and chemical sector is rising over the years . This indicates that the pharmaceutical industry plays a leading role for the R&D activities in the country. Further, the rise in the proportion of firms with higher R&D intensity (more than 4%) in the Indian pharmaceutical industry from 1991 is another significant outcome (Figure 6, Appendix B). This indicates that the Indian pharmaceutical industry is allocating increasing amount of its sales towards R&D spending.

Given the fact that R&D is gaining ground for the Indian pharmaceutical companies' two distinct and inseparable questions turns out to be crucial to understand the R&D behavior of the firms viz; ***(a) What factors induce firms to do R&D? (b) What factors encourage firms to do R&D more intensively?*** The first question boils down in estimating the probability of the firms to do R&D and the second one to estimate R&D intensity regression. The appropriate model to answer these questions is to use a Probit model for the first case and a Tobit model for the second case.

The use of the Probit and a Tobit model is justified because the dependent variable here takes a value of zero for a large proportion of firms and hence a simple OLS estimation will be biased. In the case of Probit model, the dependent variable is a binary (0, 1) variable depending on whether or not the firm undertake any R&D. The probit estimate then gives the conditional probability of an individual firm investing in innovative activity for a given set of explanatory variables. The intensity to do R&D is then explained by using a Tobit model. The model used for our study then takes the following form

$$R\&D_{it}=X_{it}\hat{a}+\grave{I}_{it} \quad (1)$$

For the Probit model, the dependent variable $R\&D_{it}$ takes the value 1 if firms do R&D and zero otherwise. For Tobit model, the dependent variable is the R&D expenses per unit of sales for a firm undertaking R&D and zero for other cases. The independent variable in our model is $X_{it,}$ where X_{it} is a vector of k factors that explains the R&D behavior of the ith firms (i=1-288) in the t-th time period (t=1991-2005). In our study information for the 288 firms are not available for all the years and therefore we have an unbalanced panel of 2437 firms for 15 years. The relevant variables for our study are obtained from the balance sheets of the companies from the prowess database.

Following the earlier theoretical and empirical literature on the determinants of R&D activity of the firms, the present study identifies a number of factors discussed below.

Firm Size and Innovative Activity

Firm size is one of the most debated issues in both theoretical and empirical literature to determine the innovative activity of the firms (see for example Kamien and Schwartz, 1982; Dosi, 1998; Cohen and Levin, 1989; Cohen 1995, for review of literature). A positive relationship between the firm size and the innovative activity was first postulated by Schumpeter (1942) and was further developed by Galbraith (1952). According to this hypothesis, large firms spend proportionately more than the small firms because the presence of the threshold limits, scale economies in R&D and the imperfection in capital market may favorably influence the size factor. Thus, with capital market

imperfection large firms may enjoy some advantages in conducting R&D because it can raise funds with less difficulty both from the external and internal sources. The minimum threshold limit and the economies of scale also discriminates the large firms against the small firms by reducing the cost and risk of R&D. However, the empirical studies conducted to test the above hypothesis for both the developed and underdeveloped countries have yielded conflicting result (see Cohen 1995; Kumar and Siddharthan 1997 for detailed surveys). This in turn has evoked the scholars to probe into the matter more deeply that motivated them to separate out the impact of scale economies and threshold limit in R&D. This was achieved by hypothesizing a non-linear relationship between the firm size and R&D by including a quadratic term in the equation, which implies that size variable may favorable influence the decision to do R&D because of the presence of threshold limit beyond which the relationship may not be significant.

The Neo-Schumpeterian economists (Dosi, 1998) have also approached the problem from a different angle. The Neo-Schumpeterian economists have argued that the nature of R&D may also differ for different firm sizes, this happens when small and large firms belong to two different strategic group undertaking different type of R&D work. In the context of the pharmaceutical sector of India, we find that the Neo-Schumpeterian argument fits well because the nature of R&D differs between different groups of firm. Thus, majority of the small firms with an R&D unit restrict themselves to minor product modification for which the expenditure for R&D is minimal. On the other hand, the medium sized firms do either process or adaptive R&D. For large sized firms the portfolio of R&D is, however, vast and it covers process and product development, incremental variety of R&D, custom synthesis and more recently in to new product innovations or inventing new chemical entity. It is then quite conceivable that there would be two different threshold levels for these groups of firms- a lower threshold level for mainly adaptive or incremental R&D and a higher threshold limit for other type of R&D. Thus, following the earlier tradition we have included in our study the firm size and along with its square and a cubic term to capture the possible non-linearities of the firm size with its R&D activity. The real sales volume measures the firm size in our model.

Market Structure and Innovative Activity

Market structure has also been posited as an important determinant for the innovation of the firms (Schumpeter, 1942). According to Schumpeter, a monopoly market structure is best suited for innovative activity because a monopoly can charge higher price and can make supernormal with which he can undertake innovative activity and in the course of action, he can make new processes for production and invent differentiated products. A competitive firm on the other hand, has no surplus and therefore cannot undertake any R&D. Thus, Schumpeter (1942:105) argues, "The introduction of the new methods of production and new commodities is hardly conceivable with perfect competition from the start. And this means that the bulk of what we call economic progress is incompatible with it". Schumpeterian argument for market structure has generated a number of theoretical and empirical studies. For example, Arrow (1962) has theoretically argued that under certain conditions competitive market structure is more conducive for R&D than monopoly. But Dasgupta and Stiglitz (1980) in their microeconomic model of innovation has criticized Arrow (1962) for taking market structure as exogenous and has established

that high research intensity and high concentration goes hand to hand. Among the empirical studies majority of them have found a positive relationship between the market structure and the R&D of the firms (first among the many was Horowitz (1962), Hamberg (1964) Scherer (1967) see for example for a recent survey). A few studies have also found evidence that concentration has a negative impact on R&D (Williamson (1965), Bozeman and Link (1983), Mukhopadhyay (1985)). In our study, we have also tried to test the Schumpeterian hypothesis regarding the impact of monopoly market structure on the innovative activity of the firm by measuring the market concentration using the Herfindahl index of concentration.

Multi-product Firm and Innovative Activity

Almost all the pharmaceutical firms produce multi-product and in that sense, their production is highly diversified. There can be many reasons for which a firm may diversify. One common argument made by the economists is the efficiency gain that a firm achieves when it diversifies because it can then share its managerial and R&D inputs into various spheres of activities. The area in which diversification can have the most likely effect is in R&D. This is because R&D is a risky endeavor and its results are also highly unpredictable. Hence, greater the range of activities of a firm the higher will be chances that the discovery will fit into different product line (Gort, 1966, P.33). It is therefore appropriate to assume that even if the research undertaken by a firm is not fruitful for solving some problem but can also be used as a valuable research input for other research project. Hence, only diversified firms with broad technological bases will find it more profitable to engage in research since they are able to market whatever their inventions or discoveries in a better way (Nelson, 1959). Further, the technological spillover among the related as well as distinct product lines is an additional advantage for a diversified firm to engage in R&D (McDonald, 1985; and Hall, 1985). In the context of the pharmaceutical industry, the argument for technological spillover holds good because even though the products produced by the pharmaceutical industry are distinct they often share the same technology and thus the knowledge useful for producing one set of good can be equally helpful in producing other goods. Moreover, the pharmaceutical products itself incorporates some peculiar features which makes diversification a natural strategy for the firms. Thus, for example, a drug with same composition but with different dosage form can effectively treat different diseases with its increased scope of operation. Therefore, the chances that the knowledge gathered for R&D undertaken for a particular product variety will further add into the R&D undertaken for other product basket are high in the pharmaceutical industry. Finally, the economies of scope (Panzar and Willig, 1981) which measures "the cost advantage for firms of providing a large number of diversified products as against specializing in the production of a single output" (Bailey and Friedlander, 1982, p.1025) provide another rationale for the multi output firms to engage more in R&D. The cost advantages generally arise from a joint utilization of inputs for inventing more good and also because of certain inputs, which have to a certain extent the nature of public goods (such as human capital, which is applicable for producing different outputs). Realizing the importance of product diversification on the R&D activity of the firms, we have postulated a positive relationship between the two in our study. Herfindahl Index of diversification is utilized for measuring diversification of the firms in our model.

Promotional Expenses and Innovative Activity

R&D in the pharmaceutical industry is closely linked with the promotional expenses a firm undertakes. This arises because the product invented can be constantly improved from the feed back received from the physician regarding its effectiveness. Thus, R&D here is not a one-time process but it is a cumulative and continuous learning process, which requires constant interaction from the beneficiaries regarding the utility of the product invented and launched. The companies are also constantly informed about the new diseases pattern emerging in the society, the severity of the problem arising out of it and the scope of operation of its product for treating those diseases from the network externality of the promotional activity undertaken by them. The portfolio of the R&D projects and the intensity of the R&D undertaken by a company is then a direct by product of the information gathered from the promotional activities undertaken by the firms and there is hardly any company that does R&D without undertaking any promotional activity. In fact as documented by Kettler, et.al (2003) the very first step in R&D starts based on the information gathered from the promotional activities incurred by the company. A company, which is well established in market, can successfully launch its product and hence the possibility that it will be awarded from the R&D endeavor will depend largely on the effort it makes to promote its product. Promotional expenses then play a vital role to boost the R&D activities of the firms and have also been included in our study.

Foreign Ownership Pattern and R&D

It is often argued that MNC plays an important role for technological innovation in a country by importing the advanced technology for its operation. One of the main arguments for introducing product patent in a country like India is to encourage the MNCs to shift its R&D base in the less developed country due to low cost operation, which will subsequently add more to the R&D pool in the country. Given the non-rival nature of R&D, increased operation of the MNC will then benefit the domestic firms through spillover effect. The counter argument is that the MNC may not spend much on R&D in the less developed country because they have captive access to the laboratories of their parent companies situated in the home country. Further, the location specific factor accumulated through history of its operation in the advanced country, strong university – industry nexus also creates disincentive for the MNC to shift their R&D base in the less developed country. The empirical studies by Kumar (1987); Kumar and Saqib (1996); Kumar and Agrawal (2000) suggest that MNC do not spend more than the domestic firms in the less developed country like India. In our study, we have examined the differences in the foreign ownership pattern in the R&D propensity of the firms by differentiating the MNC from the domestic companies by introducing an intercept dummy for the MNCs.

Internal Resources and the Innovative Activity

The profit margins may affect the propensity to undertake R&D activity of enterprises in many ways. Firms may be unwilling to fund R&D with borrowed funds given the high uncertainty of returns from it. High-profit margins then indicate internally generated funds with which a firm may transact its R&D activity. The lack of a well-developed venture capital market is also a big bottleneck for pharmaceutical firms in India to borrow fund from external sources and conduct R&D. Under such circumstances retained profit of the companies act as a valuable source of resources to do R&D. Retained profit per unit of sales is then included as a proxy for internal resources to transact the R&D expenses of the firm.

Age of the Firm and R&D

Innovation is not a one-time process but depends on the technological capacity of a firm accumulated through constant learning, continuous interactions among the various personnel, skill developed through continuous changes in the operating expertise in the production process and in its product development (Bell and Pavit, 1992; Aw and Batra, 1998). It is often argued that the innovative capacity of a firm depend largely on the position of the firm in the life cycle of the product and of the industry (Acs and Audretsch, 1987, 1988). Accumulated experience of the firm is then extremely valuable for the technological advancement of a firm. Age of the firms can then be used as a proxy for accumulated experience and technological learning of a firm to examine its impact on its R&D propensity.

Product Variety, Firm Structure and R&D

Pharmaceutical companies produce two broad categories of products viz., bulk drug and the formulation the technology and the economics of which are distinct and different. Bulk drugs are the raw-material and the active pharmaceutical ingredients, which is used to produce the medicine. The formulation is the final product, which is composed of the active pharmaceutical ingredients, the raw material, and the impurities the various combinations of which is used for final consumption. The R&D targeted for these two categories of product is then different. R&D targeted for formulation is then meant for product improvement whereas for bulk drug the thrust of R&D is mainly for incremental and process engineering. Novel R&D on the other hand involves the following step-inventing new molecule, synthesizing it with other raw-material, producing it in bulk form, and its ultimate development in different form of formulation for final usage. Companies, which produce both the bulk and formulation form of medicine, are then best suited for doing novel R&D. Given the environment in which the Indian pharmaceutical companies have operated, it can be conjectured that firms producing both bulk and formulation have the maximum thrust for R&D mainly because they have to do the R&D for both varieties of product and also because the scope of success and operation in R&D is high. In our study, we have also differentiated between these three categories of firms keeping in mind the nature of R&D undertaken by them. We have hypothesized that firms producing both varieties of product or only the bulk drugs will have greater probability to undertake R&D and also in higher intensity than the formulation companies because most of the formulation companies do very little R&D the major thrust of which is in minor product innovation. The production of the three varieties of the product also gives some indication about the structure of the firms operating in the pharmaceutical sector of India. Thus, firms producing only bulk or formulation are horizontally integrated whereas the firms producing both the bulk and formulation variety are vertically integrated. Thus differentiating the firms based on the product variety also help us to analyze whether a vertically or a horizontally integrated companies are better suited for undertaking R&D.

Time Dummy

A time dummy has also been introduced from 1995 onward to examine the impact of various policy changes on the R&D behavior of the firms. The year 1995 has been selected meticulously keeping in mind the important policy changes that have taken place in the industry. In particular, the drug and the cosmetic act have been amended in 1995 by abolishing the licensing system, by liberalizing the FDI policy and by reducing the price control. Further, strict quality control and good manufacturing practice has also been incorporated in the amended act, which requires increased R&D. The emphasis is then

on increased competition with strict quality control. The year 1995 is also important because India became the member of WTO in 1995. Conjecturing the possible challenges that the pharmaceutical companies might face in the coming years due to the likely imposition of Product Patent the forward-looking pharmaceutical companies started investing heavily in R&D keeping in mind the gestation period through which they had to pass to realize fully the impact of R&D. We can expect that from 1995 onward the R&D endeavor of the Indian pharmaceutical companies might have increased due to the policy changes. The effect of the policy changes has been captured by including a dummy variable taking value of 1 from 1995 onwards and 0 for the other years.

Outward Orientation of the Firms

It is expected that with outward orientation firm's need for in house R&D will increase. This is because exporting in the international market is not easy given the stringent regulatory mechanism of the developed country for the pharmaceutical product. For that, a firm has to adapt the product to the nature of the demand, diseases pattern, product standard, and population composition of the foreign market. The in-house R&D effort then plays a supporting role for firms to capture the global market. It can then be hypothesized that with outward orientation the R&D effort of the firms will rise. Outward orientation of the firms is measured by the export earning of the firms per unit of the sales.

The factors listed above are important to explain the propensity of the firms to do R&D. Additionally, we have also identified two more factors like the technology import and industry wise spill-over effect which may not be important to influence the decision of the firms to do R&D but might have significant impact in the second stage of its decision to do R&D more intensively. The justification for using these variables to explain the R&D intensity of the firms is explained below.

Technology Import and R&D

It is assumed that firms in the developing counties have limited technological capacity, which they fulfill by importing technologies from abroad. A firm can import technology through two channels either through the disembodied channel like patents, designs and drawing, blueprint for the technology, product licensing or through embodied channel like plant and machinery. What ever be the form of technological import an important question that has always raised the interest of the scholars (for a recent survey see Bluementhal, 1979 Kumar and Siddharthan, 1997) is how the import of technology affects the in-house R&D propensity of the firms. This question is highly contextual because if technological import is a substitute for in-house R&D efforts of the firms then the country will always have to depend on the availability of foreign technology for upgrading its production process, which can be a serious impediment for further development of its own internal capability at least in the long run. If on the other hand, technological import requires further adoption and absorption it can then be a complements to the in-house R&D efforts of the firms. This in the turns can help to build the internal capacity and capability of the firms through greater assimilation of knowledge, greater know-how and also through the technology spillover in the internal production process acquired through the continuous learning process of the firms. Empirical studies in this context is mixed, thus the studies by Lall 1983; Katrak 1985; Kumar, 1987; Deolalikar and Evenson 1989; Siddharthan 1988, 1992; Kumar and Agarwal 2000, have posited a complementary relationship, whereas Fikkert have (1993) reported an inverse relationship between technology imports and R&D in a framework that treated them as jointly determined. On the other hand, Kumar and Saqib (1996) found neither complementarity nor substitution in the relationship. However, in

the context of the determinants of in-house R&D activity of the firms all the above-mentioned empirical studies suffers from the limitation in the direction of causation. Thus, the decision to do R&D might induce the firms to import foreign technology, which might further effect the decision of the firms to do R&D more intensively. In our study, we have two different set of questions about the R&D behavior of the firms and hence we have not included the import of foreign technology, as the determinant of the firm's decision to do R&D. The problem of causality therefore does not arise in our model. Moreover, in line with the above argument we have also introduced a one year lagged value of technological parameter in the R&D intensity equation that further takes care of the problem of causality. Technology imported is measured as a ratio of firm's expenditure on imported technology to its total value of sales.

Spillover Effect and R&D

Spillover effect takes place when a firm benefits from the innovative activity undertaken by other firms in the industry. Knowledge spillover exists because the fruits of the innovation are non-rival and partially non-excludable in nature. Non-rival means that the use of the knowledge by one agent does not preclude others from using it and partial excludability means that owner of the knowledge cannot exclude others from the use of the stock of knowledge at free of cost or at least at a low cost compared to the initial investment made by the firm (Romer, 1990; Aghion and Howitt, 1992). Generally, technology spillover is a complementary factor for the R&D activity of a firm. However, the ability of the firm to derive its benefit from the knowledge pool of the sector is determined by the proximity of its position in the technological space of the sector. The spillover effect in our study is measured by using two variables i) the knowledge pool of the sector, which is measured as the sum of the R&D capital stock of the firms in the industry and ii) the distance of the firm from the knowledge pool which is measured as the weighted difference between the total industry R&D expenditure for a given year and the firm's own R&D expenditure for that year. The weights are calculated by the ratio of firm's R&D in the total industry's knowledge pool. The spillover index constructed has two components; the first component-the difference between the industry's and the firm's R&D is the external technological opportunity available before a firm. The weights on the other hand measure the strength of appropiability of a firm. Thus higher a firm spends on R&D the more will be its ability to appropriate the technological opportunity available for the industry.

Empirical Results and Findings

Table No. 3 and 4, summarizes the main finding from the Probit and the Tobit model. In view of the panel structure of our model, we have estimated the random effect Probit and Tobit models in our study. We have also utilized a one-way error component model for our analysis where $u_{it} = u_i + v_{it}$ where u_i' s are the unobservable firm specific effect and v_{it}' s are the remaining disturbances identically and independently distributed (normal) with zero (0) mean and variance σ_v^2 (IID, $0, \sigma_v^2$). The Wald Chi-square statistics indicates that overall the set of coefficient in the Probit as well as the Tobit models are statistically significant at 1% level to explain the overall variation of our model. This means that taken together all our independent variables explains a significant portion of the variation in the dependent variable. The findings pertaining to the individual independent variables are then discussed below.

Firm Size

For both Tobit and Probit model, firm size turned out to be a significant variable. This

implies that with the expansiveness in the scale of production the probability to undertake R&D and its intensity also increases. The quadratic relation with a negative coefficient and the cubic relation with a positive coefficient fit well for both the Probit and Tobit model. This indicates an inverted horizontal S shaped relationship between the size factor and R&D activity. This also implies that the probability as well as the intensity of undertaking R&D increases with the firm size up to a threshold level after which it falls, it rises for another threshold limit before falling again with size. The inverted horizontal S shaped relationship between firm size and R&D confirms the presence of two strategic groups of firms in the context of Indian pharmaceutical sector. For one strategic group of firm (mostly small and medium sized firm) the basic thrust in R&D is in minor product modification and in reverse engineering for which we have one threshold limit in R&D. The other strategic group of firm is, however, more ambitious and target their R&D in new product innovation or in advanced process technology like New Drug Delivery System(NDDS), advanced generics, superior custom synthesis etc. This requires advanced equipment, sophisticated laboratory, excellent human capital base etc. We therefore find a second threshold limit for this group of firm.

Market Structure

Market concentration variable, viz: Herfindahl index, have a positive sign but its coefficient is not significantly different from zero. This is expected because in the pharmaceutical industry of India there are large number of small companies (about 10,000) and few large companies (about 35 to 40) indicating a fragmented market structure. As of now product patent was not recognized and therefore all the large companies have developed competency to produce product for almost all the therapeutic groups indicating a differentiated monopolistic product market. The value of Herfindhal index for different years is also low which implies negligible concentration (see Figure 7) in the industry. We thus find that market concentration plays no role to the R&D behavior of the firms.

Age of the Firms and Accumulated Experience

Accumulated experience proxies the age of the firms is also highly significant in both the model upholding our contention that firms with longer production experience are more likely to set up a R&D unit and also spend higher amount of resources for R&D.

Product Mix, Firm Structure, and R&D

Results in Table 3 and 4 also confirm that both the firms producing only bulk drugs and or bulk and formulation drug has higher propensity and intensity to do R&D compared to the firms producing only formulation. This also indicates that both the vertically and horizontally integrated companies are equally good in doing R&D. Among the horizontally integrated companies that produce only bulk drug are better suited to do R&D. This is because the recent scientific advancement (biotech-revolution) has disintegrated the R&D process of the pharmaceutical companies and it is not always necessary for a company to do the whole sequence of R&D under a common roof. A company on the other hand can also place itself in the different stages of R&D according to its comparative advantage and can outsource the other activity or can benefit from other firms by purchasing the necessary technology. In a sense, we can then argue that due to the biotechnology revolution the horizontally integrated companies are equally suited for undertaking R&D along with the vertically integrated companies.

Increased Exposure to International Market and R&D

The extent of export orientation has a statistically significant with positive

coefficient for both the model. This implies that the diversification in the international markets increases the firms need to invest more in R&D to adapt the product to the demand of the international market.

Diversification and R&D

Herfindahl index of diversification comes up with a statistically significant coefficient though at ten percent level for the probit model; however, it is not statistically significant for the Tobit model. This implies that multi-product firms have higher probability to do R&D. However, a more diversified product basket does not mean that a firm has to spend a greater amount of resources for R&D. This is because the initial decision to do R&D is favorably influenced by the presence of multi-product basket, which enables the firm the spread the risk of R&D among the different product, however, once the allocation of resources are made for R&D; firms do not necessarily spend more just because it is diversified.

Time Dummy and R&D

The time dummy employed to study the impact of policy changes on the R&D behavior of the firms turned out to be one of the crucial variables to explain the R&D behavior of the firms and is statistically significant at one percent level. Thus in increased competition and the changes in patent law have induced the pharmaceutical companies to do R&D in an intensive manner.

Internally Generated Resources and R&D

Internally generated resource proxied by the retained profit of the firms is another positively significant variable at one percent level in both the models. This confirms to our hypothesis that the internally generated funds of the firms is an important source of resources to undertake R&D in the absence of well-defined market for venture capital.

Foreign Ownership Pattern and R&D

Foreign ownership pattern is positively significant though at ten percent level in the probit model but it is not statistically significant in the Tobit model. This implies that while the firm's decision to do R&D is influenced by the foreign ownership pattern, it does not have any impact on the R&D intensity of the firms. This is because the MNC establishes the R&D unit in India with the sole motive of doing minor modification of their product to cater to the local need of the population. However, beyond that they are not enthusiastic to do R&D because of the strong linkage effect with the R&D unit of the parent company and due to other location specific advantages of the parent country. Also due to the lack of product patent for a considerable period, the MNC runs the risk of technological imitation by other firms in the country. Thus while the presence of MNC favorably influences the decision to do R&D it does not contribute to the R&D intensity of the firms.

Promotional Expenses and R&D

Promotional expenses by the companies turned to be another highly significant variable with positive sign for both the models. This upholds our contention that firms with vast network facility has higher probability to do R&D and also in a more intensive fashion because of the strong association between the R&D undertaken by it and the promotional expenses incurred by it.

Technology Import and R&D

The technology import variable turn out to be with coefficient having positive sign but not statistically different from zero in the Tobit models. It therefore appears that technology import do not influence the R&D intensity of the firms. This suggests that the relationship between the technology import and R&D is marked neither by substitution nor by complementarity.

Spillover Effect and R&D

Spillover effect is significant at one percent level in the Tobit model with positive coefficient. This indicates the presence of strong positive externality in the R&D environment in the Indian pharmaceutical sector from which the firms benefit. The lack of product patent is an important reason for the presence of spillover, which enables the firms to appropriate the research benefit of the other firms in the sector. Moreover, in the recent years due to the increasing cooperation between the public research institute and the in-house R&D wings of the firms the intensity of spillover is also high.

Section D: Concluding Remarks

The present paper has analyzed the nature of R&D pursued by the Indian Pharmaceutical companies. It has traced that the low level and the imitative nature of R&D pursued by the Indian pharmaceutical companies is largely an outcome of the institutional and technological environment under which the sector has developed. However realizing the increasing importance of R&D among the pharmaceutical companies after the TRIPS agreement in 1995 the paper investigated the factors that induce firms to do R&D using a Probit and a Tobit model. The empirical findings from the Probit and Tobit model have identified a number of important factors that plays a decisive role to influence the probability of the firm to undertake R&D and also to carry out the R&D more intensively. Our study indicates that firm size plays a crucial role to influence the decision of the firms to undertake R&D and it also has a positive impact on the R&D intensity. The two-threshold limit also indicates the presence of two strategic groups of firms undertaking two different form of R&D. The impact of policy change has also favorably influenced the R&D behavior of the firms. Thus contrary to the popular perception our findings indicate that with product patent firms are doing more of R&D. This implies that the policy change has a stimulating effect on the R&D behavior of the firms and therefore the government should carry forward with its liberalization policy without any fail. Technologies imported do not have any affect the R&D behavior of the firms. However, the degree of export orientation of the firms favorably influences its decision to set up an R&D unit and also on the intensity of R&D expenditure. This has a clear-cut policy implication where the government should focus more on removing the obstacles that inhibit firm's participation in international market via exports or by outward foreign direct investment. The presence of MNC has a stimulating effect on the R&D behavior of the firms; this implies that government should implement appropriate policies to encourage foreign direct investment and should provide proper incentive to the MNC to establish their plants here. Internally generated resources, age of the firms, promotional expenses also have a positive impact on the R&D behavior of the firms. Our study shows that both the vertically and horizontally integrated companies are best suited for R&D. This happens due to the new technological revolution (biotechnological revolution) pertaining to this sector. The government should therefore take proper steps to kindle the biotech environment of the country. Lastly, the spillover has a positive impact on the R&D intensity of the firms. This implies that firm's R&D behavior is largely influenced by the R&D environment of the country. One important component of the overall R&D environment of the country is the public expenditure for R&D. Given the fact that R&D spillover has a stimulating effect on the R&D behavior of the firms, the government should invest more resources in the public research institutes to strengthen the R&D environment of the country.

References

Acs, Z.J. and D.B. Audretsch (1987) "Innovation, market structure and firm size", *The Review of Economics and Statistics*, 71: 567-74.

Aghion, Philippe & Howitt, Peter, 1992. "A Model of Growth through Creative Destruction," Econometrica, Econometric Society, vol. 60(2), pages 323-51,

Arrow, K.J. (1962). "The Economic Implications of Learning By Doing". *Review of Economic Studies*, 29: 155-73.

Bailey E.E. and Friedlander A.F. (1982) 'Market structure and multiproduct industries', *Journal of economic literature*, 1024-1048.

Bell, Martin. And Keith Pavitt (1992) 'Accumulating Technological Capability in*Proceedings of the World Bank Annual Conference onDevelopment Economics, 1992*, pp. 257-581.

Bozeman, B, and A.N.Link (1983). *Investment in Technology: Corporate Strategies and Public Policy Alternatives*. New York: Praeger.

Blumenthal, Tuvia (1979). 'A Note on the Relationship between Domestic Research and

Development and Imports of Technology', *Economic Development and Cultural Change*, 27: 303-6.

Chaudhuri, Sudip, *The WTO And India's Pharmaceutical Industry* Oxford University Press, New Delhi, 2005.

Cohen, W.M., R.C.Levin, (1989). "Empirical Studies of innovation and Market Structure", in: R, Schmalensce, and R.D.Willig (Editors), Handbook of Industrial Organization 2(Elsevier Science Publishers B.V., Amsterdam) pp. 1060-1107.

Cohen, W.M. (1995). 'Empirical Studies of Innovative Activity', in Paul Stoneman (ed.), *Handbook of the Economics of Innovation and Technological Change*, Oxford: Blackwell; 182-264.

Dasgupta, P., and J. Stiglitz (1980). "Industrial Structure and the Nature of Innovative Activity." *Economic Journal*, 90: 266-93.

Deolalikar, Anil B. and Robert E. Evenson (1989). 'Technology Production and Technology Purchasein Indian Industry: An Econometric Analysis', *The Review of Economics and Statistics*, 71(4): 687-92.

Dosi, G.(1998) "Sources, procedures and microeconomic effects of innovation", *Journal of Economic Literature*, 36:1126-71.

Dimasi, J A, (2001), Tufts Centre for the Study of Drug Development Annual Forum, Philadelphia.

Fikkert, Brian (1993).'An Open or Closed Technology Policy? The Effects of TechnologyLicensing, Foreign Direct Investment, and Technology Spillovers on R&D in Indian Industrial Sector Firms', unpublished Ph.D. dissertation, New Haven, CT: Yale University.

Galbraith, J.K. (1952). American Capitalism: The Concept of Countervailing Power, Boston: Houghton Mifflin.

Gort, Michael. 1962. *Diversification and Integration in American Industry*.Princeton, N.J.: Princeton University Press.

Hall, Bronwyn. 1988. "The Effect of Takeover Activity on Corporate Research and Development." In Alan Auerbach, ed., *Corporate Takeovers: Causes and Consequences*. Chicago: University of Chicago Press.

Hamberg, D. (1964). "Size of Firm, Oligopoly, and Research: The Evidence". *Canadian Journal of Economics and Political Science*, 30: 62-75.

Horowitz,I. (1962). "Firm size and Research Activity". *Southern Economic Journal*, 28: 298-301.

Kamien, M.L., and N.L. Schwartz (1982) *Market Structure and Innovation*, Cambridge University Press.

Katrak, Homi (1985). 'Imported Technology, Enterprise Size and R&D in a Newly Industrialising Country: The Indian Experience', *Oxford Bulletin of Economics and Statistics*, 47: 213-30.

Kettler Hannah E, White Karren and Jordan, Scott (2003), *Valuing Industry's Contribution to Public-Private Partnerships for Health Product Development*, Geneva: The initiative on Public-Private Partnerships on Health.

Kumar, Nagesh (1987). 'Technology Imports and Local Research and Development in Indian Manufacturing', *The Developing Economies*, 25:220-33.

Kumar, Nagesh and Aradhna Agarwal (2000) 'Liberalization, Outward Orientation and In-house R&D Activity of Multinational and Local Firms: A Quantitative Exploration for Indian Manufacturing', *RIS Discussion paper* #07/2002.

Kumar, Nagesh and Mohammed Saqib (1996). 'Firm Size, Opportunities for Adaptation, and In-house R&D Activity in Developing Countries: The Case of Indian Manufacturing', *Research Policy*, 25(5): 712-22.

Kumar, Nagesh and N. S. Siddharthan (1997). *Technology, Market Structure and Internationalization: Issues and Policies for Developing Countries*, Routledge and UNU Press,London and New York.

Lall, Sanjaya (1983). 'Determinants of R&D in a LDC: The Indian Engineering Industry', *Economics Letters*, 13:379-83.

MacDonald, James M. 1985. "R&D and the Direction of Diversification." *Review of Economics and Statistics* 67 (November): 583-90.

Mansfield. E(1961) "Technical Change and the rate of imitation", *Econometrica* 29: 741-66.

Mukhopadhayay, A.K.(1985). "Technological Progress and Change in Market Concentration in US, 1963-77." *Southern Economic Journal*, July, 141-48.

Nelson, Richard R. 1959. "The Simple Economics of Basic Scientific Research." *Journal of Political Economy* 67 (June), *297-306.*

Panzar, John C., and Robert D. Willig. 1981. "Economies of Scope." *American Economic Review* 71 (May): 268-72.

Romer, P. (1990). "Endogenous Technological Change" *Journal of Political Economy, 98(5):S71-102.*

Scherer, F.M. (1967) "Market Structure and the employment of scientists and engineers", *American Economic Review*, 57:524-31.

Schumpeter, J.A. (1942) Capitalism, socialism, and democracy (3rded). New York: Harper

Siddharthan, N.S. (1988). 'In-house R&D, Imported Technology and Firm Size: Lessons from Indian Experience', *Developing Economies*, 26:212-21.

Smith, Sean Eric. (2000), "Opening Up to the World: India's Pharmaceutical Companies Prepare for (2005)", Stanford: Asia/Pacific Research Centre, Institute for International Studies, Stanford University, www.aparc.stanford.edu/docs/smith.pdf.

Appendix A

Table No. 1: Market Shares of MNC and the Indian Pharmaceutical companies in the Indian Pharmaceutical Industry

Year	MNCs (%)	Indian Companies (%)
1952	38	62
1970	68	32
1978	60	40
1980	50	50
1991	40	60
1998	32	68
2004	23	77

Source: Sudip Chaudhuri (2005)

Table No. 2: New Drugs Developed in India

Drug	Year	Use	Institutions	Marketing Status
Urea Stibamine	1921	Kala-zar	School of Tropical Research, Kolkata	
Methaqualone	1956	Non-barbiturate hypnotic	Regional Research Laboratory (RRL), Hyderabad	
Hamycin	1961	Anti-fungal	Hindusthan Antibiotic Limiited, Pune	
Centimizone	1972	Anti -Thyroid	CDRI, Lucknow	
Sintamil	1978	Anti-depressant	Ciba Geigy,Mumbai	
Tinazolin	1978	Nasal Decongestant	Ciba Geigy,Mumbai	
Isaptent	1985	Cervical dilator	CDRI, Lucknow	
Gugulipid	1986	Hypolipideamic	CDRI, Lucknow	Available
Centbucridine	1987	Local anasthetic	CDRI, Lucknow	
Centibutindole	1987	Neuroleptic	CDRI, Lucknow	
Centchroman	1991	Nonsteroidal Oral Contraceptive	CDRI, Lucknow	
Chandonium Iodide	1994	Neuromascular blocking agent	CDRI, Lucknow	
Arteether	1997	Anti-Malarial	CDRI, Lucknow	Available
Standardized Brahmi Extract	1997	Hermal remedy for memory	CDRI, Lucknow	Available
Bulaquin	2000	Anti-Malarial	CDRI, Lucknow	Available
Consap	2004	Local contraceptive cream	CDRI, Lucknow	Available

Source: Sudip Chaudhuri (2005)

Table No. 3: Results of Probit Estimation

Explanatory Variables	Coefficients	Prob> % Z %	Z-values
Age*	0.0281085	0.000	7.49
mnc*	0.5873391	0.007	2.72
bulk drug*	0.8600878	0.000	4.31
bulk and formulation*	0.9272756	0.000	4.33
Promotional Expenses*	1.085055	0.002	3.15
Internal Resources*	0.553254	0.001	3.36
Export Intensity***	0.3737977	0.063	1.86
Herfindahl Index of Diversification*	0.5218365	0.004	2.85
Year Dummy*	0.9943363	0.000	8.79
Herfindahl Index Concentration*	3.349914	0.586	0.54
Real Firm size*	1.779451	0.000	6.8
Square Real Firm Size *	-0.3697982	0.000	-4.26
Cubic Real Firm Size *	0.0230615	0.002	3.09
Constant	-4.044349	0.000	-11.98

*Significant at 1% level **Significant at 5% level ***Significant at 10% level

Wald chi2(13) = 364.06
Log likelihood = -920.7669
Prob > chi2 = 0.0000

sigma_u 1.695592
rho .7419376

Table No. 4: Results of Tobit Estimation

Explanatory Variables	Coefficients	Prob> % Z %	Z-values
Age**	0.0002947	0.021	2.31
MNC*	0.0281588	0.000	5.47
Bulk*	0.0381027	0.000	6.21
Bulk and Formulation*	0.0370009	0.000	5.69
Promotional Expenses	0.0540198	0.000	4.6
Internal Resources*	0.0277788	0.000	5.38
Export Intensity*	0.0173903	0.006	2.75
Technology Imported	0.0006906	0.152	1.43
Herfindahl Index of Diversification	0.0063428	0.108	1.61
Time Dummy*	0.0161901	0.000	4.72
Herfindahl Index of Concentration	0.2423051	0.172	1.37
Real Firm Size***	0.0069274	0.018	2.36
Square of Real Firm Size***	-0.0009045	0.033	-2.13
Spillover effect*	0.8960997	0.000	10.99
Cubic Real Firm Size***	0.0000247	0.087	1.71
Constant	-0.1125686	0.000	-12.38

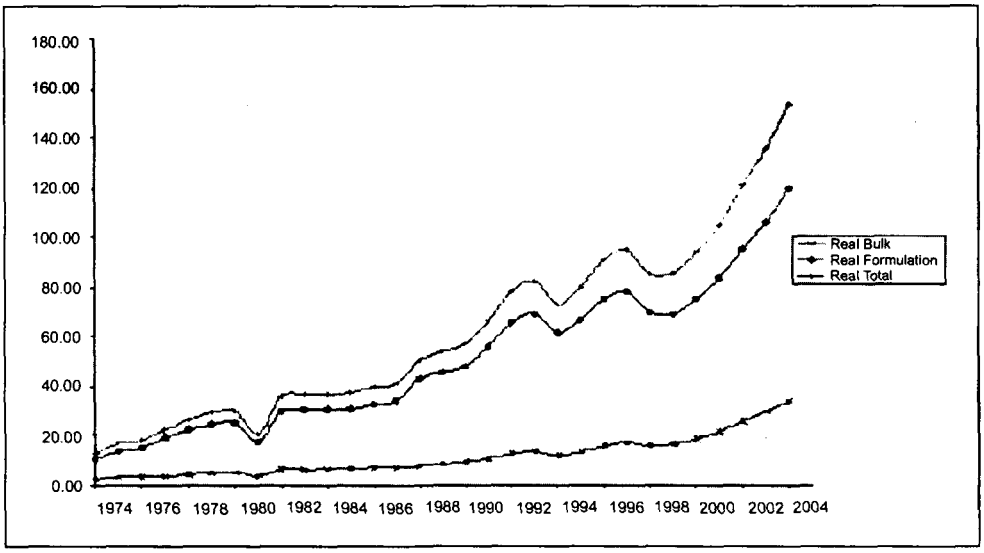
*Significant at 1% level **Significant at 5% level ***Significant at 10% level

Wald chi2(15) = 473.36
Log likelihood = 1313.5762
Prob > chi2 = 0.0000

sigma_u .0498613
rho .5797969
sigma_e .0424478

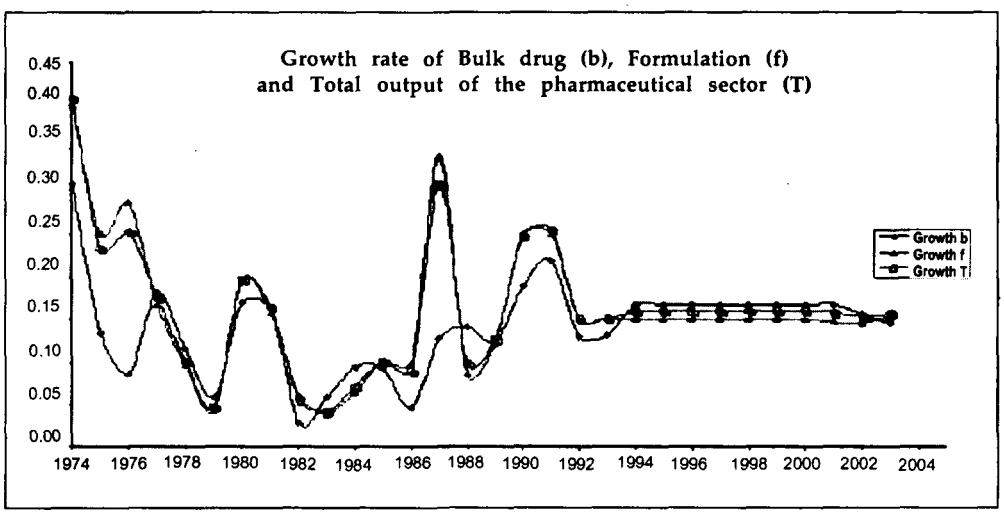
Appendix B

Figure No. 1: Real volume of production in bulk, formulation, and total output of the pharmaceutical sector



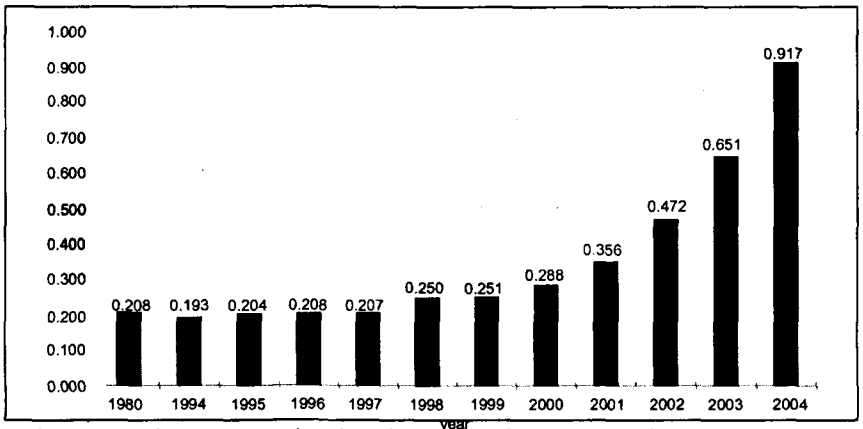
Source: Authors own calculation based on data from ww.india.stat.com.

Figure No 2: Real growth rate in the bulk drug, formulation, and total output of the pharmaceutical sector



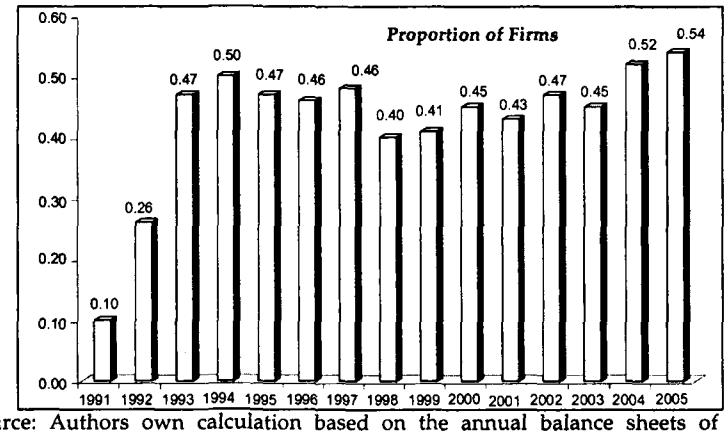
Source: Authors own calculation based on data from www.india.stat.com.

Table No. 3: Real R & D Expenditure (Crores in Dollar) in the Indian Pharmaceutical Sector



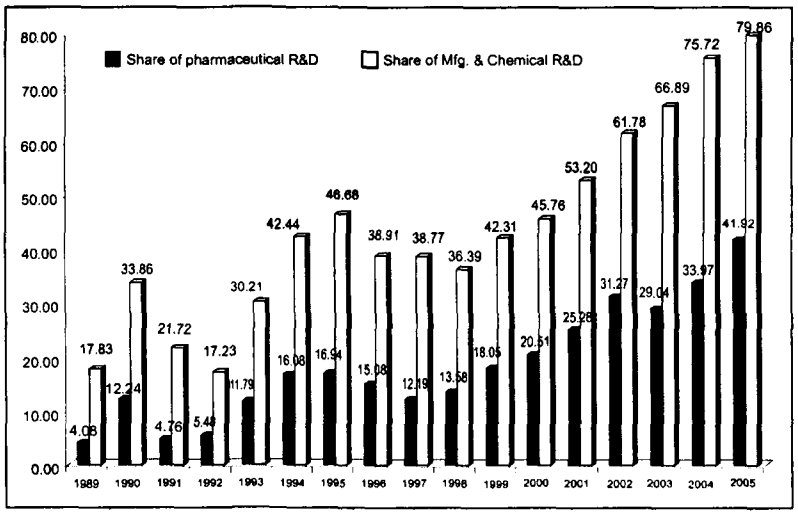
Source: Author computation based on data from www.indiastat.com.

Figure No. 4: Proportion of firms with R&D units (over the years 1991-2005)



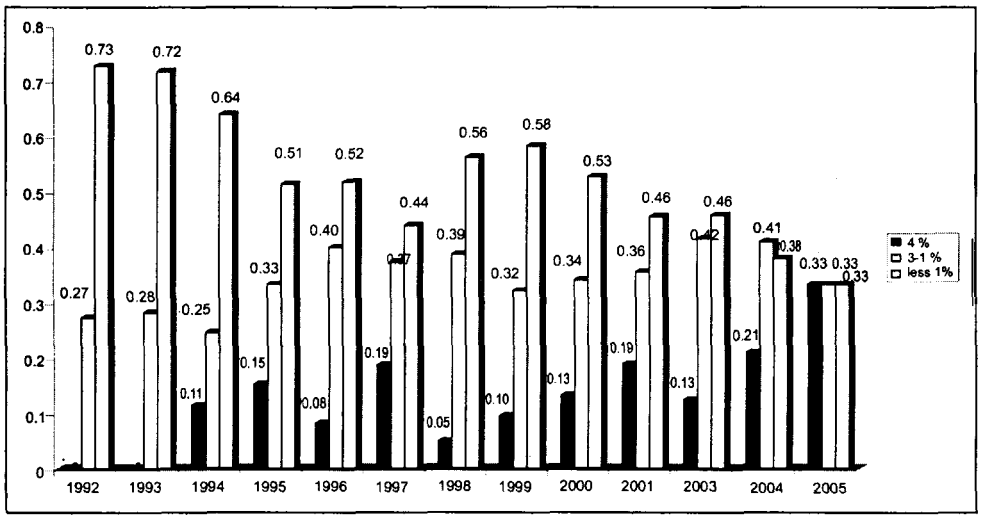
Source: Authors own calculation based on the annual balance sheets of the companies from the prowess database

Figure No. 5: Share of Pharmaceutical R&D in the Manufacturing and Chemical R&D



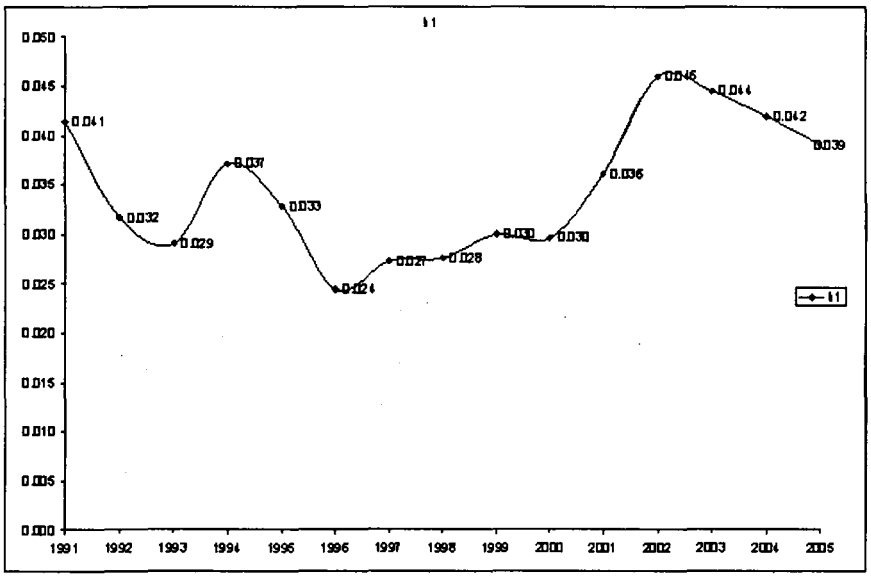
Source: Authors own calculation based on the annual balance sheets of the companies from the prowess database.

Figure No. 6: Proportion of firms according to R&D intensity, 1991-2005



Source: Authors own calculation based on the annual balance sheets of the companies from the prowess database.

Figure No. 7: Value of H-Index calculated over the years



Source: Authors own calculation from the balance sheet of the companies

About the authors:
Mainak Majumder is a research fellow at Institute for Social & Economic change (ISEC), Bangalore.
He can be reached at mainakecon@gmail.com

Meenakshi Rajeev is RBI Chair Professor at Institute for Social & Economic change (ISEC), Bangalore.