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Who is interested in biotech? R&D strategies, knowledge base and market sales of Indian biopharmaceutical firms

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Abstract

This paper addresses three main questions on Indian pharmaceutical firms that have integrated biotechnology in their marketing, production or research activities: (i) What kind of labour stocks of the knowledge base have an impact on market sales? (ii) Which components of the R&D strategy are strategic substitutes and which are strategic complements? (iii) What are the distinguishing features of firms that have already integrated biotechnology in their research activities? The paper shows that market sales are an increasing function of qualified labour stocks. Internal R&D and foreign collaborations are strategic substitutes, while patents and publications are strategic complements. Firms that are active in biotechnology research are likely to be younger and implementing more aggressive learning strategies.

Keywords: India; Biotechnology; Pharmaceutical sector; R&D strategies

1. Introduction

The biopharmaceutical sector refers to pharmaceutical firms that have integrated modern biotechnology in their research, production or marketing activities. Modern biotechnology pertains to a set of techniques that involve manipulation or change of the genetic patrimony of living organisms. Since from 1980s, modern biotechnology has been integrated in a number of industries such as pharmaceuticals, chemicals, agribusiness, agriculture and environment. In the pharmaceutical sector, advances in modern biotechnology have initiated a radical change in the nature of the search processes for the creation of new drugs (i.e. creation by rational design rather than by trial and error methods). They have also led to the creation of radical and incremental product innovations and brought down the costs of production of pharmaceutical products (OTA, 1991). At present, the 10 top selling biopharmaceutical drugs have an annual world wide sales of more than US$ 6 billion and all of them have been created and are being marketed by American or Western European firms (Ernst and Young, 1998). It is clear that biotechnology will have an increasing influence on the evolution of the global pharmaceutical industry and that the bulk of the investment in biotechnology will continue to be in the pharmaceutical sector.

The Indian pharmaceutical industry is the 12th largest in the world accounting for a market of about US$ 2.5 billion. The supply side is highly fragmented with at least 3000 firms in the “organised” sector and at least 13,000 firms in the “unorganised” small-scale sector (CMIE, 1996). However, only about 48 pharmaceutical firms have been listed in government directories as being active in the biopharmaceutical field.

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At present, the firms in the biotechnology bandwagon are of two types. The first type is marketing a foreign product or producing a biotech-based product using a license without undertaking research in biotechnology (though it may be doing research in some other discipline). The second type is integrating biotechnology in its research activities. Given these two types of biopharmaceutical firms, this paper tries to address three central questions: (i) What kind of labour stocks forming the knowledge base have an impact on market sales? In particular, do labour stocks allocated to R&D have a positive influence on market sales? (ii) Which components of the R&D strategy are strategic substitutes and which are strategic complements? (iii) What are the distinguishing features of firms that have already integrated biotechnology in their research activities?

Though, very small, it is important to study the nature and impact of the R&D strategies of this set of firms for three reasons. Firstly, they are the only Indian firms, which, in the future, may be able to offer cheaper local equivalents of the biopharmaceutical products presently being sold in India by Western firms (either directly or through an Indian marketing partner). Secondly, time is running out to catch up with Western firms in this field because once India implements the WTO–GATT agreement (in 2005) Indian firms will be effectively barred from replicating innovations patented in Western countries. Thirdly, the success of these biopharmaceutical firms will determine whether this sector is likely to grow in the future.

By studying the Indian biopharmaceutical sector, the present article attempts to make two types of contributions. The first is to the existing literature on the R&D activities of Indian firms and the second is to the literature on the integration of biotechnology in Indian firms. With respect to the former, the paper re-examines the issues raised in the context of the biopharmaceutical industry. Furthermore, it considers the knowledge base of firms in terms of their labour stocks and expands the definition of an R&D strategy to include a vector of actions and examines their relations with market sales. Finally, it distinguishes between firms that are active in biotechnology research, as different from firms that are only marketing or producing a biotechnology-based product, and identifies their specific characteristics. These contributions taken together attempt to provide some insight on the integration of biotechnology in the Indian pharmaceutical sector in more concrete, quantitative terms than existing studies, which are mainly of a historical or institutional nature (Acharya (1995); Sasson (1993); Ramani and Visalakshi (2001)).The principal results of the paper can be summarised as follows. In the Indian biopharmaceutical sector, R&D expenditure intensity is not linked to firm size, but to research orientation. Market sales are positively correlated to the knowledge base of firms as embodied in their qualified personnel outside of their R&D department. An R&D strategy of these firms is given by a three dimensional vector related to the acquisition of knowledge, disclosure of knowledge and internal creation of knowledge. Either knowledge can be acquired in-house through employing more people in the R&D department and spending more on R&D or it can be acquired from abroad through foreign collaborations. Either new knowledge can be disclosed in the form of patents and publications or it can be kept within the firm by having more qualified people in the R&D department. Thirdly, firms can choose to create knowledge throughout the firm by recruiting qualified personnel or focus on creating knowledge through the R&D department by allocating more qualified personnel exclusively to the R&D department. Finally, firms that are doing research in biotechnology are likely to be young, with a higher R&D expenditure intensity, a higher proportion of qualified employees and a higher proportion of employees in the R&D department.

If India can be taken as a case study of an emerging economy, then it means that in such countries, the participation in the biotechnology revolution (with respect to the pharmaceutical sector) is limited to a very small fraction of local firms. Research is mainly undertaken by younger, small or medium sized firms. Large firms serve to provide market partnerships for foreign multinationals. The major differences with biopharmaceutical firms in developed countries are that patents and publications play an insignificant role as strategic tools for creating value or market signalling and R&D collaborations between local agents (firms or public laboratories) have a very marginal impact on the creation of innovations.

This article is organised as follows. Section 2 presents the background of the context being studied. It contains a brief note on the evolution of the pharmaceutical sector and biotechnology in India. It

then reviews the literature on the R&D activities of Indian manufacturing firms. Section 3 presents the hypotheses, the construction of the database and the variables considered. Section 4 details the methodology, the statistical results obtained and a discussion of the results. Finally Section 4 concludes with policy implications that can be inferred from the analysis.

2. Background of the context studied

2.1. Evolution of the Indian pharmaceutical industry [1]

When India attained its independence in 1947 it had a pharmaceutical industry of a very modest size with a market of about US$ 28.5 million (Ahmad, 1988). There were several Indian-owned firms in the field but their operations were on a much smaller scale than those of the foreign multinationals or MNCs. The production of pharmaceuticals involves two phases: the manufacture of basic ingredients that are called "bulk drugs" and their subsequent "formulation" for final use by consumers, in the form of tablets, capsules, syrups, injectibles, drops and sprays. No Indian company was a major factor in either field at the time of independence and there was heavy dependence on imported foreign drugs which were marketed either by MNCs already established in India or by local agents of other MNCs that did not have a local presence. In order to reduce the dependence on imports and on Western MNCs, at least for vitally needed antibiotics, the government of India undertook large investments to establish a network of public sector enterprises (Singh, 1985). The most important among these were Hindustan Antibiotics Limited (HAL) and Indian Drugs and Pharmaceuticals Limited (IDPL). The move was useful and timely but it was not a comprehensive response to the country's healthcare needs.

The foreign multinationals formulated their drugs in India, importing the bulk drugs from their home countries. It was their contention that the locally available bulk drugs were not of the desired quality. This led to drug prices that were regarded as being too high by the consumers as well as by the government. Thus, in 1965 the government pegged drug prices at levels that prevailed as on 1 April 1963. The "drug price control" order of 1970 brought under price control a number of bulk drugs and selected formulations and also set a ceiling on the overall profits of companies in the pharmaceutical sector. The control regime was continually opposed by both MNCs and fledgling Indian companies. They argued that high import duties were largely responsible for pushing up prices and that price controls discouraged the flow of investment into the industry by depressing the earnings of companies. Discouraged by what they regarded as low margins that could be made under the price control regime, MNCs became disinclined to increase their investment in their Indian subsidiaries or expand their manufacturing activities significantly. They evinced little interest in developing R&D activities based in India.

In order to develop the indigenous pharmaceutical industry at a much faster pace, the Indian government enacted the Indian Patents Law in 1972. The act ensured patent protection only to production processes and not to the products themselves. The provision left the way open for Indian companies to develop and market substitutes for MNC products by simply evolving some process variations. This expedient was not something invented by the government of India. Japan, for instance had such a provision in place for several years in order to promote its own indigenous pharmaceutical industry (Probert, 1994). The communist countries did not respect Western patents either. That the government of India made its move a quarter of a century after the country attained its freedom testifies to its inadequate awareness and appreciation during earlier years of what countries like Japan were doing and of what Indian private enterprise might be capable of achieving in the pharmaceutical industry.

Initially the multinationals did not see the new patent act as a threat to their market position as they assumed that it would be beyond the technological competence of the Indian pharmaceutical companies to do "reverse engineering" and formulate products equivalent to those of the MNCs (Redwood, 1994). The immediate impact was slight. However, the patent act opened up opportunities which in time some alert and aggressive Indian companies equipped themselves to exploit. Those that were unimaginative and timid were left behind. The MNCs had underesti-

[1] This section on the historical evolution of the Indian pharmaceutical sector is largely drawn from Ramani and Venkataramani (2001).

mated the capability of Indian technologists and the entrepreneurial skills of the Indian businessmen, and overestimated the appeal of their brand names for the price conscious consumer. The consumer was quite willing to go for a lower priced Indian product with its own brand name.

In 1976, among the top 20 firms which held 57.19% of the pharmaceutical market, there were only 4 Indian firms. However, by 1995 only 7 MNCs (including their subsidiaries) figured among the top 20 pharmaceutical companies in India and together they could claim only 15.1% of the total market. Indian companies that had won a place in the 1995–1996 list ranked in order of their market share were: Ranbaxy, Lupin, Cipla, Dabur, SOL Pharma, Sarabhai, Torrent, Dr. Reddy's, Allembic, Kopran, Ipca and Cadilla. In addition, there were 38 other Indian owned pharmaceutical companies that were among the top 50 in terms of sales (US$ 22 million or more) during 1995–1996. Only 12 MNCs figured in the list, of whom only 3 made it to the top 10: Glaxo, Hoechst, and Pfizer.

Clearly, in order to compete against entrenched and popular MNC brands, the Indian substitutes had to become of comparable quality and cheaper in price. These requirements made it incumbent on Indian engineers and managers to pay continuing attention to cost reduction and quality control. Many of the companies in the top 100, recognising the opportunities afforded by the Indian Patent Law, made modest investments in R&D activities resulting in an enhancement of their technical capabilities in working out processes for the production of selected drugs identified by them as having good commercial prospects. However, R&D expenditures as a percentage of sales still remained quite low compared to figures in the advanced countries and companies generally tended to raise it to just the point needed for the production of the identified drugs. Most importantly, while successful Indian companies had demonstrated their capabilities in bringing out very satisfactory substitutes for a number of patented Western products and expanded their sales in India and in the overseas markets through lower prices, none of them had come up with a significant innovation in the form of a new drug based on indigenous R&D. The Indian pharmaceutical firms had their knowledge base firmly embedded in organic and synthetic chemistry. They had not made any efforts to integrate other scientific disciplines to create or re-engineer innovations. These firms were then confronted with biotechnology during the 1980s, a set of techniques based on recent developments in the life sciences that was new, different and much more complex to integrate requiring a multi-disciplinary team to create a product.

2.2. A note on biotechnology in India [2]

Biotechnology in India emerged largely due to the key role played by scientists turned administrators in the government ministries. In this note, we briefly outline the strategy and role of the Indian government in the initiation of the biotechnology sectors. The strategy of the Indian government can be grouped into three stages: initiation, building scientific competence, and reaching out to the private sector.

2.2.1. Initiation [1981–1986]

In India the push to develop the biotechnology sectors came from reputed scientists who had been brought into the administration. In 1982, Dr. S. Varadarajan, then secretary of the Department of Science and Technology headed the National Biotechnology Board (NBTB). Its objectives were to: (a) identify priority areas in biotechnology; (b) identify infrastructural needs and (c) implement a co-ordinated programme to realise certain national objectives. To this end, a number of pilot programmes were proposed in the 6th (1981–1985) and 7th (1986–1990) five year plans. However, during its 4 years of existence from 1982 to 1986, the NBTB seems to have achieved only objectives (a) and (b).

In 1986, the NBTB was replaced by a separate government department called the Department of Biotechnology (DBT, 1993). It functioned under the aegis of the Ministry of Science and Technology. The main reason for this evolution seems to have been the realisation that biotechnology is a generic technology whose progress requires the development of a variety of competencies in a variety of scientific disciplines. In order to achieve this co-ordinated development, an agency working together in tandem with the Ministry of Science and Technology was deemed necessary. It set out to implement the objectives of the earlier body such as the development of scientific competence in

[2] The note 2.2 on government strategy for biotechnology in India is based on Ramani and Visalakshi (2001).

selected non-capital intensive disciplines (genetic engineering, vaccines, food production, edible oils). The establishment of DBT served as a signal that the government considered biotechnology to be a priority area for development. It was welcomed by academics, national laboratories as well as industrialists.

2.2.2. Creation of scientific competence [1986–1990]

The first target was to create a core of researchers competent in biotechnology. Grants were given to the network of research institutions and university departments to undertake biotechnology related projects. Grants were also provided to selected teaching and research institutes partially supported by the government, such as the Indian Institute of Sciences, Indian Institutes of Technology, All India Institute of Medical Sciences, National Chemical Laboratory, Tata Institute of Energy Research, Tata Institute of Fundamental Research etc. The DBT also participated in the creation of new institutions such as the National Institute of Immunology, Centre for Cellular and Molecular Biology, National Facility for Animal Tissue and Cell culture, and International Centre for Genetic Engineering (in collaboration with UNIDO).

2.2.3. Reaching out to the private sector [since 1990]

In India, as in most developing countries, the number of financial institutions that invest in a new technology is extremely limited and even then they tend to be risk averse and bureaucratic in their approval process. The government of India tried to remedy this problem through the creation of the Biotechnology Consortium of India Ltd. (Biotech Consortium Ltd., 1994) or BCIL as a public company in 1990. It was set up jointly by the DBT (1993) government sponsored financial institutions like the Industrial Development Bank of India, the Industrial Credit and Investment Corporation of India and "about 30 industries, mainly in the private sector". It was to fulfil the same functions as the venture capital companies in the US, i.e. promote the creation of firms by not only providing venture capital but also complementary competencies required by scientists to set up firms. Thus, it was to guide start-ups, arrange technology transfers and support their efforts to find financing. As of 1997, they had been involved in fund syndication for 3 companies, technology scale up of 1 project, packaging technology for 3 projects, and transfer of technology from laboratories for 6 companies.[3] BCIL's main activity seems to be conducting techno-economic feasibility studies and monitoring activities for its institutional shareholders like the ICICI and government bodies like the Department of Science and Technology. In short, the impact of BCIL, both in the creation of new firms and new products has been rather limited. A few other venture capital fund companies have also set been set up since then by the government.

2.3. Impact of the government strategy on the integration of biotechnology in the pharmaceutical sector

The strategy of the Indian government focused on the two ends of the commercialisation spectrum: public research networks and final markets. It funded public research and regulated the final market. Its weak point was the link. It did not have a strategy for the efficient transformation of research into usable technology. There were no well thought out practical goals or plans made for the effective utilisation of competent manpower. While this indispensable intermediate exercise to transform scientific competence into technological competence was largely skipped, the government concerned itself with the final product markets and fiscal measures such as price control and distribution measures to benefit the masses.

From the period of initiation of biotechnology, the pharmaceutical industry did not figure high in the thinking of the National Board (NBTB), and the non-association of any competent scientist or industrialist from the pharmaceutical sector in its deliberations, had its own consequences. Afterwards, no grants were available from the DBT for the modest R&D establishments that were being set up by some pharmaceutical majors. The thrust of government strategy was on agriculture rather than healthcare, because of the former's intrinsic importance to the economy and the existence of a good record of indigenous research accomplishment. The meagre research output of pharmaceutical enterprises and the minor role of pharmaceuticals related research in the large government supported research establishment had their inevitable impact on the resources made avail-

[3] BCIL — a profile, New Delhi, Biotechnology Consortium of India Ltd., 1996.

able to the pharmaceutical industry. There were also none from the industry itself to make the point that a determined effort should be made for developing new drugs through biotechnological techniques even for the major diseases afflicting the people of the third world.

However, the efforts of the Indian government created substantial awareness of the implications of biotechnology for firms. A number of large firms in the pharmaceutical industry began to invest in biotechnology. A few new dedicated biotechnology firms were created by public laboratory researchers or industrial scientists. At present there are about 100–150 firms active in biotechnology in India (i.e. they have integrated biotechnology techniques in either their research or production or are marketing biotech-based products). About one-third of these firms are active in the pharmaceutical sector. A small proportion of the biotech firms are newly created firms (about 10–15%) and a smaller proportion of them have been created by scientists from public laboratories. With respect to the pharmaceutical industry, the biotech industry has currently well developed strengths in the following areas: vaccine technology, antibiotic fermentation, enzyme fermentation, rDNA technology for R&D, diagnostic probes for tropical diseases, screening of plant and microbial extracts for molecules and clinical testing.

2.4. Review of the literature on R&D in the Indian manufacturing sectors

The literature on the R&D activities of Indian firms has mainly focused on three issues: (i) the impact of R&D expenditure on factor productivity; (ii) the relationship between R&D expenditure intensity and firm size; and (iii) the relationship between R&D expenditure intensity and foreign collaborations, where R&D expenditure intensity is the ratio of R&D expenditure to market sales.

2.4.1. R&D expenditure intensity and factor productivity

Several empirical studies have examined the impact of R&D strategies on the knowledge base of Indian firms through econometric estimations of the production function (Basant and Fikkert (1996); Raut (1995); Ferrantino (1992)). Basant and Fikkert (1996) find that factor productivity has increased in the scientific industries (chemicals, drugs and electrical appliances) by about 2%, and decreased in the non-scientific industries due to R&D expenditure. On the other hand, Raut (1995) concludes that while in-house R&D of firms have not had any significant effect on firm productivity, firms have gained from the industry wide R&D spillovers resulting from the R&D efforts of other firms in the industry. Finally, Ferrantino (1992) asserts that factor productivity of Indian firms has stagnated while there has been a substantial increase in the qualification of personnel.

We do not examine the impact of R&D strategies on a representative production function because clearly the firms in our sample set have become more productive in the sense that they have diversified into a new field. Furthermore, this issue cannot be studied unless the functional form of the production function is assumed to remain constant which is very unlikely to be the case for an emerging sector.

2.4.2. R&D expenditure intensity and size of the firm

A number of authors have studied the relationship between firm size and R&D expenditure intensity in the Indian manufacturing sectors. Desai (1980) and Kumar and Saqib (1996) find that R&D intensity is an increasing function of firm size because a firm needs to be of a minimum size in order to be able to invest in R&D. Having established an R&D unit, it then enjoys increasing returns to scale. However, Katrak (1989, 1994), Siddharthan and Agarwal (1992) show that R&D intensity is a decreasing function of firm size. Their argument is that returns to R&D do not proportionately increase with increase in size and therefore large firms tend to have lower research intensity. Furthermore, large firms have established market niches and the required technological competence to ensure products of quality and hence do not perceive any need to engage in R&D. Still others like Siddharthan (1988) and Nath (1993) propose a U-shaped relation between R&D intensity and size. Nath (1993) argues that large firms engage in R&D to conceive major innovations to create a competitive advantage in the long run, while small firms spend on R&D to create minor innovations to maintain their competitive advantage in the short run but this relation is influenced by the structure of the industry being considered.

2.4.3. R&D expenditure intensity and foreign collaborations

In the literature, the relation between internal R&D and foreign collaborations remains an ongoing debate. Some economists assert that internal R&D is a substitute for import of technology. Desai (1980, 1988) argues that Indian R&D given its limited sources can only focus on short term projects and therefore it is more economical to buy rather than make technology that requires medium to long term investment in knowledge generation. Basant and Fikkert (1996) find that the stock of technology imports is always significantly negatively related to in-house R&D. They argue that since returns to technology imports are greater than to internal R&D and since both are substitutes in knowledge production, firms buy from abroad when they can. Spillovers from abroad on the other hand are significantly positively related to in-house R&D indicating that such spillovers are complements to in-house R&D.

Others however assert that technology imports are a complement to internal R&D (Katrak, 1985, 1989, 1994; Deolalikar and Evenson, 1989). Here the basic assumption fuelling the analysis is that Indian R&D is mainly adaptive rather than innovative. Therefore, in order to be efficient in identifying and adapting useful information, processes, or products obtained from Western firms it is necessary to maintain a sufficient level of knowledge through engaging in internal R&D. Siddharthan (1988) further notes that this complementarily is a decreasing function of the technological sophistication of the sector concerned. However, Siddharthan and Agarwal (1992) find that when other firm characteristics like past successes or expenditure on skilled personnel are taken into account, R&D intensity ceases to have any relationship with technology imports. Kumar and Saqib (1996) call for a fresh look at this debate, as they find no significant relation between technology imports and R&D intensities.

Thus, there is no consensus on any of the three issues raised in the literature on the R&D activities of Indian firms. Such diverse results on the impact of R&D strategies could stem from the fact that they analyse different databases and they consider different indicators of R&D strategies. In what follows, we will examine the second and third issues, i.e. the relationship between R&D expenditure intensity and firm size and the relationship between R&D expenditure intensity and foreign collaborations with respect to the Indian biopharmaceutical sector.

3. Formulation of hypotheses, database and variables

In this section, we define the notion of "knowledge base" and "R&D strategy" as used in this paper. Then we present the construction of the database, the variables considered and the sample set of firms.

3.1. Knowledge base embodied in labour stocks and R&D strategy vectors

According to traditional economic theory, the technical knowledge of a firm about the production process is given by its production function, that indicates the maximum output that can be produced from a given combination of tangible inputs, say capital and labour. When a multi-product firm is considered, the production function is replaced by a production possibilities set, which gives the set or combinations of maximum outputs that can be produced from a set of inputs. In both cases, this production technology of the firm is considered to be fixed and constant over time. However, it is now commonly acknowledged that the productivity of factor inputs can change as the firm learns more about the production process or acquires "knowledge stocks". (Grilliches, 1979, 1995).

Thus, a firm starts with four elements: (i) a production possibilities set giving the technology blueprint available to the firm; (ii) an initial knowledge base embodied in its labour stocks; (iii) non-labour stocks and (iv) a mode of governance including an R&D strategy. As a function of these four elements, a firm produces in each time period, new knowledge stocks and final commodity bundles. The final commodity bundles generate market sales which are used to maintain the resources of the firm. The new knowledge stocks change the production possibility set of the firm and may lead to quality improvement, cost reduction or increase in the variety of products produced. Furthermore, if we assume strong market competition and price taking firms, then market performance can be given by market sales.

Why do we evoke this simple scheme, when there exists so many sophisticated theories of the firm? This is for two reasons. The first is to focus on the need to examine the relation between the composition of labour stocks and market sales. In high tech sectors, where human ingenuity is the key to the creation of innovations and increase in market shares, it seems likely that the composition of the knowledge base of the firm as embodied in its labour stocks is crucial to its market performance. Labour stocks can consist of qualified or non-qualified labour and it can be allocated to R&D or non-R&D tasks. This gives rise to four types of stocks (qualified R&D, non-qualified R&D, qualified non-R&D, non-qualified non-R&D) whose values and proportions are likely to impact the market performance. In any sector, where knowledge generation is important for market performance, the latter is likely to depend on the stocks of labour in the R&D department or at least the total stock of qualified labour in the firm.

The second notion that is sought to be promoted is that an R&D strategy is actually a vector of possible actions rather than being identified with simply R&D expenditure. Let us define an R&D strategy as the vector of decisions related to the acquisition and disclosure of knowledge.

With respect to the acquisition of knowledge, two kinds of decisions can be considered, labour allocations and technology transactions. Labour allocations refer to the quantity, quality and distribution of labour within the firm and have an impact on the "learning by doing" of employees. Knowledge can also be acquired from outside of the firm through technology transactions. Technology transactions refer to technology purchases (i.e. R&D expenditure on capital stocks) and technology alliances. The latter can be either with public laboratories or with other firms.

Once new knowledge is created, a firm has to decide how much of the knowledge should reside within a firm and how much should be disclosed. Disclosure can take two forms: with protection in the form of patents or without protection in the form of publications.

What is likely to be the relation between the different components of the R&D strategy? A priori all the components of the R&D strategy would seem to be strategic complements. In reality, it would depend on the context studied and the constraints of the firms considered.

In the pharmaceutical sector of developed countries, Cockburn et al. (1999) assert that "science-driven", or "rational" drug discovery is both a technology for discovering new drugs and a set of managerial practises for organising and motivating research workers. They point out that firms invest in leading edge research because it increases the efficiency of the knowledge production process (Henderson and Cockburn, 1994; Gambardella, 1995). They confirm that in the pharmaceutical sector some firms have become active participants in the creation of scientific knowledge instead of being only passive users. These firms publish and patent actively and have extensive research networks with research laboratories. Investment in patenting in the biopharmaceutical sectors has also been noted to be a means by which firms can mark their territory in limited technological space to gain future rent. If the situation is similar in developing countries we should find the same pattern. In other words, we should find that all parameters of the R&D strategy take on higher values for firms which undertake biotech research as compared to firms which are simply marketing or producing a biotech-based product without doing research.

The central questions of the paper as may be recalled are: (i) What kind of labour stocks forming the knowledge base have an impact on market sales? (ii) Which components of the R&D strategy are strategic substitutes and which are strategic complements? (iii) What are the distinguishing features of firms that have already integrated biotechnology in their research activities? From the arguments developed in this section, we can propose the following three hypotheses as initial responses to the above questions to be tested with data.

H1: market sales are an increasing function of the stocks of qualified labour or an increasing function of labour stocks allocated to R&D activities.

H2: all parameters of an R&D strategy are strategic complements.

H3: all parameters of an R&D strategy will take on higher values for firms which are active in biotechnology research (as opposed to firms which are only marketing or producing a biotech product but not doing biotech research).

Table 1
Variables considered

Variables considered
Market performance
Market sales
Firm characteristics
Age
Technological orientation = (0 if not doing biopharmaceutical R&D, 1 if doing biopharmaceutical R&D)
Knowledge base
Size/total number of personnel
Qualified personnel
R&D personnel
Qualified personnel in R&D
R&D strategies
R&D expenditure
R&D expenditure intensity = R&D expenditure/total sales
R&D employment intensity = employees involved in R&D/total number of employees
Qualification intensity = number of employees with a masters or Ph.D. degree/total number of employees
R&D qualification intensity = number of employees with a masters or Ph.D. degree in R&D/total number of employees in R&D
Academic collaborations = (number of technology agreements since 1970)
Foreign collaborations = (number of technology agreements since 1970)
Publications = (between 1970 and 1994)
Patents = (granted between 1970 and 1994)

3.2. Construction of the database

We first compiled a list of firms active in the biopharmaceutical sector from three documentary sources published by the Ministry of Science and Technology of the government of India: (i) reports of the Department of biotechnology; (ii) the "Directory of biotechnology industries and institutions in India" and (iii) the directory on the "Research profile of biotechnology activities in India". They yielded 48 pharmaceutical firms as being active in the biotechnology sectors. From the various reports of the department of biotechnology we were able to compile information on the different variables for 24 of the 48 firms. We were able to interview the CEOs of 8 more firms and obtain information directly on these also. The information on labour allocations, patents, publications and R&D expenditures are not normally published in company reports. Both the reports of the department of biotechnology and our information were based on answers to questionnaires. Thus, all information were voluntary disclosures by the firms themselves including data on whether they were undertaking biotech research or simply marketing or producing a biotech product without doing in-house biotech research. Information on patents were also obtained from the responses to questionnaires and referred to patents actually obtained by the firm between 1970 and 1994.[4] Pooling these two sources of data we obtained information on 32 of the 48 firms. The information collected pertained to the year 1994–1995.

3.3. Variables considered

Four types of variables were considered market sales, firm characteristics, initial knowledge base as embodied in labour stocks and R&D strategies. They are given in Table 1. Two kinds of firm characteristics were noted: age and technological orientation. The latter was a dummy variable that associated value 1 with a firm conducting biopharmaceutical research and value 0 with a firm that was not conducting biopharmaceutical research at the time of the data

[4] This period was considered by the department of biotechnology in their reports and we had to use the same to be consistent.

collection. This distinction was made to differentiate the firms active in biopharmaceuticals through marketing a product for a multinational or producing a biotech-based product on the basis of a license without undertaking their own biotech research.

The knowledge base of the firm embodied in its labour stocks was classified as follows. Labour within in a firm can be either qualified (with a Masters degree or more) or non-qualified. These two kinds of labour can be allocated to R&D or non-R&D tasks. This gives the four kinds of labour stocks: total personnel, total qualified personnel, total personnel in R&D and total qualified personnel in R&D.

R&D strategies were considered in terms of labour allocations, technology transactions and disclosed knowledge. This gave us 9 indicators of the R&D strategy of a firm as shown in Table 1. R&D expenditures were taken into account both as a stock and as an intensity variable because larger firms usually spend more in absolute amounts on R&D, but this does not mean that such large firms are pursuing a more aggressive R&D strategy. They might in fact be re-investing a lower proportion of their sales revenue in R&D activity or having a lower rate of new knowledge creation. Two kinds of technology alliances were noted: alliances with public laboratories or with foreign firms. These were technology agreements with or without equity participation of the foreign partner. There were no alliances between Indian firms themselves in our data set.

3.4. Firms in the sample set

Among the 32 firms in our sample set, there were 3 Indian subsidiaries of MNCs, 2 government or public sector firms and 27 private sector firms. Out of the 32 firms, 26 were established firms that had diversified into biotechnology and 6 were new founded dedicated biotechnology firms. All the firms in our data set were either marketing, producing or doing research on a biotech-based product. About 19 firms, were only marketing or producing a biotech-based product without doing biotech research. In terms of size, 11 firms were very large firms with more than 1000 employees, 15 were medium sized firms with between 100 and 1000 employees and all the remaining 6 firms were new dedicated biotechnology firms with less than 100 employees.

4. Methodology and results

4.1. Methodology

To identify the relation between market sales, knowledge base in the form of labour stocks and R&D strategies, a correlation matrix was computed. Next a model of market sales as a linear function of the labour stocks forming the knowledge base was estimated using the method of "step wise linear regressions". There was also an attempt to model R&D intensity as a function of market sales, firm characteristics and other R&D strategies but this did not yield results that were more definite than the correlation analysis. Next, to understand the relation between the different R&D strategies, a principal component analysis (PCA) was conducted on the R&D strategies.[5] Finally, the distinctive features of firms active in biopharmaceutical research were identified through an ANOVA analysis.

4.2. Relation between market sales, knowledge base and R&D strategies

The correlation matrix between all the quantitative variables (i.e. all except biotech research) is given in Table 2. Evidently it could throw light only on the first two hypotheses because the firms doing biotech research were not distinguished from others.

- The first hypothesis H1 is strongly supported as the market sales are significantly correlated to knowledge stocks in the form of total personnel, total qualified personnel and total R&D personnel.
- The second hypothesis H2 is weakly supported. All the different components of an R&D strategy are not strategic complements. R&D expenditure intensity is significantly positively correlated with R&D employment intensity. Not surprisingly, firms with a higher proportion of R&D personnel spend a higher proportion of their sales revenue on R&D activities. Such firms are likely to be small and young firms. Foreign collaborations are significantly negatively correlated with qualification intensity, but they are positively correlated with the stock of qualified personnel in R&D. Patents and publications are strate-

[5] R&D expenditure in absolute terms was dropped out of the PCA and ANOVA analysis as we wanted to examine the relations between all the intensity measures.

Table 2
Descriptive statistics on sample firms[a]

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Mean	S.D.
Market sales	1.0															40.11	54.47
Firm characteristics																	
Age	0.23	1.0														27.16	18.80
Knowledge base																	
Total personnel/size	0.69**	0.34	1.0													1459.75	1876.49
Qualified personnel	0.8**	0.35	0.86**	1.0												817.62	1184.01
R&D personnel	0.50**	0.15	0.65**	0.42*	1.0											64.31	58.74
Qualified personnel in R&D	0.8	0.21	0.6**	0.25	0.63**	1.0										32.32	34.27
R&D strategies																	
R&D expenditure	0.78**	−0.03	0.43	0.61*	0.40	−0.06	1.0									1.23	2.39
R&D expenditure intensity	−0.12	−0.36*	−0.21	−0.17	−0.22	−0.13	0.05	1.0								0.04	0.07
R&D employment intensity	−0.2	−0.37*	−0.42*	−0.42*	−0.06	−0.22	−0.07	0.64**	1.0							0.12	0.14
Qualification intensity	0.13	−0.02	−0.02	0.25	−0.30	−0.39*	0.28	0.03	−0.16	1.0						0.57	0.20
R&D qualification intensity	−0.31	−0.15	−0.01	−0.09	−0.36*	0.36*	−0.33	0.04	−0.24	0.06	1.0					0.58	0.33
Academic collaborations	−0.21	−0.37*	−0.16	−0.22	0.01	−0.17	−0.14	0.09	0.21	0.30	−0.18	1.0				1.69	1.38
Foreign collaborations	−0.02	0.03	0.15	0.03	0.31	0.38*	−0.08	−0.34	−0.20	−0.54**	0.08	−0.22	1.0			2.69	3.34
Publications	0.2	0.06	0.30	0.02	0.41*	0.30	0.07	−0.14	−0.06	−0.12	−0.15	−0.05	0.1	1.0		5.20	12.17
Patents	0.4*	0.14	0.22	0.24	0.24	−0.05	0.17	−0.07	−0.16	0.10	−0.23	0.02	−0.08	0.51**	1.0	3.47	10.31

[a] Units: US$ million.

* Pearson's correlation coefficient is significant at 1%.

** Pearson's correlation coefficient is significant at 5%.

Table 3
Model of market sales

Explanatory variable	Coefficient (β)	t-Value
Qualified personnel in non-R&D	0.102	−3.19*
Non-qualified personnel in R&D	1.15	6.38*
Constant	−4.487	3.64
$R^2 = 0.78$	$F = 38.7$*	

* $p \leq 0.005$.

gic complements but they are not significantly correlated to any other R&D strategies. It is noteworthy that publications are positively correlated to R&D personnel while patents are positively correlated to market sales. This reveals that patents are of some importance to market performance.

Two other points of interest concern academic collaborations. Younger firms seem to be entering into more collaborations with public laboratories than older ones. The mean of number of academic collaborations is less that of foreign collaborations, implying the Indian firms tend to initiate more collaborations with foreign firms than with research centres in their own country.

With respect to the issues raised in the literature on Indian R&D, it can be inferred that R&D expenditure intensity is likely to depend on the characteristics of the firm such as age rather than size. In fact, R&D expenditure intensity is negatively correlated to firm size and market sales though this is not statistically significant. It is more difficult to draw conclusions on the relationship between foreign collaborations and internal R&D. While foreign collaborations are significantly negatively correlated with qualification intensity, they are positively correlated to the absolute stock of qualified personnel in the R&D department.

To further identify the labour stock that impact market sales, a stepwise regression was run and the result is given in Table 3. It indicates that market sales increases with an increase in the qualified labour outside of the R&D department or the non-qualified labour in the R&D department.

We also tried to estimate a model for R&D intensity by means of a stepwise regression but the only significant coefficient in the model was that of R&D expenditure intensity and age as already revealed by the correlation matrix. Younger firms or firms with a higher ratio of personnel allocated to R&D activities exhibit a higher R&D expenditure intensity.

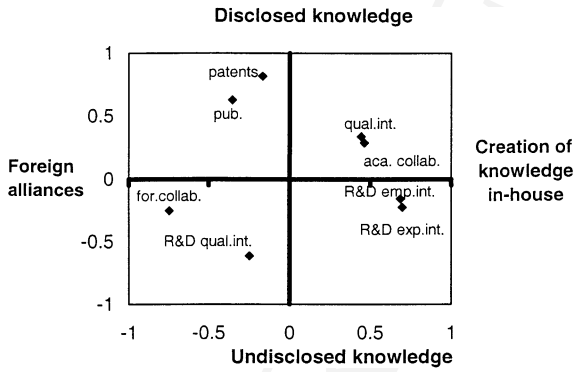

Fig. 1. Relations between R&D strategies; for. collab: foreign collaborations; pub.: publications; qual. int.: qualifications intensity; aca. collab: academic collaborations; R&D emp. int.: R&D employment intensity; R&D exp. int.: R&D expenditure intensity; R&D qual. int.: R&D qualifications intensity.

4.3. Relations between the different R&D strategies

In order to understand the relations of substitutability or complementarily between the different R&D strategies, a principal component analysis was conducted. The analysis yielded three factors that accounted for about 60% of the total information (or variance) contained in the sample. Fig. 1 shows the variables mapped along the first and second factors and Fig. 2 shows the variables mapped along the first

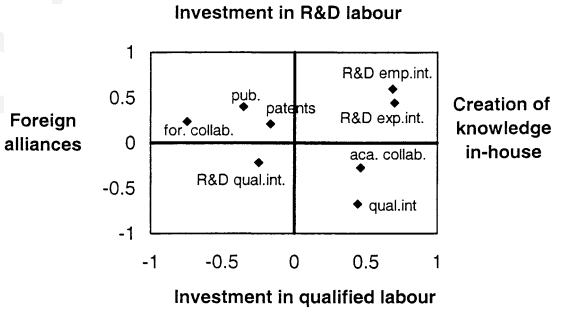

Fig. 2. Relations between R&D strategies: for. collab: foreign collaborations; pub.: publications; qual. int.: qualifications intensity; aca. collab: academic collaborations; R&D emp. int.: R&D employment intensity; R&D exp. int.: R&D expenditure intensity; R&D qual. int.: R&D qualifications intensity.

Table 4
Distinctive features of firms active in biotechnology research

Variable	Mean of variable for firms not active in biotech research	Mean of variable for firms active in biotech research
Market sales	165.84	102.52
Firm characteristics		
Age**	42.56	21.13
Knowledge base		
Size/total personnel	2121.00	1201.00
Qualified personnel	861.86	803.54
R&D personnel	86.33	55.69
Qualified personnel in R&D	60.50	22.52
R&D strategies		
R&D expenditure intensity**	1.38	5.29
R&D employment intensity**	0.056	0.14
Qualification intensity**	0.45	0.61
R&D qualification intensity	0.64	0.56
Academic collaborations	1.11	1.91
Foreign collaborations	4.67	1.91
Publications	7.0	4.54
Patents	4.50	3.09

** *t*-Test for distinct means significant at 5% or less.

and third factors. The three factors seem to embody the following three axes of R&D strategy:

- acquisition of knowledge (as defined by R&D employment intensity, R&D expenditure intensity, foreign collaborations);
- disclosure of knowledge (as defined by patents, publications and R&D qualification intensity);
- creation of knowledge within the firm (as defined by R&D employment intensity and qualification intensity).

Fig. 1 shows that in the acquisition of knowledge there are two possible substitutable strategies. Either knowledge can be created by the Indian firms through internal R&D or be acquired from abroad. Internal R&D is given by R&D expenditure intensity and R&D employment intensity. Foreign acquisitions are given by foreign collaborations. It is interesting that while collaborations with public laboratories are complements to internal R&D (both variables being on the same side of the horizontal axis), foreign collaborations are substitutes to internal R&D (both variables being on opposite sides of the horizontal axis). Thus, foreign collaborations and internal R&D seem to be substitutes and not complements.

Let us now come to the disclosure of knowledge. Fig. 1 shows patents and publications to be on the opposite side of R&D qualification intensity in terms of the horizontal axis. This indicates that either the firms can disclose knowledge in the form of patents or publications (which are complements) or let the knowledge reside within the firm by increasing the proportion of qualified people in the R&D department.

Finally, with respect to the creation of knowledge, in Fig. 2, the two furthermost variables on the vertical axis defining the third factor, are qualification intensity and R&D employment intensity. These are also aligned on opposite sides of the horizontal axis. This indicates that the firm can either choose to create knowledge throughout the firm by recruiting more qualified people and distributing them throughout the firm or it can focus on creating knowledge through the R&D department through allocating more personnel to this department.

4.3.1. Distinguishing features of biotech firms

The distinguishing features of biotech firms were identified through an ANOVA analysis, the results of which are given in Table 4. The distinguishing features

that are statistically significant are age and learning strategies. Firms active in biotechnology research are younger, allocate a higher proportion of personnel to R&D, reinvest more of their sales revenue on R&D and have a higher proportion of qualified personnel on their payrolls. It may be recalled that according to hypothesis H3, all parameters of R&D strategy are expected to take on higher values for firms undertaking research in biotechnology. This is clearly not the case for R&D qualification intensity, foreign collaborations, publications and patents.

4.4. Discussion of results

Two issues that have been examined in the literature of Indian R&D and that are of relevance to the subject at hand are the relationship between firm size and R&D expenditure intensity and the relationship between foreign collaborations and R&D expenditure intensity. Our results support the view that R&D expenditure intensity decreases with size of the firm and is a strategic substitute for foreign collaborations.

As in the developed countries, the Indian pharmaceutical sector comprises three kinds of companies: large incumbent firms, small and medium sized incumbent firms and new dedicated biotechnology firms (usually very small). The firms that are active in biopharmaceuticals are mainly medium sized and big companies and new dedicated biotechnology firms. The medium sized and big firms have the resources to diversify into a new field. The new firms are created through commercialisation of a specific biotech-based knowledge. However, many of these firms are simply marketing the product of a Western multinational or producing a biotech-based product using a license. Only some of them are trying to build their own knowledge base through investment in biotechnology research. We would expect such firms, which are investing in diversifying their knowledge to have a higher R&D intensity than others. Thus, R&D intensity would not be dependent on the size of the firm but rather on the research orientation of the firm.

Foreign collaborations and R&D expenditure intensity could be strategic substitutes because of two possible reasons. Firstly, Indian firms have a knowledge retard with respect to biotechnology. Therefore, they may not yet have the absorptive capacity to use foreign technology as a complement to their own knowledge base. Secondly, it could be due to the difficulties and uncertainties of international technology transfer. Often, a pertinent knowledge transfer does not occur. Thus, foreign collaborations are sought only for technology that cannot be developed economically in-house.

We now discuss the results that were unexpected or counter intuitive. The first was with respect to the determinants of market sales. It was hardly strange that market sales increased with the qualified labour outside of the R&D department. However, it was surprising that market sales increased with the non-qualified personnel in the R&D department. The latter relation is very counter intuitive and could be due to two possible reasons. Either the qualified personnel in the R&D departments are mis-managed and contribute little to market performance or this is due to the nature of our sample. In our sample, firms with a high R&D qualification intensity are younger, smaller firms, which have lower market sales and this could be leading to a positive relation between market sales and the non-qualified personnel in the R&D departments.

It has been mentioned that patents and publications are strategic tools for a firm to improve its market position in the biopharmaceutical sectors of developed countries. In contrast, in the Indian case, while patents and publications are clearly strategic complements, they were not correlated to any indicators of R&D strategy. Moreover, they are aligned in opposition to R&D qualification intensity, implying that firms with a high proportion of qualified people in the R&D department do not seek to patent or publish. This is quite counter intuitive.

This result may be due to the state of the patenting bureaucracy in developing countries including in India. In the Indian pharmaceutical sector, Redwood (1994) and Lanjouw (1998) assert that it is not common to publish or patent because most of the research is on the engineering side and therefore the knowledge created is tacit residing in an individual or sets of individuals. It is difficult to translate such knowledge into writing and therefore there is no incentive to apply for patents. They also note that India at present does not have the infrastructure to ensure an efficient patenting process. The patent offices are very poorly staffed, they have very limited resources, there are not many patent lawyers and there are not many people who know both the science and the law. This makes patent

application a time consuming and costly affair within India and too costly an investment outside of India. Finally, patent protection is not effective because patent litigation usually costs more than out of court settlements. This is surely going to change but it will take time. Thus, patents and publications may be more the result of a firm specific managerial orientation rather than being correlated to other R&D strategies.

Another counter-intuitive result is that firms that are active in biotech research are less interested in publications and patents and they are less connected to international networks. A number of explanations are possible. Such firms could be working on projects close to being commercialised and therefore have no interest in publishing their work. The lack of concern for patenting may be because they do not perceive its benefits to be sufficiently high, or because patenting is not a routine that firms are forced to think about, since the patenting bureaucracy is not yet well developed in India. Finally, it could be due to the nature of the sample set. Firms that are active in research are younger and they may not have accumulated a large number of patents or publications yet.

The fact that firms undertaking biotech research are less inserted in international networks could be due to the strategic foundations of international collaboration. Many of the firms undertaking biotech research are small dedicated biotechnology companies with a strong knowledge base in biotechnology. They often focus on creating drugs and diagnostics for diseases prevalent in India such as leprosy, malaria, filariasis, etc. that are not of interest to the Western multinationals. Western firms also prefer to collaborate with large rather than small Indian firms since they perceive the large firms to pose less of a market risk.

5. Conclusions

Strategic positioning of firms for the integration of new technology in emerging economies is not frequently studied because the set of firms engaged in such activity is small and data is often not available. Most of the existing works have looked at the Indian manufacturing sector at large using data pertaining to the pre-liberalisation era. In contrast, this paper has focused on one sector, namely the biopharmaceutical sector, and its objective was to examine the impact of knowledge stocks and the nature of R&D strategies of firms in this sector.

Our analysis showed that market performance is positively correlated with the knowledge base of the firm as embodied in its qualified labour outside of the R&D department. The three factors defining the R&D strategies were acquisition of knowledge, disclosure of knowledge and internal creation of knowledge. New technology could be acquired from abroad or created within Indian firms through increasing the R&D personnel. Knowledge could be disclosed in the form of patents or publications or remain as tacit knowledge within the firm. Knowledge could be created in the firm by increasing the R&D department personnel or in a diffused manner throughout the firm by increasing the qualified personnel.

Finally, the analysis revealed that firms that are likely to make inroads into the biopharmaceuticals sector have to be identified by their technology strategy and not their resources. It showed that firms that are producing biotechnology products are likely to have a strong research base. They may not be into publishing or patenting but they allocate a high proportion of their labour to R&D activities and employ a substantial number of qualified personnel for conducting R&D.

5.1. Recommendations for foreign firms, small Indian firms, and large Indian firms

The study indicates that Indian firms seeking foreign technological collaborations in the biopharmaceuticals sector are likely to be not doing research in biotechnology and are likely to have a lower proportion of qualified personnel. These firms buy technology because it is more economical to buy than to create internally. In the same market, there are new and small firms, which are research-intensive and which allocate a substantial proportion of their employees to R&D activity. Therefore, a potential exists for forming "research contracts" or technological collaborations between these small R&D intensive Indian firms and Western firms, as has happened between Indian and Western firms in the field of micro-electronics. These have to be initiated by Western firms since the small Indian firms are usually not searching to collaborate with foreign firms. At the same time, if small firms seek foreign collaborations, then they have to become

more visible on the international scene through publications and patents.

The negative correlation between R&D strategy indicators and market sales indicates that employing educated engineers and technicians who have acquired sufficient knowledge in the universities largely satisfies the needs of large firms. Large firms also tend to have fewer academic collaborations. However, since knowledge stocks clearly have a positive impact on the market performance of large firms, they might well reconsider whether increasing these parameters would be better for maintaining their competitive advantage in the long run.

An often highlighted feature of biopharmaceutical firms in the developed countries is their complex web of strategic alliances with other firms and public research laboratories (Orsenigo, 1989; Pisano, 1991). It is usually proposed that knowledge creation through internal R&D and external strategic alliances are strategic complements. In the case of large firms, it has been shown that larger the investment in internal R&D or internal learning, larger the number of external strategic alliances (Arora and Gambardella, 1990). Such a phenomenon is completely absent in the Indian pharmaceutical sector.

Most of the interfirm collaborations in biotechnology in developed countries occur at a pre-competitive stage, i.e. they are on projects that are not close to being commercialised. They are also initiated when the R&D costs or the R&D risks are too high to be supported by a single firm. Thus, one plausible reason for the non-initiation of interfirm collaborations between Indian firms could be due to the fact that there has been intense competition only to develop and commercialise already patented drugs. In such cases, the R&D costs are not high, the R&D risks are not high and the product can be immediately commercialised, which leaves little incentive for interfirm co-operation. In the technology races, which occur periodically in the Indian bulk drugs market, "a winner takes most" game is set into motion leaving little scope for inter-firm co-operation. However, as production in the pharmaceutical sector becomes more and more knowledge intensive, in order to compete in the international arena, firms can do better by initiating co-operative alliances with research laboratories and other firms on projects at a pre-competitive stage.

5.2. Policy recommendations

In terms of policy formulation, the two most striking features in need of reform are the lack of interfirm co-operation between Indian firms and the low impact of public research laboratories on the market sales or research strategies of Indian firms. Given the paucity of resources to which all emerging economies are subject to, and in order not to aggravate the north–south gap, it is necessary to maximise the economic returns from existing investment in public research. Thus, conventions have to promoted for the transfer of knowledge from public laboratories to private firms and then for its transformation into commercialisable technology. Ramani and Visalakshi (1999) have argued that with respect to biotechnology, the Indian policy so far has tried to emulate the American model to some degree, whereby public research is funded and promoted and the market is expected to generate new firms and new innovations. In the American context, there is conversion of knowledge into technology by the market itself, because of actively functioning networks between the different agents of the innovation system, such as public laboratories, pharmaceutical firms, new biotechnology firms, government and financiers. Such networks are already less active in Europe and even more dormant in emerging economies like India. India has been successfully able to develop the nuclear bomb, satellites and the super computer because such projects involved a group of scientists who were given directives under a "mission mode", i.e. under a clearly defined system of milestone targets and associated rewards. This route cannot be pursued in the integration of biotechnology because biotechnology involves a variety of techniques with multi-sectoral applications. A variety of agents have to mobilised in order to integrate biotechnology in any particular sector. Thus, it may be worthwhile for the Indian government to consider more intervention in the creation of networks between Indian firms and between public laboratories and private firms themselves through national programs, as some European countries such as France have successfully done, in order to accelerate the integration of biotechnology and generally the creation of innovations in the Indian pharmaceutical sector.

5.3. Limitations and suggestions for further study

Our primary problem was to obtain comprehensive data on the biopharmaceutical firms. There is not much data available on the R&D activities or technology related purchases of firms. Often data from different sources are contradictory and a considerable time has to be spent in identifying the correct information. Telephone interviews or direct interviews are necessary to obtain relevant data on many private limited firms. Any extension of the present work can thus envisage the amelioration of the database used. Secondly, different measures of market sales such as net profits can be considered in the place of sales if such data can be obtained. Case studies can also be conducted to open "the black box" of international strategic alliances in order to identify the conditions favourable to the initiation and success of technology collaborations with Indian firms.

Uncited references

Arrow (1962), Malerba (1992).

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References

Acharya, R., 1995. The impact of New Technologies on Economic Growth and Trade: A case Study of Biotechnology. Ph.D. Thesis, University of Masstricht.

Ahmad, H., 1988. Technological Development in Drugs and Pharmaceutical Industry in India. Navrang, New Delhi.

Arora, A., Gambardella, A., 1990. Complementarity and external linkages: the strategies of large firms in biotechnology. Journal of Industrial Economics 4, 361–379.

Arrow, K.J., 1962. The economic implications of learning by doing. Review of Economic Studies 29, 155–173.

Basant, R., Fikkert, B., 1996. The effects of R&D, foreign technology purchase, and domestic and international spillovers on productivity in Indian firms. Review of Economics and Statistics, pp. 187–199.

Biotech Consortium Ltd., 1994. Directory of Biotechnology Industries and Institutions in India. New Delhi, India.

Centre for Monitoring Indian Economy (CMIE), 1996. The Indian Corporate Sector, Bombay.

Cockburn, I., Henderson, R., Stern, S., 1999. The diffusion of science driven drug discovery: organizational change in pharmaceutical research. Working paper 7359. National Bureau of Economic Research, 1050 Massachusetts Avenue, Cambridge, MA 02138.

Deolalikar, A.B., Evenson, R.E., 1989. Technology production and technology purchase in Indian industry: an econometric analysis. Review of Economics and Statistics, pp. 687–692.

Department of Biotechnology, Government of India, 1993. Research Profile of Biotechnology Activities in India. New Delhi, India.

Desai, A.V., 1980. The origin and direction of industrial R&D in India. Research Policy 9, 74–96.

Desai, A.V., 1988. Technology acquisition and application: interpretations of the Indian experience. In: Lucas, R.E., Papanek, G.F. (Eds.), The Indian economy. Oxford University Press, Oxford.

Ernst, Young, L.L.P., 1998. New Directions 98, The 12th Biotechnology Industry Annual Report, CA.

Ferrantino, M.J., 1992. Technology expenditures, factor intensity and efficiency in Indian manufacturing. The Review of Economics and Statistics, pp. 689–699.

Gambardella, A., 1995. Science and Innovation in the US Pharmaceutical Industry. Cambridge University Press, Cambridge.

Grilliches, Z., 1979. Issues in assessing the contribution of research and development to productivity growth. Bell Journal of Economics 10, 92–116.

Grilliches, Z., 1995. R&D and productivity, Handbook of the Economics of Innovation and Technological Change. Oxford University Press, UK and Cambridge University Press, USA, Blackwell Scientific Publications, Oxford, pp. 52–89.

Henderson, R., Cockburn, I., 1994. Measuring competence? Exploring firm effects in pharmaceutical research. Strategic Management Journal 15, 63–84.

Katrak, H., 1985. Imported technology, enterprise size and R&D in a newly industrializing country: The Indian experience. Oxford Bulletin of Economics and Statistics 47, 213–229.

Katrak, H., 1989. Imported technologies and R&D in a newly industrialising country. Journal of development economics 31, 123–139.

Katrak, H., 1994. Imports of technology, enterprise size and R&D-based production in a newly industrializing country: the evidence from Indian enterprises. World Development 22, 1599–1608.

Kumar, N., Saqib, M., 1996. Firm size, opportunities for adaptation and in-house R&D activity for developing countries: the case of Indian manufacturing. Research Policy 25, 713–722.

Lanjouw, J.O., 1998. The introduction of pharmaceutical patents in Indian: heartless exploitation of the poor and suffering? National Bureau of Economic Research, Working paper 6366.
Malerba, F., 1992. Learning by firm and incremental technical change. The Economic Journal 102, 845–859.
Nath, P., 1993. Firm size and in-house R&D: the Indian experience revisited. The Developing Economies 3, 329–344.
Office of Technology Assessment, O.T.A., 1991. Biotechnology in a global economy. US congress office of Technology Assessment, US Government Printing Office, Washington DC.
Orsenigo, L., 1989. The Emergence of Biotechnology. Pinter, London.
Pisano, G.P., 1991. The governance of innovation: vertical integration and collaborative arrangements in the biotechnology industry. Research Policy 20, 237–249.
Ramani, S.V., Venkataramani, M.S., 2001. Rising to the technological challenge: possibilities for integration of biotechnology in the Indian pharmaceutical industry. The International Journal of Biotechnology, in press.
Ramani, S.V., Visalakshi, S., 2001. The chicken or the egg problem revisited: the role of resources and incentives in the integration of biotechnology techniques. The International Journal of Biotechnology, in press.
Raut, L.R., 1995. R&D spillover and productivity growth: evidence from Indian private firms. Journal of Development Economics 48, 1–23.
Redwood, H., 1994. New Horizons in India. Oldwicks Press Limited, Suffolk, England.
Sasson, A., 1993. Biotechnologies in Developing Countries, Present and Future, UNESCO, Paris.
Siddharthan, N.S., 1988. In-house R&D, imported technology, and firm size: lessons from Indian experience. The Developing Economies 3, 212–221.
Siddharthan, N.S., Agarwal, R.N., 1992. Determinants of R&D decisions: a cross-section study of Indian private corporate firms. Economic Innovation and New Technology 2, 103–110.
Singh, S., 1985. Multinational Corporations and the Indian Drug Industry. Criterion Publications, New Delhi.