A statistical examination of the integration of biotechnology in the Indian pharmaceutical sector

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Abstract: From the beginning of the 1970s a number of Indian pharmaceutical firms had invested in gaining technological competence without having 'formal R&D centres'; and through efficient 'reverse engineering' had slashed the prices of products otherwise sold by Western multinationals. However their knowledge base was founded on the chemical technology of creating bulk drugs and during the second half of the 1980s these firms were confronted with biotechnology, a set of techniques that was new and more complex to integrate. Using detailed panel data on a sample of 32 firms active in biopharmaceuticals, this paper attempts to understand the relationships between their size, R&D strategies and market sales. Given the small sample size, the statistical analysis of our data set is limited to the identification of associations between the different variables and is not extended to estimation of models. The methods used are descriptive statistics, principal component analysis and analysis of variance.

Keywords: India; pharmaceutical market; biotechnology.

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1 Introduction

When India obtained independence in 1947, foreign direct investment was looked down upon as a continuation of Western economic imperialism and therefore its industrial policy was not conducive to such investment. Despite this stance, the Indian pharmaceutical market was dominated by foreign multinationals (MNCs from now on) for 20 years thereafter. As late as 1976, among the top 20 firms, which held 57.19% of the pharmaceutical market, there were only four Indian firms [1]. Given the high prices, at which the MNCs sold their products and the fledging private sector, the Indian government set up a network of public sector or government controlled firms to ensure an alternative supply of basic drugs like antibiotics at prices that the Indian consumers could afford. However the combined supply of these three types of firms was not adequate to satisfy the needs of the nation.

The above situation began to change with the initiation of two measures during the early 1970s which aimed at providing incentives to Indian firms to undertake investment in the high-tech sectors. The first of these was a change in the patent law in 1972 that enabled Indian firms to patent new processes rather than products. It was a landmark development, but this course was no different from what a number of other countries (e.g. USSR, Middle East, China) and even advanced countries like Japan were pursuing to promote their own knowledge based industries [2,3]. The act ensured patent protection only to production processes and not to the products themselves. The Indian firms were legally free to make products developed by foreign corporations as long as they involved a different manufacturing process. The second was a series of incentives given to firms to invest in R&D. For instance, firms with an R&D laboratory of a certain minimum size could import R&D related capital goods and raw materials more easily. Investment in in-house R&D units was tax deductible. Thus, during the 1970s a number of Indian pharmaceutical firms invested in gaining technological competence and through efficient 'reverse engineering' slashed the prices of products otherwise sold by the MNCs. The market share of the MNCs dropped from around 80% in 1970 to 39% in 1993 [4]. Dependence on imports was further drastically reduced by the beginning of the 1990s when the country became almost totally self-sufficient in formulations and 80% self-sufficient in bulk drugs [5].

Despite this good record it is necessary to take a fresh look at the Indian pharmaceutical sector, because in the last ten years it has been subject to two kinds of significant shocks. Firstly, the environment in which the Indian firms function has changed dramatically since 1991, with the initiation of economic liberalization as part of state policy. With the end of the 'licence raj' or 'the rule of the licence', Indian firms have had to formulate their investment strategies according to market signals instead of consecrating a substantial amount of their time to obtaining Government licenses through political lobbying. Price control on drugs has been reduced, import tariffs have been reduced and there is now no limit on foreign direct investment, permitting MNCs full ownership of their Indian subsidiaries. India has signed the GATT agreement and has agreed to implement the international patent standards by the year 2005, which will ensure product patent protection for 20 years from the time of filing of a patent [6,7].

Secondly, at the international level, there has been tremendous technological progress in the pharmaceutical sector through integration of biotechnology techniques (i.e. techniques involving change or manipulation of the genetic patrimony of living

organisms). These have led to the creation of incremental and radical product innovations, refinements in the search processes for the creation of new chemical entities and reduction in the costs of production of many products [8]. By the middle of the 1980s, foreign made pharmaceutical products (diagnostic kits, vaccines etc.) based on recombinant DNA began to be sold in the Indian market.

Indian scientists brought the importance of biotechnology for a developing country like India to the attention of the Indian government as soon as it emerged in Western countries. It was clear that access to these new products and processes developed by biotechnology techniques was critical for the provision of healthcare, population control, industrial competence and sustainable development. The government programs that followed during the 1980s concentrated on creating scientific competence through launching new academic programs in universities, creating new scientific institutions and building awareness among industrialists through diffusing information on biotechnology. However there were no state led plans for the integration of new technology among Indian firms [9].

Table 1 lists the top ten bio-pharmaceutical products worldwide and the names of the firms that are furnishing them in India. As the Table indicates, Indian firms have entered this market, but only some vaccines and diagnostic kits are being produced by the Indian firms themselves. Most recombinant DNA products are still imported from abroad or distributed by Indian firms through licensing arrangements with foreign firms. This situation will change in the future if Indian firms incorporate biotechnology more at the research and production level. Thus Indian pharmaceutical firms are at a crossroad. Currently their knowledge base is founded on the chemical technology of creating bulk drugs and they are confronted with biotechnology, a set of techniques that is new (being interdisciplinary based on molecular biology and biochemistry) and more complex to integrate. They must decide if they want to integrate biotechnology at all and if so, how to do it. In this context, the objective of this paper is to examine the R&D strategies of a small set of Indian pharmaceutical firms that have either publicly announced their intent of investing in biotechnology or have done so already.

The existing literature on R&D activity in India focuses on three issues: the motivations for (or impact of) undertaking R&D investment, the relation between firm size and proportion of sales revenue allocated to R&D activities and the relation between in-house R&D and foreign collaborations. However there is no consensus on the answers to any of these questions. This could be because different manufacturing sectors have been studied, using different databases and during different time periods. Furthermore, all of them pertain to the pre-liberalization period when firms were not reacting to market signals as much as government controls. In this context, the present article attempts to contribute to the existing literature by examining the three relations with respect to a single sector, namely biopharmaceuticals and in the post-liberalization period. In addition, it identifies the distinguishing features of firms that have already incorporated biotechnology in their research or production activities in order to aid in a better understanding of the possibilities of the integration of biotechnology in the Indian pharmaceutical sector.

Table 1 The ten top bio-pharmaceutical products (worldwide)

*Brand**	*International marketer*	*Generic name of product*	*Marketers of branded product in India*	*Names of other marketer/producers of the generic product in India***
Neupogen	Amgen ($719 million)	Epoietin/ Erythropoietin (to treat anaemia especially in cancer and AIDS)	Piramal Health Care	Ethnor, HAL, Cadilla, Johnson & Johnson
Epogen	Amgen ($587 million)	Epoietin/ Erythropoietin	Ethnor	HAL-Indon
Procrit	Ortho Biotech ($500 million)	Epoietin/ Erythropoietin	Not available	
Intron A	Schering-Plough ($572 million)	Interferon (used for cancer/AIDS/ hepatitis B)	Schering-Plough	Oncomed, Torrent, Piramal
Roferon-A	Hoffman-La Roche ($172 million)	Interferon	Fulford India	
Huminsulin	Eli Lily ($560 million)	Insulin from human source	Eli Lily	Torrent, Boots, Knoll, Sarabhai, Hoechst.
Engerix B	SmithKline Beecham ($480 million)	Vaccine for Hepatitis B	SmithKline Beecham	Bharath Serums, Shanta Biotech, Panacea
RecombinNAK HB	Merck ($245 million)		Not available	
Activase	Genentech ($236 million)	rTPA (to dissolve blood clots)	Not available	
Protropin	Genentech ($217 million)	Somatotropin or human growth hormone	Not available	Pharmacia, UpJohn

* The Economist, 'A survey of biotechnology and genetics', 25th February, 1-18,1995. The figures given in brackets in the column are the net sales of international marketers in 1993 in $million.

** Drug Index, Passi Publications, July-September 1997 available in most Indian hospital pharmacies. This was also supplemented by visits to some Indian hospitals and information supplied by Dr. Visalakshi of NISTADS, New Delhi, India.

2 Survey of the literature

As mentioned earlier, the debate in this literature revolves around three central questions:

- What kinds of firms undertake R&D?
- Why do these firms undertake R&D?
- What is the relation between internal R&D and technology imports?

R&D activity is measured sometimes in terms of input i.e. expenditure on R&D and sometimes in terms of output i.e. patent applications.

The majority of the papers studying the first question have examined the relation between the intensity of R&D expenditure (i.e. R&D expenditure/sales) and the size of the firm. Katrak [10], Siddhartan and Agarwal [11] show that R&D expenditure 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.

However, according to Kumar and Saqib [12], research intensity is an increasing function of firm size as 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. Still others like Siddharthan [13] and Nath [14] propose a U-shaped relation between R&D expenditure intensity and firm size. They argue that in high tech sectors, small firms need to establish niches on the basis of their technological competence and hence engage in R&D to maintain their technical quality. Large firms on the other hand have established R&D units in order to adapt imports to local conditions and to avail themselves of fiscal concessions.

Now coming to the issue of why Indian firms engage in R&D, Desai [15] proposes three types of objectives for R&D: exploratory, developmental and operational. Exploratory R&D is creative R&D i.e. whose target is to create product or process innovations through internal R&D efforts. Developmental R&D is adaptive R&D, to adapt or reengineer imports to suit local conditions. Finally, operational R&D is to solve the day-to-day technical problems in production plants. According to Desai [15] exploratory R&D accounts for about 2-3% of R&D expenditure, developmental R&D for 30-40% and the rest for operational R&D. Despite the above, Basant and Fikkert [16] and Raut [17] find that R&D expenditure has increased factor productivity in Indian firms. However, this positive impact is contested by Ferrantino [18] who finds stagnation of factor productivity in Indian firms at the same time as a substantial increase in the qualification of personnel in firms. He concludes that there is either mismanagement of R&D personnel, or the R&D effort is not adapted to suit local needs or substantial non-R&D related expenditure is submitted as R&D investment in order to avail companies of fiscal concessions.

The third raging debate in this literature is on the relation between 'technological imports' or 'foreign technological collaborations' and internal R&D. Technological imports can be intra-firm transfers though foreign equity participation or market transactions. Furthermore, there can be two kinds of market transactions. Either licences can be granted to Indian firms for the use of patents or brand names against payments in the form of royalties; or technical services can be provided for the construction of plant or production systems against negotiated technical fees [19].

Some economists assert that internal R&D is a substitute for import of technology. Desai [20] 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 [16] find that returns to technology imports are greater than to internal R&D and since both are substitute goods in knowledge generation, firms buy from abroad when they can. Deolalikar and Evenson [21] however assert that external collaborations are a complement to internal R&D. The basic assumption fuelling the analysis here is that Indian R&D is 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. Still other papers find no significant relation between technology imports and R&D intensities [12,11].

Thus there is no consensus on the motivations for conducting R&D, the relation between firm size and R&D expenditures and the relation between internal R&D and foreign collaborations.

3 Construction of database and formulation of variables

We first compiled a list of firms active in the bio-pharmaceutical sector from three sources:

- reports of the Department of Biotechnology,
- the *Directory of Biotechnology Industries and Institutions in India* and
- the directory on the *Research Profile of Biotechnology Activities in India*.

All the documents used were published by the Ministry of Science and Technology of the government of India. They yielded 48 pharmaceutical firms as being already active or intending to be active in the biotechnology sectors. We then gathered information on their firm characteristics, R&D strategies and market sales from government documents and business journals. An important source of information were the data given in the report of the Department of Biotechnology by Visalakshi, Sandhya and Abrol [22]. Information was also gathered through direct interviews with the CEOs of eight firms conducted by the author. Pooling these various sources of data we obtained information on 32 of the 48 firms in the target sample set.

Though the sample was small it included all the different types of firms that are active in the pharmaceutical sector. Among the 32 firms there were three Indian subsidiaries of MNCs, two government or public sector firms and 27 private sector firms. Among the private sector firms there were six dedicated biotechnology firms. A number of private sector firms were not public limited which meant that we could not have access to their company reports giving financial information (even companies that are public limited rarely publish any data on their R&D strategies in their company reports). Thus primary collection of data through direct interviews was necessary. The information collected pertained to the year 1994.

The firm characteristics considered were size, age and technological orientation. Size of the firm was taken to be the total number of personnel employed. Technological orientation was captured in the form of qualitative variables. These variables indicated the degree of integration of biotechnology in the research and production activities of the firm.

Three kinds of R&D strategy indicators were considered: technology acquisitions, in-house creation efforts and external alliances. New technology can be incorporated within a firm either through the creation or acquisition of new technology. The acquisition of new technology embodied in machines or other forms of codified knowledge was captured in terms of R&D expenditure. R&D expenditure was taken into account both in absolute and relative terms. Furthermore, new technology can be created through in-

house efforts or external alliances. Labour stocks represented in-house efforts, since most or all learning within a firm is by humans and not machines. Labour stocks were constructed to reflect the quality of the labour recruited and their allocation to R&D functions or non-R&D functions. Two kinds of external alliances were considered: collaborations with foreign firms and collaborations with public laboratories. There were no collaborations between Indian firms in our sample. The R&D strategies and all other variables considered are given in Table 2. As can be seen, all of the other R&D strategies except collaborations were defined in terms of allocations of resources to R&D activity.

Table 2 Variables considered

Indicator/s of	*Quantitative variables*
Firm characteristics	1 Size = Total number of personnel
	2 Age
Market sales	3 Market sales
R&D strategies	4 R&D expenditure
	5 R&D expenditure intensity = R&D expenditure/sales revenue
	6 R&D employment intensity = employees involved in R&D/total number of employees
	7 Qualification intensity = number of employees with a masters or PhD degree/total number of employees
	8 R&D qualification intensity = number of employees with a masters or PhD degree in R&D/total number of employees in R&D
	9 Academic collaborations = number of agreements with Indian public laboratories since 1970.
	10 Foreign collaborations = number of technological collaborations with foreign firms since 1970.
Resources	11 Total number of qualified personnel
	12 Total number of personnel in R&D
	13 Total number of qualified personnel in R&D
Technological Orientation	*Qualitative variables*
	14 Integration of biotechnology in research = {yes, no}
	15 Integration of biotechnology in production = {yes, no}

4 Results

4.1 Distinguishing features of sample set of firms

We first conducted descriptive statistics on the quantitative variables (i.e. all except the integration of biotechnology in research and integration of biotechnology in production) and the results are shown in Table 3 along with the names of the firms that are out of the box plot. These firms are atypical with respect to the population under study in the sense that the quantitative characteristic considered is particularly low or high in these firms with respect to the other firms in the sample set. Thus it can be noted that the two top firms in our sample in terms of sales are Ranbaxy and Glaxo. In 1995 the top five firms by decreasing order of market share were Ranbaxy, Glaxo, Lupin, Cipla and Hoechst. Glaxo is among the oldest pharmaceutical firms in India having been set up by the British before independence. Ranbaxy is among the set of Indian firms that was able to challenge

successfully the MNCs through independent development of drugs in the aftermath of the change in the Indian patent law in 1972. It is known for its independent development of the anti ulcer drug 'cephalosporin'. Ranbaxy patented this drug in the USA, a feat given that Eli Lily the original creator of this drug had patented several stages of the production of this drug and considered it extremely unlikely that another company could find another method of producing this drug. Now Ranbaxy and Eli Lily have a joint venture.

Table 3 Descriptive statistics on sample firms

Variable	*Mean*	*S.D.*	*Firms out of the box plot*
Firm characteristics:			
Size	1459,75	1876,49	Cipla, Ranbaxy
Age	27,16	18,80	Anglo French
Market Sales	40,11	54,47	Glaxo, Ranbaxy
R&D strategies:			
R&D expenditure	1,23	2,39	Ranbaxy, Stangen, Orthodiagnostics, Cipla, Sarabhai
R&D expenditure intensity	0,04	0,07	S.S. Clonetech, Span, Stangen, Transgene
R&D employment intensity:	0,12	0,14	S.S. Clonetech, Bangalore Genie, Cadilla
Qualification intensity	0,57	0,20	J.Mitra, Orthodiagnostics (Sarabhai, Synbiotic)*
R&D qualification intensity	0,58	0,33	None
Academic collaborations:	1,69	1,38	None
Foreign collaborations	2,69	3,34	HAL, Synbiotic, Sarabhai
Resource stocks:			
R&D personnel	64,31	58,74	None
Qualified personnel	817,62	1184,01	Ranbaxy, Cipla, Glaxo, Lupin
Qualified personnel in R&D	32,32	34,27	IDPL, HAL, Glaxo, Cipla

Units: $million

*The two firms Sarabhai and Synbiotic have a qualification intensity that is significantly lower than that of other firms in the sample set.

In terms of 'total employees' and 'qualified personnel' two new Indian firms Cipla and Lupin are among the firms outside of the box plots along with Ranbaxy and Glaxo. Cipla is associated with the development of the anti-cancer drug 'vincristrine' which was also initially sold by Eli Lily. Lupin is credited with the development of a new cost efficient production process for the anti-TB drug 'ethambutol'. Now even the original inventor Lederle buys the drug from Lupin.

Coming to the R&D activities, no company is particularly distinct in terms of number of people working in R&D but the public sector firms HAL (Hindustan Antibiotics Ltd.) and IDPL (Indian Drugs and Pharmaceuticals Ltd.) are among the set of firms that have the maximum qualified personnel working in R&D. Paradoxically these very public sector firms rank very low in terms of net profit generated.

The high spenders on R&D in our sample are: Ranbaxy, Cipla, Stangen, Orthodiagnostics and Sarabhai. Stangen is a subsidiary of Dr.Reddy's lab and Orthodiagnostics is a subsidiary of Johnson & Johnson. Dr.Reddy's has developed a

number of 'first in India bulk drugs' including 'Ciprofloxacin' whose European patent will end in the year 2001. These are among the top 500 brands by pharmacy sales in India. The company 'Sarabhai' is interesting because it is a high spender on R&D but has one of the lowest proportions of qualified personnel (low qualification intensity) and a large number of foreign collaborations. Thus it seems to be integrating new technology through market transactions with foreign firms rather than through internal R&D.

Most of the firms with strong R&D intensities (R&D employment intensity, R&D expenditure intensity and R&D qualification intensity) are new (less than ten years old) and dedicated biotechnology firms. Bangalore Genei, Transgene, S.S. Clonetech are new biotechnology firms that have been created by researchers from public laboratories. Bangalore Genei was created by Dr. T. Babu, initially a scientist at ISRO. A medical doctor Dr. K.K. Rao started Transgene. S.S.Clonetech was also started by an eminent geneticist. These companies started by producing traditional biochemical kits and are now slowly moving into biotech based diagnostics.

The two firms with the largest number of foreign collaborations are Sarabhai and Synbiotic and they also have the lowest qualification intensity. In terms of age, the AngloFrench Drug Company, another firm existing since British times, is the oldest.

4.2 Relation between sales, market size and R&D strategies

As a first step towards understanding the relationship between size, market sales and R&D strategies, a correlation matrix was computed. The significant correlations are indicated with a star in Table 4. It can be seen that 'size' is significantly positively related to all forms of human labour stocks such as R&D personnel, qualified personnel, qualified personnel in R&D as well as market sales. Market sales are significantly positively related to size and R&D expenditure. In other words larger firms have greater sales and tend to spend more absolute amounts on R&D activities. However none of the other R&D strategy indicators is correlated strongly with market sales. This would hint that intensity of R&D activity does not have a strong impact on the market sales of a firm.

According to Table 4, R&D expenditure intensity is higher in firms with a higher proportion of personnel allocated to R&D activities. But both R&D expenditure intensity and R&D employment intensity are negatively correlated with firm size (though these relations are not statistically significant). Therefore the intensity of R&D activities is less in larger firms.

Foreign collaborations are significantly and negatively correlated with qualification intensity, indicating that external alliances with foreign firms and internal R&D are strategic substitutes rather than strategic complements. It should also be noted that the mean of (or average) number of 'academic collaborations' is also less than that of 'foreign collaborations', implying that the Indian firms tend to form collaborations with foreign firms more easily than with research centres in their own country.

Table 4 Correlation matrix between variables considered

Variable	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*
Firm characteristics													
1 Size	1.00												
2 Age	0.34	1.00											
3 Market sales	**0.69***	0.24	1.00										
R&D strategies													
4 R&D expenditure	0.43	-0.03	**0.78***	1.00									
5 R&D expenditure intensity	-0.21	-0.37	-0.12	0.05	1.00								
6 R&D employment intensity	-0.42	-0.37	-0.20	-0.07	**0.64***	1.00							
7 Qualification intensity	-0.02	-0.02	0.13	0.28	0.03	-0.16	1.00						
8 R&D qualification intensity	-0.01	-0.15	-0.31	-0.33	0.04	-0.24	0.06	1.00					
9 Academic collaborations	-0.17	-0.37	-0.21	-0.14	0.09	0.21	0.30	-0.18	1.00				
10 Foreign collaborations	0.15	0.03	-0.02	-0.08	-0.34	-0.20	**-0.54***	0.08	-0.22	1.00			
Resource stocks													
11 R&D personnel	**0.65***	0.15	**0.50***	0.40	-0.22	-0.06	-0.30	-0.36	0.02	0.31	1.00		
12 Qualified personnel	**0.86***	0.35	**0.80***	**0.61***	-0.17	-0.42	0.25	-0.09	-0.22	0.03	0.42	1.00	
13 Qualified personnel in R&D	**0.60***	0.21	0.08	-0.06	-0.13	-0.22	-0.39	0.36	-0.17	0.38	**0.63***	0.25	1.00

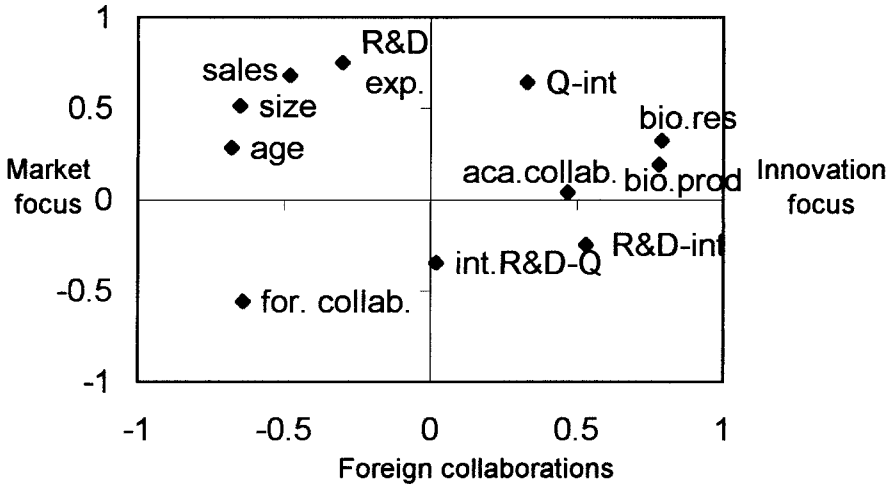
Units: $million

*Pearson's correlation coefficient is significant at 5%

Having identified pairwise relationships between any two variables, we moved on to identifying relations (of positive correlation, negative correlation or independence) between groups of variables using the method of principal component analysis, or PCA. This method was particularly favoured because it presented two advantages; it does not require any statistical condition to be satisfied and it does not necessitate the exclusion of any of the variables. We did not estimate any models of market sales or any of the R&D strategies using regression analysis, because our objective was to identify the direction i.e. positive or negative of relations, if any, between these variable, rather than to test any particular theory relating to these variables.

The PCA analysis yielded four factors, whose eigen values were greater than one. These four factors captured 77% of the total variance. The results pertaining to the first two factors that captured 53% of the total variance is shown in Figure 1.

Figure 1 Results of the principal component analysis internal R&D



R&D exp: R&D expenditure, RD-int: R&D expenditure intensity, R&D empl. int: R&D employment intensity, R&D qual int: R&D qualification intensity, Qual. int.: Qualification intensity, Bio research: Integration of biotechnology in research, Bio production: Integration of biotechnology in production, Acad coll: academic collaborations, Foreign coll: Foreign collaborations.

The first factor can be interpreted as representing the focus of the firm. Thus a firm could be focused on being competent in production and thereby in the final market, or being focused on building up its innovative capacity. Firms with a 'market focus' are older, with greater market sales, with a larger size and with a larger number of foreign collaborations. On the other hand firms with an 'innovation focus' are younger, smaller firms with a higher probability of engaging in biotechnology research or producing a biotechnology based product.

The second factor can be interpreted as representing the mutually exclusive strategies for the creation of innovations, either through in-house efforts or foreign collaborations. The Figure shows that the qualification intensity and foreign collaborations, which best

represent this factor, are on opposite sides of the horizontal axis. This clearly indicates that they are strategic substitutes.

The variables that determine the third factor are R&D employment intensity and R&D qualification intensity that are negatively correlated. This implies that firms choose to create knowledge either through inflating the quantity of personnel in the R&D department or the quality of the personnel in the R&D department. The fourth factor is determined by academic collaborations and biotechnology production that in turn are negatively correlated. This shows that firms commercializing a biotechnology-based product tend to have fewer collaborations with public laboratories. This further implies that the knowledge created by public laboratories has a very limited impact on the integration of new technology in this sector.

4.3 Distinguishing features of biotech firms

Having studied the relation between size, market sales and R&D strategies, we now focus on the integration of biotechnology. The method of 'analysis of variance' was used to identify the characteristics of firms that have achieved different degrees of integration of biotechnology. In the earlier Section, integration of biotechnology could be considered only as a binary variable given the method used (i.e. PCA). However the integration of biotechnology could be considered as a multi-state variable in the 'analysis of variance'. Finally, to conduct the analysis of variance we removed all the resource variables and R&D expenditure (as required) since they were already present in the intensity measures.

Like any new technology, biotechnology can be integrated into a firm's functions at the R&D, production or marketing level. At the R&D level it may or may not result in the commercialization of a product. Thus integration of biotechnology in research is considered as a variable that can take three values: no integration of biotechnology in research activities, some integration and production of a biotech product based partly or wholly on internal R&D activities.

Extending this argument, integration of biotechnology in production is also considered as a variable that can take three values: no integration of biotechnology in the marketing or production functions, integration of biotechnology only at the marketing level and integration of biotechnology at the production level. Integration of biotechnology at the marketing level means that the firm concerned is acting as a distributor of a biotechnology product and may produce it in the future. Integration of biotechnology at the production level means that the concerned firm is producing a biotechnology-based product.

The results given in Table 5 indicate that the distinguishing features of firms that are active in biotech research (statistically significant at the 1-% level) are mainly their age, foreign collaborations, qualification intensity and R&D expenditure intensity. Again, it is revealed that the younger the firm the more the integration of biotechnology at the research level. Similarly, the qualification intensity and R&D expenditure intensity are highest in firms that are commercializing innovations from their own R&D.

Table 5 Distinguishing features of biotech firms. Means of explanatory variables for the different groups of firms

	Firms active in biotech research			
	Firms with no biotech research	*Firms with some biotech research*	*Firms producing a biotech product based on own research*	*Mean of variable in sample*
Age	41.57	24.6	18.46	25.97
Foreign collaboration	4.25	3	0.69	2.3
Qualification intensity	0.45	0.53	0.66	0.57
R&D expenditure intensity	0.01	0.02	0.06	0.04
	Firms active in biotech marketing or production			
	Firm with no biotech integration	*Firm only marketing biotech product*	*Firms producing a biotech product*	*Mean of variable in sample*
Foreign collaboration	4	2.25	0.72	2.69
R&D expenditure intensity	0.01	0.02	0.06	0.04

Foreign collaborations are clearly substitutes for in-house research in biotechnology. It is not clear whether this is due to any intrinsic strategy on the part of the small or new Indian firms to avoid foreign collaborations or due to the preferences of foreign firms. It is well-known that foreign firms feel more secure in initiating collaborations with large established firms rather than start-ups in India.

The distinguishing features of firms that have integrated biotechnology in production are their R&D expenditure intensity and foreign collaborations (statistically significant at the 1-% level). Firms that have integrated biotechnology at the production level are likely to be spending a high proportion of their revenue on research and having very few foreign collaborations. This indicates that the knowledge required for producing biotech based products is either generated through hiring competent personnel or bought from the market, rather than being integrated through knowledge-sharing contracts with foreign firms.

5 Conclusions

Based on detailed panel data of a sample of 32 firms, the main objective of this paper was to understand the relationships between firm size, market sales and R&D strategies, in the Indian biopharmaceutical sector. A second objective was to identify the distinguishing features of firms that had already incorporated biotechnology in their research or production activities, as compared to firms that had not done so yet, but intended to do so in the future. Given the small sample size, the statistical analysis of our data set was limited to identification of associations between the different variables and not extended to estimation of models.

The matrix of correlation indicated that the market sales of Indian pharmaceutical firms depended on some components of their resources and R&D strategies. Market sales were highly correlated with 'qualified personnel' and 'R&D expenditure'. This reflected the intense competition that exists in the Indian pharmaceutical sector and the need for firms to be technologically competent in order to survive in such a market. Larger firms tended to have higher market sales. None of the other R&D strategies were correlated with market sales. Moreover none of the R&D strategies was related to the size of the firm. This showed that intensity of R&D activity in this sector was neither related to the size nor to the market sales of firms.

The PCA analysis further identified that firms chose between being focused on the present market sales or building future competitive advantage through the creation of innovations. Firms that were market focused were less likely to have integrated biotechnology in their research or production activities. Once firms had chosen their strategic orientation, they decided between creating new technology in-house or acquiring it from the international market through foreign collaborations.

Then the analysis of variance highlighted the distinguishing features of firms that had successfully integrated biotechnology at the research or production level. The former were likely to be young, with very little foreign collaboration and a highly qualified research team focused on the creation of innovations. The latter were also marked by a disinterest in foreign collaborations and higher R&D expenditure intensity.

Three trends can be clearly inferred from the above analysis for the integration of biotechnology in the Indian pharmaceutical sector. Firstly, some of the large established firms are increasing their internal R&D efforts through augmenting either the quantity or the quality of labour allocated to R&D activities. Secondly, other large firms and especially those that do not have a significant number of qualified personnel in their R&D departments are going in for foreign collaborations. Since the Indian firms that are initiating foreign collaborations are those that are either not engaged in research or those with a weak internal R&D group, they are either paying the foreign firms directly through lump sum transfers or royalties or entering into reciprocate arrangements by which they cooperate with the foreign firms in some other form. For instance, an Indian firm could distribute products of the foreign firm in return for a licence to produce that product in the future. Thirdly, small and newly created firms are also entering the market through commercialization of minor innovations. R&D strategies are not related to any particular firm characteristic. This confirms the intuition that in an emerging sector like biopharmaceuticals and in emerging economies like India, there is still a lot of technological and market uncertainty and hence R&D strategies are firm-specific depending on the vision of the management.

It is difficult to compare our results with those in the economics literature because unlike their studies, ours concentrates on the 'post-liberalization' period and only on one sector. However we can discuss what our analysis has to offer by way of answers to the three central questions posed in the existing literature:

- What kinds of firms undertake R&D?
- Why do these firms undertake R&D?
- What is the relation between internal R&D and technology imports?

Our work indicates that in the bio-pharmaceuticals sector, it is not the large firms but the small and new firms that are the most active in research. They conduct research mainly to bring out innovations or integrate new technology and clearly internal R&D and foreign collaborations are strategic substitutes.

Finally, policy makers have to make note of two disturbing features of the Indian pharmaceutical sector. Inter-firm cooperation which so marks the pharmaceutical sectors in Western countries and which is especially used as a means of integrating new technology is completely absent in the Indian context. Secondly, public research laboratories have no significant impact on the creation of technological competence. A few firms are communicating with academic institutions through publications and are integrating biotechnology through the transfer of knowledge from public laboratories. But the scale on which such a phenomenon is occurring is extremely limited.

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