The chicken or egg problem revisited: the role of resources and incentives in the integration of biotechnology techniques

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Abstract: During the last 15 years, most countries of the developing world have declared investment in biotechnology to be strategic to their national programs of development and yet none of them has attained an industrial competence in the biotechnology sectors comparable to that of the developed nations. Is it simply a question of inadequacy of resources or is there something more to the building of industrial competence in an emerging highly science-based industry? How do developed and developing countries differ in their capacity to exploit a new field like biotechnology? We explore the problem of creating industrial competence in biotechnology in developing countries through a case study of India. We show that underdevelopment is characterized not only by scarcity of resources, but also by inflexibility of public institutions, absence of crucial networks and myopic vision of firms. These features lower both 'incentives' and the 'degree of responsiveness to incentives' for investment in biotechnology. Thus the technology strategy in developing countries should not only concern itself with finding the optimal allocation of resources for the integration of biotechnology, but should also attempt to maximize the returns to any such investment through improving incentives.

Keywords: Biotechnology; India; France; incentives; resources.

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1 Introduction

The use of modern biotechnology techniques [1] has had three types of impacts in the pharmaceutical, agro-business, agricultural, and chemical industries. It has resulted in a change in the nature of the search process for the creation of new chemical entities, creation of radical and incremental product innovations, and the integration of biotechnology techniques in the production process to bring down production costs. While all of the radical product innovations or 'block busters' have been commercialized and sold by US or Western European firms, the creation and integration of incremental product and process innovations since the mid-1980s in the developing world have also been well documented [2]. Biotechnology is especially important for the developing countries as it could hold the key to pressing problems such as feeding their nations, achieving sustainable development and remedying damage caused by environmental pollution.

During the last 15 years, most countries of the developing world [2] have declared investment in biotechnology to be strategic to their national programs of development and yet none of them has attained an industrial competence in the biotechnology sectors comparable to that of the developed nations. This is especially striking when we take into account the fact that the European countries (barring the UK) were also latecomers to the biotechnology field. Some studies [2–4] postulate the lack of financial resources as the principal and evident reason for low investment in biotechnology in developing countries. Is it simply a question of resources or is there something more to the building of industrial competence in an emerging highly science-based industry? How do developed and developing countries differ in their capacity to exploit a new field like biotechnology? In this paper, we explore the problem of creating industrial competence in biotechnology in developing countries through a case study of India.

This paper is organized in four sections. Section 1 presents the theoretical framework for our analysis. Section 2 focuses on the nature and level of the integration of biotechnology in India. Section 3 attempts to explain the facts put forward in Section 2 through an examination of the problems particular to India as a developing country. Finally, Section 4 presents our conclusions.

2 Integration of new technology: the role of incentives

At the national level, new technology can lead to augmentation of industrial competence through the creation of new firms based on new technology or through the utilization of the new technology by incumbent firms. We refer to these two phenomena interchangeably as the integration of new technology in firms. The firms can gain access to the new technology through internal R&D, a market transaction (licensing agreement, purchase of technology or purchase of firm), or a strategic alliance with other firms or research institutes. A strategic alliance is distinct from a market transaction in that it involves joint control of resources for an agreed period of time.

We assume that in any country the degree and speed with which a new technology is integrated depends upon the national system of innovation. The commercialization of innovations in a new science-based sector is a collective process whereby the creation, development, adoption and integration of innovations depends on the existence and functioning of networks between a variety of institutions and agents in the economy, such as researchers, the government, firms, consumers and financial institutions. Thus the national system of innovation refers to all the institutions involved in the creation, adoption and integration of a new technology. The national system of innovation sets the investment patterns in the new technology, both by the state, the public sector and the private sector. This is a largely accepted assumption.

In an incisive article, Eliasson and Eliasson [5] explain that the degree of integration is potentially determined by the generation of scientific ideas that can be commercialized and the generation of funds for financing the search process for the creation of innovations. The type and speed of integration, or the actual realization of new products or processes, then depends on the selection mechanism that decides which ideas are actually going to be tried out for commercialization. They then assert that given the technological uncertainty surrounding the emergence of a new science-based sector, the system that permits the testing of the maximum variety of ideas will be the most successful in the integration of the new technology.

We further propose that the capacity of the national system of innovation to generate new scientific ideas, transform them into usable technology, and finally integrate the new technology into the production processes of firms would depend on:

- resources;
- the prevailing incentives for investment in the new technology;
- the responsiveness of the components of the national system of innovation to such incentives.

By resources, we refer to the knowledge base, physical capital, financial capital, social capital (i.e. the network structure of the firm with other entities), and any other specific competencies of the components of the national system of innovation. By incentives, we refer to the expected pay-off that can be earned through an allocation of resources to the new technology. However, even if resources are available and incentives are high, unless the responsiveness to such incentives is also sufficiently great, transformation of scientific knowledge into innovations may not take place. For instance, the managers of public sector firms, under the constraint of having to satisfy government targets for production, may be less responsive to profit signals associated with investment in new technology, as compared to private sector firms guided by the profit motive. Cultural and historical factors play a crucial role insofar as they influence the system of governance and the objectives of the unit concerned. By way of illustration, the expected profit that is sufficient to induce one community to invest in new technology may not be acceptable to another community. Europe has a smaller number of new firms involved in biotechnology compared with the USA and this is often attributed to the more risk averse and less entrepreneurial attitudes of investors.

It must be noted that resources, incentives, and responsiveness to incentives, are not independent parameters but interdependent ones which influence one another. For example, the initial endowment of a firm's resources can be changed through investment to create new resources. In turn, such investment patterns will be determined by the incentives for investment. Similarly, incentives to invest in a new technology may be lower if certain crucial complementary resources, like infrastructural facilities, are inadequate.

While paucity of resources and a weak national tradition of innovation are evident facts for developing countries, feeble 'incentives' and 'responsiveness to incentives' are insidious problems that the governments of developing countries often neglect. The incentive problem is actually more insidious because it is a reality that can be changed (unlike initial endowments), but which at the same time, is very difficult to change in the short term. The 'incentives' problem and the 'resource responsiveness to incentives' problem are those which plague developing and transitional economies more than developed economies because in the former, institutions are governed more by conventions rather than by market signals.

In this context, the objective of this paper is to illustrate how a developing country may fall short of realizing the maximum economic profit from a new technology, and from its available resources, if it does not attack the 'incentives' and 'resource responsiveness to incentives' problems adequately. This point is made through an examination of the evolution of the biotechnology sectors in a resource-rich developing country like India. Our work is based on articles from academic journals, articles from business and trade journals, documents of the Department of Biotechnology of India, databases (data of the Centre for Monitoring the Indian Economy, Derwent Biotechnology Abstracts, Science Citations Index) and interviews with industrialists, scientists and policy makers.

3 Initial conditions in India at the end of the 1970s

Unlike many developing countries, India has a large and established infrastructure of scientific institutes. Since gaining its independence, the Indian government began setting up a large network of research institutions for advanced research outside the university system. The three apex bodies whose activities relate to life sciences are the Indian Council of Medical Research (ICMR), the Indian Council of Agricultural Research (ICAR) and the Council of Scientific and Industrial Research (CSIR). The state also partially supports certain reputable independent research institutes.

At the end of the 1970s, scientists at the Regional Research Laboratory in Hyderabad (now the Centre for Celluar and Molecular Biology, CCMB), the Indian Institute of Science at Bangalore, the National Chemical Laboratory, Pune, and the Department of Applied Chemistry at Calcutta were very much aware of the latest developments in the USA and UK [2].

However, apart from these elite institutions, scientists in the majority of universities and public research laboratories were inadequately acquainted with the latest developments in the biological sciences. This could have been due to the fact that incentives for excelling in science were not clear (and still are not) due to certain functional features that are perhaps peculiar to India, in terms of the extent to which they are pervasive. Five features of note are as follows:

- heads of public academic institutions are appointed by the government with the result that the functioning and strategy of these institutions fluctuate according to the predilections of ministers of the central and state governments;
- research institutions and university departments are hierarchy-driven and charges of nepotism and cronyism are frequently aired in the media and in the courts;
- a very substantial percentage of positions (50–85%) is reserved by a rigid quota system for appointments at several levels in public research centres and for admission to many universities. The system is based not on academic or research credentials but on the basis of *birth* in what are characterized as socially disadvantaged communities. Similar considerations manifest themselves in promotions to higher positions in research institutes and university departments;
- though plans and targets are systematically announced there is no system of accountability for poor performance from the top down in the academic and research establishments;
- similarly, lack of timely and fair recognition for good performance leads competent performers to become apathetic or to seek a better work environment abroad. Currently the *incentives* system in public research is so distorted that it is a generally accepted opinion [6] that the standards of Indian science are maintained by dedicated individuals in isolated pockets, in different laboratories of the country, despite the system and not because of the system.

Let us turn to the vision of formulation of technology strategy in the private sector. While the popular explanation for the negative impact of long decades of foreign rule is partly valid, native ailments call for frank acknowledgment. Indian companies suffer from an ingrained obsession with quick and assured profits and many exhibit the mentality of a trader in established products rather than a risk-taking manufacturer of new products involving large investment, high risk and uncertain profits. The idea of investment in R&D to create new products using advanced technology is virtually alien to most, even among the successful Indian companies. After independence in 1947, industrialization was basically initiated and promoted through a series of government plans. Investment was guided not through market signals but through public investment, government control and a policy of licensing (or permits for private investment). Thus financial markets did not develop as in Western countries and financial institutions that lent to firms tended to be risk averse.

In pursuance of its policy of import substitution and self-sufficiency and in order to generate local competition with foreign multinationals which dominated high-tech industrial sectors like pharmaceuticals and chemicals, the government changed the patents policy in 1972. It initiated a period when process rather than product patents were recognized. At that time the foreign multinationals did not view this as a threat and did not lobby to have this policy reversed [7]. However, it led to the acquisition of significant technological learning on the part of Indian firms, which for the first time had clear incentives to invest in R&D.

Thus, for the next 20 years *the response to incentives* of Indian firms took the form of R&D aimed at technology absorption, improvement of processes in imported technology, and import substitution through reverse engineering of items not covered by patent under Indian law and of those whose patents had expired. Indian firms were more innovative on the marketing, production and distribution side, searching for guaranteed ways of making quick profits in the short term, and avoiding the committing of funds for R&D where returns were uncertain and distant. As recently as 1991, in the Department of Scientific and Industrial Research's 'Compendium of 100 major in-house research centres' [8] only one pharmaceutical company, Wockhardt Ltd., mentioned biotechnology as an area of interest.

4 Initiation of biotechnology and the role of the government

In India, biotechnology research was undertaken at the elite research institutions mentioned earlier, but the dissemination of results and the undertaking of new projects were mainly due to the efforts of motivated individuals with no central body to coordinate the research efforts in biotechnology. Thus at the request of the research community, a six-member National Biotechnology Board (NBTB) with six members was formed in 1982. Its objective was to coordinate the research efforts in the various ministries and research establishments: Department of Science and Technology, Department of Atomic Energy, the University Grants Commission, CSIR, ICMR, and ICAR. In 1983, they drew up a very large program that not only covered investment in agriculture and health care, but also included strategies for patents, biosafety, regulation and manpower planning. Their plans were to be realized in the course of the implementation of the sixth five-year plan (1980-1985). The NBTB is best remembered for its role in the creation of a number of research institutions like the National Institute of Immunology (1981), the Centre for Cellular and Molecular Biology (1981), the National Facility for Animal Tissue and Cell culture (1983), and the Institute of Microbial Technology (1983).

In 1986, the NBTB was replaced by a separate government department called the Department of Biotechnology (DBT) that functioned under the aegis of the Ministry of Science and Technology. The main reason for this change seems to have been the realization 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 coordinated development, an agency working 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 development of competence in genetic engineering, control or eradication of major communicable diseases through creation of vaccines, increase in food production (especially milk), attainment of self-sufficiency in edible oils, and creation of scientific competence in techniques that were not capital intensive. 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 and national laboratories as well as industrialists.

The first target was to create a core of researchers competent in biotechnology. Grants were given to enable public research laboratories 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, and the Tata Institute of Fundamental Research. The International Centre for Genetic Engineering and Biotechnology was created in 1988, in collaboration with UNIDO.

Academic programs in biotechnology were started at the Masters and PhD level in several universities. Scholarships were created to send Indian students for post-doctoral work in Indian and foreign research centres. Infrastructural investment was undertaken in the form of setting up microbiological culture collections, blue green algae and marine bacteria collections, a plant tissue culture repository, animal house facilities, biochemical engineering research and process development, oligonucleotide synthesis, and the import and distribution of chemicals and genetic engineering units.

Thus the strategy of the Indian government was focused on the creation of scientific competence and certain infrastructural facilities and not on the creation of industrial competence *per se*. However it had a positive indirect impact both on *incentives* for investment in biotechnology through the creation of scientific competence, and *responsiveness to incentives* through the creation of awareness of biotechnology.

5 Creation of scientific competence

According to the directory, *Research Profile of Biotechnology Activities in India* published in 1993 by the DBT, there are 19 CSIR units, 34 ICAR units, 10 ICMR units, 42 universities supported by the state, and 61 independent research or teaching institutes that are active in biotechnology. There seem to be two classes of priority in fields of application. The highest priority is given to research having an impact on agriculture, agro-business, and health sectors; the second level of priority is given to research on food, chemicals and environment. There are about 800 researchers in the public research sectors working on biotechnology and there are about 100 post graduates every year in biotechnology [9–13]. Of the latter, about 14% are absorbed in industry, about 67% into research, and about 17% go abroad [14].

What is the impact of Indian science on the international research market? To measure this we consulted two databases: Derwent Biotechnology Abstracts and the Science Citations Index. The Derwent Biotechnology Abstracts contain information on national and international journals, including both academic and industrial journals, relating directly to biotechnology. The Science Citations Index relates only to international journals in all the biological sciences which are directly or indirectly related to biotechnology. The results were very different according to the two databases and therefore it is surmised that the reality lies in between the two estimates. As shown in Table 1, according to the Derwent Biotechnology Abstracts, the output of Indian scientists compares favourably to that of any developed country, and it improves further when the number of publications produced per billion dollars of R&D expenditure is considered. In all our Tables, we take France as the representative country of Europe because of the major involvement of the French government in the creation of its biotechnology sectors (as is also the case in most developing countries). However, when we consider publications in international academic journals only, as indicated in the Science Citation Index, we find the output of Indian publications to lag behind considerably in absolute numbers. Moreover, according to the Science Citations Index, India lags behind both in terms of publications per researcher, and publications per billion dollars spent on research. Thus Indian scientists appear more productive only when we consider the publications in Indian journals.

Table 1 Indicators of R&D activity in selected countries

	USA	*France*	*India*
R&D expenditure in $billion (1992)**	169	26.5	7.1
R&D expenditure/ GNP (1992)**	2.50%	2.40%	0.80%
Number of researchers (in thousands, including all sciences) (1992)**	949.3	126.5	106
As % of world researchers (1992)**	22	2.9	2.5
Percentage of world scientific publications in 1992*	*34.80%*	*5%*	*2.10%*
Number of publications in biotechnology(1991-1996) (Science Citation Index)	182,2506	27,673	5,538
Number of publications (Science Citation Index) in biotech/ total number of researchers in all sciences	1.91	.218	.052
Number of publications (Science Citation Index) in biotech/ $billion spent on public research (for 1992)	107,84.059	1,044.2642	780
Number of publications in biotechnology (1991-1996) (Derwent Biotechnology Abstracts)	18,223	2,634	2,245
Number of publications (Derwent Biotechnology Abstracts) in biotech/ total number of researchers in all sciences	0.019	.021	.021
Number of publication (Derwent Biotechnology Abstracts) in biotech/ $billion spent on public research (for 1992)	107.83	99.39	316.19
Number of biotechnology firms created by public researchers	more than 400	40*	4
Number of firms in biotechnology	1308+	90-100+	130-150++
Market sales of indigenously produced products	$9.3 billion in 1996	-	$.33 billion in 1995++

* Mustar, P. (1997) 'Les chiffre cles de la science et de la technologie', *Economica*, 49 rue Hericart 75015, Paris, p.79, p.83., p.41, p.53.

** Science et Technologie Indicateurs (1996), 'Rapport de l'observatoire des sciences et des techniques', *Economica*, 49 rue Hericart 75015, Paris, p.238, p.340, p.341.

\+ Joly, D. and Ramani, S.V. (1996), 'Technology creation in the biotechnology sectors: the French connection', *International Journal of Technology Management*, *Special issue on Access to Technological and Financial Resources for SME Innovation*, Vol. 12, Nos. 7/8, pp.830-848. 'European Biotech 96, Volatality and Value', (1996) Ernst and Young's *Third Annual report on the European Biotechnology Industry*, p.56.

++ 'Directory of biotechnology industries and institutions in India 1994-1995', Biotech Consortium India Ltd., Kundan House, 16 Nehru Place, New Delhi-110 019. Dattareyulu, M. (1995), 'Good scope in thrust industries', *Business Line*, 16 June.

An often used indicator of the commercialization of research is patent data. However this is not a credible indicator with respect to Indian biotechnology because of a number of factors. Patenting at the national level is rarely undertaken as most R&D is at the engineering level, and constitutes tacit knowledge that cannot be patented. The intellectual property regime is not well defined, and it is both difficult and costly to settle patent disputes in court. Therefore the benefits from patenting are not clear. Patenting at the international level is too costly for most Indian units. Nevertheless, an examination of the existing data on patents obtained at the international level, as given in the Derwent Biotechnology Abstracts, reveals interesting facts. There are 16 patents that are linked with India. Out of these, one is a patent obtained by the Indian Council of Medical Research, 11 patents are attributed to US or European multinationals and four to Japanese firms. Some of the patents taken out by the foreign companies involve products that have either been obtained from extracts of Indian soil, Indian plants or Indian insects, or have been tested on Indian patients.

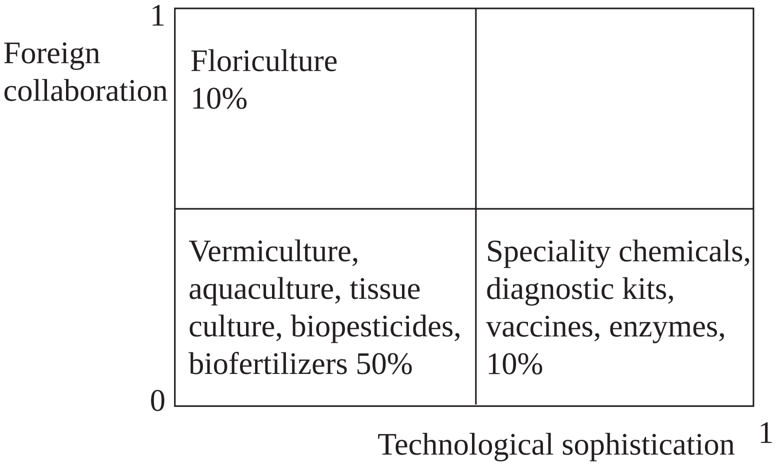
Another plausible indicator of the commercialization of science is the number of firms created by researchers from public labs. If we take this as a benchmark, then as Table 1 reveals, India's weakness is not in scientific competence but in commercialization of science for industrial use or sales.

6 Industrial competence in biotechnology

It is difficult to assess the number of companies active in biotechnology since it covers various sectors and there are large discrepancies in existing assessments. According to the *Research Profile of Biotechnology Activities in India 1993* published by the DBT there were only 47 companies active in biotechnology, 10% of which were equipment suppliers. The latest *Directory of Biotechnology Industries and Institutions in India 1994-1995* published by the Biotech Consortium India Ltd. (BCIL) indicates that there are 97 production units and 45 equipment suppliers. Of all companies active in biotechnology, the production units which are public sector companies form 22%, private sector companies that are publicly held form 24%, and private sector companies that are partnerships or privately held form 29%. However, fairly explicit information is given on only 69 of the production units. BCIL does not state what criteria it adopted to decide that a company is qualified to be included in its listing; the impression lingers that any company that sought to be included was included [15]. The *Biotech Industry Guide* released by the DBT details (without giving addresses or details) 459 units active in the biotechnology sectors. These discrepancies are indicative of a lack of coordination among high level agencies. But this phenomenon is not peculiar to India alone; barring exceptions like the USA and the UK, existing databases on most European countries are incomplete and contradictory, owing to the fact that biotechnology is an emerging technology with multisectoral applications.

Comparing some figures on firms in the biotechnology sectors, as in Table 1, it can be seen that in terms of the number of firms, India compares favourably with a European country like France. However, integration of biotechnology is better depicted in Figure 1, which maps the typology of firms in the Indian biotechnology sectors according to technological sophistication and degree of foreign collaboration. The percentages given are the estimates of the authors computed on the basis of the different sources of information.

Figure 1 Mapping of Indian biotechnology firms



A majority of firms are in vermiculture, aquaculture, or tissue culture. They include both new firms, and those that have diversified into this technology. Large firms in totally unrelated fields have also diversified into this field, (e.g. Cadilla, a pharmaceutical firm; Rallis, a major chemicals firm). One measure of development of industrial competence in this sector of biotechnology, is that every metropolitan city now has plant micropropogation centres where, five years ago, there were none. These firms use mostly indigenous technology to create their products.

Another sector that is not sophisticated technologically but is capital intensive is floriculture. It comprises some Indian firms such as Indo-American Hybrid Seeds whose technological competence is up to international standards. However, because of the capital intensive nature of this sector (greenhouses, air conditioning, etc.) it is also marked by the presence of foreign firms, predominantly Dutch and Israeli, which often supply the capital and plant cuttings. The flowers are grown in India and then flown to international markets. The future of this sector is not clear as the uncertain nature of the demand in international markets, and problems of commitment on the part of foreign buyers have led to a high failure rate.

Other sector products which are heavily affected by foreign collaboration are diagnostic kits, vaccines, enzymes and specialty chemicals. Some foreign companies sell their products through subsidiaries of their own companies in India without any form of cooperation with Indian firms, for example SmithKline Beecham, Boehringer, Hoechst, Eli Lily and NovoNordisk [16]. Others enter into a variety of cooperative arrangements as described below. We illustrate each type of collaboration with foreign companies with one example as we do not have sufficient data at this stage to do a comprehensive mapping.

- An Indian company may be created through minor or major equity participation of a foreign company. ProAgro seeds, which will be the first company in India to produce seeds using genetic engineering, is entirely financed and owned by Plant Genetic Systems (Belgium).

- An Indian company may obtain working capital via production contracts with a foreign company. Indo-American Hybrid Seeds started out by contracting its production to a US company.
- An Indian company may market the product of a foreign company. Wipro, one of the established firms in the computer industry, has created Wipro Med, a company that sells and services biotechnology-related equipment manufactured by Beckmann Ltd.
- An Indian company may enter into a strategic alliance with a foreign firm. Ranbaxy, the top pharmaceutical firm has entered into a joint venture with Eli Lily.
- An Indian company may buy technology from a foreign firm. Harrisons Universal Flowers Ltd., a leading floriculture firm, bought its technology from the French company, Meilland International.
- Finally there are a few Indian firms, including some new firms that have been created by Indian researchers, which have produced or are in the process of producing products using modern biotechnology techniques and Indian expertise. They include Bangalore Genei (specialty chemicals), Ranbaxy (diagnostics, vaccines), Span (diagnostics), Malladi Drugs (new chemical entities).

It is clear that there are substantial gaps between the USA and countries in Europe that are late comers to biotechnology and between the latter and a developing country like India in the creation of industrial competence in biotechnology. This is most clearly illustrated by the following facts. Firstly, in the USA, both large and small firms are pursuing the creation of radical innovations (i.e. new products with a market value of more than $100 million). In most European countries (barring the UK) only the large firms are investing in the creation of radical innovations. Compared to this, in India, even the large firms are only pursuing independent development of existing biotechnology products that have been created by Western companies.

7 Explanation: resources, incentives and incentive responsiveness constraints

First and foremost, in developing countries there is a variety of resource constraints which constitutes bottlenecks for the integration of a new technology. Moreover, given their complementarity, when taken together, they also serve to lower *incentives* to invest in a new technology. For instance, in India there is a serious resource constraint in terms of the financial capital available for investment in research, both to the government and industry (see Table 1). The total expenditure on biotechnology research in India increased from $13 million in 1988 to $28 million in 1994 [17]. Private sector expenditure contributed 15% of the total R&D expenditure, reflecting the important role played by the government. Compared with this, under the French national biotechnology program Bioavenir alone (1992-1997), $58 million is spent annually, with about 62% coming from the private sector. Even this is dwarfed by the mammoth spending on biotechnology R&D by the USA, which for instance exceeded $5 billion in 1994, with industry contributing over 80%.

In India there is a shortage of scientists in general and in particular there is a shortage of highly skilled scientists with industrial experience in modern biotechnology techniques.

Indian scientists are familiar with rDNA and MAB techniques at the laboratory level. However, knowledge of the scaling-up process from laboratory level to a pilot plant level is often vague. There are few technicians with this knowledge in India. Some of the companies we visited were trying to recruit experienced engineers from abroad.

A scarce resource that is difficult to quantify is infrastructural facilities. A market exists for infrastructural facilities like water, electricity and land. Access to infrastructural facilities is obtained through licences that have to be bought from the local government body. But the cost of transactions is made higher, because they not only involve money, but also a time delay that depends on the personal networks of the buyer, and sheer luck.

However, a more serious problem is the lack of non-marketed infrastructural facilities like appropriate storage facilities at airports, phytosanitory certification facilities, cheap and fast transport, and a rapid customs evaluation, etc. which are essential for movement of most fragile chemicals, plants and other micro-organisms. At present, the industrial lobbies are applying pressure on the government to ameliorate these regulations and facilities.

As mentioned earlier, the commercialization of innovations in a new science-based sector is a collective process that depends on the existence and functioning of networks between a variety of institutions and agents in the economy. In developing countries like India, the absence of the relevant networks constitutes one of the biggest constraints, lowering the *incentives* for integration of the new technology.

Firstly, the number of financial institutions that are supposed to invest in a new technology is extremely limited and even 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 BCIL as a public company in 1990. It was set up jointly by the DBT, 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 play a role in guiding start-ups, arranging technology transfers and supporting their efforts to find finance. To date they have been involved in fund syndication for three companies, a technology scale up of one project, packaging technology for three projects, and transfer of technology from laboratories for six companies [18]. 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 as a selection mechanism playing the role of venture capitalist, has been rather limited.

Secondly, university-company links are very weak. There is very little pressure or encouragement for public researchers to commercialize their research findings. It is only recently that the CSIR labs had to earn a third of their annual budget through research contracts with outside bodies. This year ICAR researchers were authorized to fund projects with private money. On the other hand, patents cannot be taken out by individual researchers. A patent must be taken out by the laboratory with the name of the individual researchers being mentioned. Scientists can offer their services for consultation and can also licence out processes to private industry but most of the revenue so generated goes to the laboratory. For instance in the CSIR, the researchers are only allowed to keep 16% of the revenue generated from an R&D project. Even then, the maximum they can retain is approximately $3,300 per annum.

To illustrate the extent of this problem, in Table 2 we list the technologies that were reported to have been transferred from public labs to firms [19]. It should be noted that out of the 63 centres of public research listed in the BCIL directory, only seven are included in the list. Out of the 101 academic institutions, only two universities have transferred technology to a private firm. Interviews revealed that only five of the given technologies are being manufactured now or are scheduled to be manufactured in the future. The reasons given for failure of commercialization ranged from unreliability/poor quality (2,4,5,9,10,16), and availability of cheaper substitutes (6,7,8,15), to problems in upscaling (13).

Table 2 Transfer of technology to the private sector

	Laboratory	*Product developed*	*Firm to which transferred*
1	National Institute of Immunology	diagnostic kit for liver abscess	Cadilla labs
2	National Institute of Immunology	diagnostic kit for blood grouping	Cadilla labs
3	National Institute of Immunology	leprosy immuno modulator	Cadilla labs
4	National Institute of Immunology	diagnostic kit for hepatitis B	Lupin
5	National Institute of Immunology	diagnostic kit for typhoid fever	Lupin
6	National Institute of Immunology	pregnancy slide test	Ranbaxy
7	National Institute of Immunology	animal birth control injection	Karnataka Antibiotics and Pharmaceuticals Ltd
8	National Institute of Immunology	pregnancy DOT-ELISA	Ranbaxy
9	Mahatma Gandhi Institute of Medical Sciences	diagnostic kit for filariassis	Cadilla labs
10	Rajasthan Univ	novel peptide from bitter gourd	Lupin labs
11	Central Drug Research Institute	diagnostic kit for Leishmanissla	Span diagnostics
12	Central Drug Research Institute	phenyl acetyl carbinol from benzaldehyde	Altus Labs
13	CFB (Centre for biotech)	F-MOC derivatives of amino acids	Atul products
14	Institute of Microbial technology, Vittal Malaya Scientific Research Foundation	osmotolerant and high alcohol tolerant yeast strain	United Breweries, Bangalore
15	AIIMS	detection kit for typhoid fever	Ranbaxy
16	University of Delhi	bamboo by tissue culture	Tata Energy Research Institute
17	University of Delhi	monoclonals to M13-phage proteins 3 and 8	Pharmacia Inc, USA

Thirdly, there is very little cooperation or networking between firms themselves to aid the creation of innovations. Large US and European firms have a complex web of strategic alliances with other large firms, NBFs, and public laboratories for the creation of innovations [20]. The slogan is 'collaborate with your competitors' on pre-competitive R&D because the research involved is too costly and too risky for a single firm to undertake alone. Indian firms are distinct from their Western counterparts in commercializing innovation either through direct purchase of foreign-made products, or technology, or development in-house. To date, research consortiums between Indian firms are non-existent.

Fourthly, in India, strategy formulation for high-tech industries tends to be a government perogative undertaken without adequate consultation or collaboration with the private sector. In India, the initiation of biotechnology and the subsequent strategy formulation for its development were carried out by government bureaucrats without the participation of industrialists. The NBTB was a board made up of top bureaucrats [21].

To identify research areas, generate projects, select and recommend financial support for projects, and to monitor the progress of research, the DBT began setting up task forces which today number 16. According to available information, during the first four years (1986-1990) there were no representatives either from the private or public sector industrial enterprises in any of the task forces.

8 Conclusions

The main intention of this article was to affirm that the integration of a new science-based technology like biotechnology depends crucially on three features of the national system of innovation:

- resources;
- incentives to invest in the new technology; and
- the responsiveness to existing incentives of any unit in the national system of innovation.

These determine the extent to which new scientific ideas are generated, transformed into useful technology, and integrated in the production process of firms. Through a case study of India, it was shown that returns to investment in biotechnology are constrained not only by resource bottlenecks, but also by incentive problems.

In India, although public research is funded by the government, its quality is not controlled by the government. It functions under an *incentive system* that does not recognize and adequately reward merit and has no system of accountability. Therefore it fails to generate a dynamic competitive environment that is essential for the maintenance of high standards and generation of new ideas. A real absence of any system of accountability leads to *low responsiveness to incentives* of public research institutions, and gives rise to a reluctance or inability to learn new competencies on their part. In India, scientific competence in biotechnology has been mainly created through the establishment of new academic institutions. It is the new institutions (besides a few elite academic and research institutes) that are the front runners in India, both in terms of scientific publications and transfer of technology to the private sector. The Indian government has not been able to reform the existing public research system, as some developed countries like France have done, to incorporate new scientific competence in existing institutions on an extensive scale. Such institutional inflexibility increases the real costs of creating scientific competence in new fields.

Selection of scientific ideas for possible commercialization is carried out by large firms and by the state. Scientists find it difficult to create companies and any transfer of technology is further hampered by the weak links between public research and industry.

Smaller firms face financial constraints and venture capitalists are not very active. Since selection is based on known routines, only ideas that are deemed profitable and low risk are pursued. These resource and incentive constraints have resulted in the majority of firms being 'low technology' firms focusing on labor intensive and 'routinized' techniques in the biotechnology sectors.

Thus a possible inference from this case study is that the technology policy of developing countries should not be concerned with '*how much to allocate to a new technology*' alone. It should also look at '*how to transform scientific competence efficiently into industrial competence*'. Developing industrial competence in a new science based sector is a complex process because it needs coordination of effort from a variety of agents and institutions. In such cases, the technology policy of developing countries has to aim both at optimal allocation of resources and also maximization of returns to any investment through the construction of appropriate incentives. This calls for institutional reform. The stakes involved in effectively implementing appropriate strategies are made even higher in view of the fact that all developing countries which have agreed to conform to the GATT-WTO norms will be prohibited from replicating radical innovations created by Western countries once their period of grace in terms of transition is over.

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References and Notes

1 By modern biotechnology techniques we refer to a set of techniques such as genetic engineering, cell and tissue cultures, protein synthesis and enzymology, involving manipulation of the genetic patrimony of an organism, which have emerged from recent developments (since 1975) in the biological sciences such as biochemistry, biophysics, molecular biology, microbiology, cellular biology and genetics.

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21 The NBTB was initially headed by M.S. Swaminathan. The other six members included the secretaries of the Departments of Science and Technology, Agriculture, Health and Family Welfare and the Director general of ICMR, ICAR and CSIR.