Brain Drain, Brain Gain and Scientific Communities: Indian Experience in the Field of Biotechnology

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Introduction

Ever since the developing countries embarked on building modern scientific and technical structures, the problems associated with the process of brain drain became a stumbling block in building local-national S & T capacities for development in many emerging fields of research. Beyond the material and economic factors, on which studies have thrown ample light, there are sociological factors related to the social organization of science and technology which influence the migration of scientists from their countries. Training scientists in high tech and frontier fields of research without the existence of a certain viable number of research groups or specialist communities (in a sociological sense of the term), in the first instance, results in the migration to places which offer a better professional climate and which have created a demand for intellectual capacities. As one of the leading Indian chemical scientists, Masheikar (1984) observed, “the brains go where the brains are. Brain goes where there is a challenge and brain goes where intellectual achievements are valued”. The status of scientific communities and the professionalisation of science and technology fields of research is closely associated with the phenomena of brain drain and brain gain - the features being the two faces of the same “ coin ”. In other words, the promotion and growth of specialist communities with a viable number of research and development groups in a given area of science not only checks the process of brain drain but given the professional climate and an intellectual context generates the potential to attract the return migration of scientists back into their home countries. This is the hypothesis which is explored in this paper taking the field of biotechnology as an empirical case study.

Beyond the central focus of the concept of scientific communities and professionalisation in understanding the problem of brain drain, the perspective of “ networks ” is also used to map the structure of biotechnology field for its research-academia-industry-market connectivities. It is seen that this network emerged in three stages over a period of two decades. As else where in the world the emergence of biotechnology industry in India is seen to have created a demand for absorption of scientific and technical personnel. Even here it was seen that the part played by the science -research- academia nexus and the process of professionalisation remained central in the formation of the network. The paper is structured into the following sections :

- Institutional background to biotechnology prior to 1980
- Emergence of biotechnology after 1980 : Government support, university courses, information networks, funding and the creation of Department of Biotechnology
- Growth of post graduates and Ph. Ds
- Features of professionalisation and Scientific Communities
- Towards biotechnology network
- Concluding remarks

Institutional background to biotechnology prior to 1980

In an effort to trace the institutional growth of biotechnology during the last decade, it is necessary to understand the status of modern biology. As some reviews suggest, the development of biotechnology has been closely related to that of basic modern biology, which includes disciplines such as biochemistry, molecular biology, cell biology, immunology, genetics and, virology, many of which envelop substantially with others (see Bhargava and Chakrabarti 1991 : 515). Even though India witnessed considerable growth of professional research groups and institutional specialities in these areas of modern biology during the period late 1960s and late 1970s, biotechnology as a specialized field of activity with recognizable community did not emerge till the early 1980s (see Padmanabhan 1991 : 510, 51 1). The nuclei for the development of modern biology in the pre-1980 era can be located in about eight research centres at Bose Research Institute, Calcutta (led by D. Burma) ; Christian Medical College, Vellore (led by B. Bachawat and A.N.Radha Krishna) ; Tata Institute of Fundamental Research, Bombay (led by Obaid Siddiqui) ; Indian Institute of Chemical Technology, Hyderabad (led by P.M.Bhargava) ; All India Institute of Medical Sciences, New Delhi (led by G.P. Talwar) ; Indian Institute of Science, Bangalore (led by G.N.Ramachandran and P.S.Sarma) ; National Chemical Laboratory, Poona (led by M. Damodaran and V. Jagannathan) ; and Department of Applied Chemistry at Calcutta University, Calcutta (led by B.C.Guha) [1].

From the mid 1970s, various post graduate departments in modern biology were established in the universities including the medical colleges and agricultural universities. Two professional societies which strengthened the modern biology research groups from the 1960s are - the Society of Biological Chemists of India (established in 1931) and the Guha Research Conferences (established in 1961). Between 1960 and 1980 various journals were launched in the areas related to modern biology as shown in table l :
The establishment of a specialised national laboratory - Centre for Cellular and Molecular Biology (CCMB) in 1977 in Hyderabad under CSIR followed by the creation of National Institute of Immunology at New Delhi ; and Institute of Microbial Technology at Chandigarh were significant milestones for the discipline of modern biology. In many ways these institutes catalysed the institutional growth of molecular biology and biotechnology from the latel970s.

With the moderate growth of modern biological research groups in over a dozen institutions, the elite biologists became receptive to institutionalize the field of biotechnology, which made revolutionary strides by that time in the west. As one of the leading biologist observed :

Some of us did recognize that we were going soon to start living in the age of biotechnology as far back as the early seventies by which time the technique of tissue culture was well establi-

Table 1. Some of the main Indian journals in modern biological launched after 1960

Year	Journals
1961	Indian Journal of Microbiology
1963	Journal of Experimental Biólogo
1966	Journal of Cytology and Genetics
1968	Indian Biologist
1971	Indian Journal of Mycology and Plant Pathology
1972	Journal of Agriculture Biology
1975	Advances in Pollen and Spore Research
1977	Biological Memoirs
1978	Cell and Chromosome Research
1979	Journal of Biosciences
1979	Journal of Environmental Biology
1985	Annals of Biology
1986	Journal of Microbial Biotechnology
1986	Indian Journal of Applied and Pure

shed and it was possible to transfer new (but only homologous) genetic information into micro-organisms through conjugation, transduction, transformation and later, transfection. Those who were guiding the destiny of science in the country around that time were fortunately receptive to these ideas.... (See Bhargava and Chakrabarty 1991 : 515)

Our survey of 13 research groups for the period before 1980 shows, that more than 60 % of the leading scientists working in the areas related to modern biology obtained doctoral and post-doctoral training in the west or spent between 3-5 years abroad before taking up positions in India. International connectivity for modern biology with labs and elite in the west was very strong during this period. Even though most of the Indian universities and research institutions offered doctoral research programs in the biological sciences, specialities *related to* biotechnology lacked higher professional base in India during the 1960s (jpto mid 1970s). In other words, there was a considerable professional gap between India and the west which made the west a natural destination to the highly motivated professionals. As the data of Gulati (1990 : 200) shows, between 1965 and 1979 an average of 91 doctorates were awarded every year to Indian graduates in life sciences from the U S universities. This figure declined to 42 doctorates every year after 1980. Beyond the immigration policies, one explanation for the decline of this trend in the number is related to the marked growth of modern biology fields in Indian institutions. Among these, the fields of biotechnology and molecular biology witnessed considerable institutional growth.

The emergence of a recognizable community and institutional growth of modern biology specialities during the late 1960s and 1970s enabled the promotion of biotechnology and molecular biology after the early 1980s. What is the institutional growth scenario of biotechnology field after 1980 ? How many research groups and specialized institutions were established during this period ? What was the role of government in fostering this field of research including higher education ? What is the relationship between the professional growth of the field and the problem of brain drain or gain ? These are some of the issues which will be addressed in the upcoming sections.

Emergence of biotechnology after 1980: Government support

As in the case of many developing countries, the state support to science and undertaking of research in publicly funded institutions has been the dominant feature of science and technology growth in India in the post-independence period. Biotechnology and its related areas of research has been no exception to this general historical trend after 1980. Given the considerable growth of modern biological research base, as seen in the preceding section, the demand for the promotion of biotechnology received considerable support from the biological community from the late 1970s. In response to this growing demand for this promising area of research, the Prime Minister announced the government’s decision create a National Biotechnology Board (NBTB) on 3 January 1982 at the 68th Annual Session of the Indian Science Congress held at Mysore. This was indeed a significant milestone in the formation of a biotechnology policy in the country in comparison to other policies relating to nuclear, space, electronics, telecommunications, agriculture, ocean development, energy etc. This Board was constituted by a high powered committee chaired by the head of the Science Advisory Committee to the Cabinet. Other members of the Board were at that time drawn from the Departments of Science and Technology, agriculture, atomic energy, CSIR, ICMR, University

Grants Commission and the Finance Ministry. The Board had the services of a full-time advisor who was also its Member-Secretary. As the review of Swaminathan (1986 : 300) indicates, the mandate of the newly created biotechnology Board covered the entire gamut of activities ranging from the financial support, support to higher educational training and research, coordination with other relevant science agencies and institutions, procurement of chemicals and equipment for the professionalisation of the field, training of human resources, exchange of experts with foreign laboratories, support to workshops and international meetings etc.

Realizing the revolutionary growth of the field in the west and the industrial potential to generate wealth, the elite biological community soon realized that a Board is an inadequate structure to usher the potential of this field in the country. Without wasting much time the government responded by reconstituting the NBTB in 1986 as a separate Department of Biotechnology with a status at par with other science and technology related Departments as mentioned earlier. This was the second milestone in the evolution of a biotechnology policy in the country. As Ramachandran (1991 : 518), the first head of this newly created Department, observed :

The two areas on which the new Department of Biotechnology (DBT) initially concentrated, in continuation of the earlier emphasis by NBTB, were manpower development and creation and strengthening of infrastructural facilities. The objective was to build up trained manpower and general competence in the field of biotechnology.

During the early 1980s, the overall expenditure on biotechnology research, development and training accounted for about 100 million rupees. During the mid 1980s this expenditure increased to 220 million rupees and from 1986-87 the expenditure further increased to about 350 million rupees per year. The current budget of DBT alone is about 700 million rupees per year. However, besides this figure, the field also attracts funding from other larger science agencies in agriculture, industrial research, medical, University Grants Commission and the Science and Engineering Research Council of the Department of Science and Technology which increases the total funding to the field at least two times the current budget of DBT per year.

In an effort to keep the scientists abreast of the advanced research and development in the fields of modern biology and related fields, the DBT has sponsored Distributed Information Centers (DICs) in 9 universities and R & D laboratories as shown in the Table 2. The provided through DICs to access the international data bases. In addition, fourteen user centres have been created in different parts of the country with access mechanism to make the information available at universities, laboratories and manufacturing institutions.

From the beginning the DBT laid high emphasis in sponsoring higher educational training in the area of biotechnology for the generation of adequate R & D human resources. From the early 1980s, DBT made available funds for institutionalising M. Sc/Ph. D and post-doctoral

Table 2. Information and Data Base Centres in biotechnology

Institution	Specialisation(s) in DICs
Indian Institute of Science	Genetic engineering
Madurai Kamraj University	-do-
Bose Institute	-do-
Jawaharial Nehru University	-do-
Poona University	Animal Cell Culture & Virology
Indian Agriculture University	Plant Tissue Culture; Photosynthesis; and Plant Molecular Biology
Centre for Cellular & Molecular Biology	Oncogenes: Reproduction Physiology; Cell Transformations; Nucleic Acid and Protein Sequences
National Institute of Immunology	Immunology
Institute of Microbial Technology	Enzyme Engineering

training in 28 selected universities and research institutions. As the report on the activities of DBT (see Ramachandran 1991 : 519) indicates, " selection (of institutions for support) was based on the strength of existing infrastructure and resource personnel, ongoing research programmes, proximity to other institutions working in the related areas ". In these selected universities, the DBT funded new faculty positions (about 3 to 4 positions on an average per university) during the last decade. In addition to the regular higher educational and research courses, DBT sponsored short-term training programmes in high-tech specialised areas, technical training programmes for industrial R & D personnel and diploma courses to train the technicians required for the biotechnology industry. According to one estimate, about 1800 personnel were trained during the last decade in the latter type of training courses.

Growth of post-graduates and doctorates in biotechnology

190 universities in India produced a substantial number of post-graduates and doctorates in the fields *related* to biotechnology during the last decade [2]. To have an idea for the recent period, India produced 259,142 and 515,486 post-graduates for 1989 and 1992 respectively in different fields *related* biotechnology. For the same periods, Indian universities produced 28,904 and 33,684 doctorates respectively. These included life sciences and chemistry. Further, in the fields directly related biotechnology Indian universities procured 2424 (biochemistry) ; 804 (applied biology) ; 10 (biophysics) ; 25 (molecular biology) 54 (molecular biophysics) ; 125 (genetics) and 322 (microbiology) doctorates for the year 1992.

In so far as the field of biotechnology alone is concerned, Indian universities produced 1017 post graduates (ie M. Scs) and 107 doctorates for the year 1991-92. It is estimated that these numbers will increase to about 2156 (for post graduates) and 96 (for doctorates) for the year 1996-97. For the data available for 1986-90, a report on the manpower analysis for biotechnology indicated that out of 276 post graduates, 100 (36 %) were employed in the Indian industry or research institutions and 176 (64 %) went abroad for pursuing Ph. D courses. What is also worth noting here is that before 1986 the percentage of neophytes in biotechnology and closely related specialities such as molecular biology who went abroad for higher professional training might be placed at as high as 80 %. With the rapid institutional and higher educational base from the mid 1980s, the percentage of post graduate students going abroad has come down to about 40-50 % for the last few years. Given that India produces substantial number (over 2000 M. Sc's per year for the current period ; and 1200-1300 per year during the last five years) of biotechnology students every year, what is important behind these numbers and statistics is the ability of the country to retain a substantial number (i.e. about 50 %) of the intellectual work force ; and at the same time attract a potential number of trained Indians in the area from abroad. This feature emerges from our porsopographical survey of leading biotechnologists and molecular biologists in the university and national laboratories centres shown in Table 3. This survey indicated that in the leading biotechnology and molecular biology centres such as Nil, CCMB, NCL and at the university departments at Poona, Madurai Kamraj University, Delhi, Baroda, among others, more than 75 % of the leading scientists (responsible for the creation of research centres/departments) have spent between 3 and 5 years abroad mainly in western Europe and North America before taking up responsible positions in India [3].

Not withstanding the personal and nationalistic reasons there are professional reasons and features related to the local/national growth of specialities which checks both the processes of " potential " brain drain and brain gain. This being the sufficient condition, there are other sociological features (considered as essential conditions) relating to the concept of scientific communities. We will explore these in the next section.

Features of professionalisation and scientific communities

Biotechnology is generally defined as the " application of science and engineering principles to the processing of materials by biological agents to provide goods and services " (see Mani 990 : M-1 15). What is also recognized is the feature that the fostering of biotechnology is closely related to various basic science specialities such as molecular biology, biochemistry, microbiology, chemical engineering, genetics etc. In other words, without a strong professional base in these basic science areas, the application and commercialization of biotechnological processes are difficult to emerge and sustain. This feature is reflected from the Indian experience. Though the Indian basic research base in the conventional biological sciences can be traced to the turn of the present century, creation of basic research base with recognizable research groups in the disciplines of modern biology (excluding biotechnology) took place during the late 1960s and 1970s. It is only after the growth of modern biology specialities during this period, the specialist community created a demand for fostering the field of biotechnology [4] which is intimately connected to molecular biology. As Balram and Ramasehan (1991 : 509) in their introduction to the special issue of *Current Science* on " Biotechnology in India observe ",.research in molecular biology also promises many practical dividends. Crop improvement in agriculture, development of vaccines and diagnostic procedures for parasitic diseases, and even the prospect of rational drug design are some areas of special relevance in India ". As shown in Table 3, over 28 leading R & D centres emerged during the last 15 years. Almost all these groups emerged from the centres at universities and national laboratories which had earlier established a basic research base in different areas of modern biology. For instance, the specialized National Institute of Immunology at New Delhi under the leadership of G.P.Taiwar developed several immunodiagnostics, anti-fertility and leprosy vaccines. The institute has an extensive programme on embryo biotechnology; the Centre for Cellular and Molecular Biology at Hyderabad is now recognized as the key centre for DNA fingerprinting techniques; the Biochemical Division at the National Chemical Laboratory at Poona evolved novel methods for tissue culture propagation and plant biotechnology; and the Institute of Microbial Technology at Chandigarh has developed processes for industrial fermentation, genetic engineering and new method for enzyme conversion. As one of the leading Indian molecular biologist observes, " from almost a zero level in the early 1980s, we now have at least two dozen laboratories where good recombinant DNA expertise is available. At the technology level, the successful demonstration of embryo transfer in animals; development of antigen-antibody-DNA-based diagnostics; RFLP analysis and DNA fingerprint analysis; and the cloning of a variety of genes attest to a high level of competence in modern biotechnology " (see Padmanabhan 1991 : 51 1).

As shown in Table 1 about fourteen specialist journals in different areas of modern biology were launched from early 1960s upto mid 1980s. The launching of a *Joumal of Microbial Biotechnology* in 1986 can be considered as an important milestone in the professionalisation of biotechnology in India. The publications in biotechnology can be seen in Table 5.

Among the two professional societies viz., Society of Biological Chemists and the Guha Research Conferences (GRCs), the part played by the latter in catalysing the professional growth of specialities (including biotechnology and molecular biology) in modern biology has been quite noteworthy [5]. From 1965 members of the GRCs meet every year and the presentations in this meeting mainly deal with the cutting edge of modern biological sciences. It has a membership of about 100 leading scientists but invites scientists and technologists in the forefront of the biological sciences to discuss their work. presentations in the annual meetings of GRC are considered as a recognition of' some considerable standing by the neophytes in the biological sciences. There is no formal hierarchy and permanency in the membership. Irrespective of the position of a member, the professional body suspends the membership if the person had not participated in annual conferences for three years. The GRC members are considered as the biological elite in the country and some of its leading members (numbering about 20) have been responsible for guiding the growth of modern biology, particularly biotechnology and molecular biology in India (see table 4). GRC can be considered as an " invisible college " in biological sciences, which over the last three decades, brought the leading modern biologists under a single platform and at the national level it provided a sense of community and intellectual pride. Besides the GRC and the Society for the Biological Chemists of lndia [6], there are several small informal networks and discussion groups.

Organizing international workshops and conferences in the areas related directly to biotechnology growth has been another feature of professionalisation, particularly, in bringing the leading biologists from India and abroad together. For instance, as P.S.Sarma who organised the first summer school of biochemistry in India in 1962 at Srinagar observed, " I arranged the proceedings with two main objectives ; firstly to cover the important recent developments in the subject and secondly to bring together active research workers in the country to have an exchange of ideas of mutual benefit by interaction and unhurried discussion " [7] Over the last two decades, as the review of Burma (1992) indicates, 18 national and international professional workshops and symposiums were organized by the leading biologists in India. These eighteen professional meetings are noteworthy in the sense that they were intellectually structured high level meetings. For instance, P.M. Bhargava organised first symposium on " Nucleic Acids structure, biosynthesis and function " in 1964 at the Regional Research Laboratory, Hyderabad. Nobel Laureate Francis Crick participated in this symposium along with other leading biologists in the world at that time. As Burma (1 992 : 221, 222) notes, the publication that came out of this symposium, " is perhaps the first written record of the advent of molecular biology in the country ".

Another example of high powered symposium is the one organized by G.N. Ramachandran in 1978 at the University of Madras on " Biomolecular structure, confirmation, function and evolution ". This meeting was chaired by the Nobel Laureate Dorothy Hodgkin and participated by another Nobel Laureate Severo Ochoa. Some of these workshops and symposiums not only strengthened the international connectivity to Indian molecular biology and biotechnology, but in varying ways played a catalysing role in strengthening and inaugurating the formal research groups in these areas in the national laboratories and universities.

If the higher training (i.e. production of M.-cc graduates and Ph. Ds) is taken as one of the indicators for the professional growth of a field - then the biotechnology during the last decade demonstrates moderately good results. Beginning with 220 M. Sc students and 40 Ph. Ds per year in the early 1980s, the figure increased to 1017 M. Sc students and 107 Ph. Ds per year in the early 1990s. As noted in an earlier section, this figure is estimated to reach 2156 M. Sc students and 96 Ph. Ds per year for current period.

The spin off from the professional growth of biotechnology and closely related fields of research has been the expansion of biotechnology industry in the country. Recognizing the growing status of the biotech industry in the areas of chemicals, drugs, agriculture, medical and health, diagnostics etc., the DBT in collaboration with financial institutions like Industrial Development Bank of India and the private sector companies set up an organization called the Biotech Consortium India Ltd (BCIL) in 1990. The major objective of this organization is to facilitate the transfer of biotechnology processes into the industry and aid its commercialization. There are over 175 biotechnology industries in India, of which 160 are in the private sector and 15 in the public sector [8]. As pointed out earlier, 36 % of the trained postgraduates were absorbed into the indian industry and institutions for the period 1986-90. The future expansion of biotechnology industry is likely create a further demand for the absorption of trained scientific and technical personnel in India. With the expansion of the biotechnology industry and the professional competence in the field, some multinational corporations have entered into the Indian market by setting up research and development units and as well as began commercial operations from India. In this growth of biotechnology industry, the role of basic research groups in the national laboratories have been remarkable in the recent years. For instance, the Swedish giant A.B. Astra group had set up a laboratory in Bangalore in the field devoted to biotechnology in collaboration with the molecular biophysics group at the Indian Institute of Science. Similarly, the National Institute of Immunology at New Delhi has been an active partner in the development of a lndoFrench venture for the production of vaccines. Based on the anti-fertility vaccines developed at this institute, the group had collaborated with the Karnataka state public sector unit for its commercial production.

Without the sustenance of a research and higher technical training base, the inputs to the growing biotechnology industry was not possible. But when we consider other crucial features behind the professional sustenance of this field over the last 15 years, one more feature stands out clearly. From a sociology of science perspective this relates to the concept of scientific communities [9]. Beyond the growth of numbers, the emergence of scientific communities or specialist groups in a particular speciality signifies the emergence of intellectual climate (i.e. professional societies, journals, conferences and workshops and informal networks of communication), leadership and its role in the institutionalization of the field including giving a direction, university courses and chairs involved in producing neophytes in the field, political and economic legitimacy to ensure state funding, a viable number (say 5 to7) of research groups working in the field at the frontiers and basic research level which have certain degree of national and international recognition, a system of rewards and recognition which provides motivation for the scientists, mobility of scientific and technical personnel and above all a pattern of international scientific connectivity with global elites and related community of specialists. We have already thrown light on some of these aspects and the limited space do not permit to explore all the features here. However, we will deal with some features such as the intellectual leadership, international connectivity and the major workshops which propelled the basic area of molecular biology.

The Table 4 shows some of the leading scientists in modern biology who were responsible for the institutionalization and professionalisation of biotechnology in the Indian universities and research institutions [10]. In many centers the initial leadership given by the leading scientists in the previous decades has given rise to the second generation of leadership. For instance, the pioneering work done by G.N. Ramachandran on triple helical structure of (who is considered as the father of Indian molecular biology) led to eminent groups in molecular biophysics at the University of Madras and Indian Institute of Science in the 1960s and 1970s. The second generation of leadership at the Indian Institute of Science after the 1970s is led by Sasishekharan, G. Padmanabhan and P. Bairam. Similarly, the initial leadership given by P.M. Bhargava in the creation of more than five groups in molecular biology at CCMB is led by others like Laiji Singh, Balasubramaniam, C.R. Dass and others.

As Table 4 indicates, many of the pioneers who were responsible for the growth of the biotechnology and molecular biology centers are connected with the foreign research groups and laboratories in North America and Europe. Personal interviews conducted with leading scientists reveals that much of their interaction, mobility and communication takes place with the relevant research groups and individual elites abroad than in India. It is also revealed that the dominant mode of foreign connections of the Indian centres and elites, also have a bearing on the Ph. D students [11]. It is estimated that these Institutions (identified in Table 4) account for 600110 of the Ph. Ds and post doctorates produced in India during the last decade. Out of this, about 50 % of doctorates go abroad. Rough estimate is that the 40 % of the people going abroad for doctorates do return back, mostly to the institution of their higher training. The interview data with the leading scientists also reveals a very week interaction between different research groups/institutions within India compared to the links abroad. This is also followed by a weak process of mobility of scientists and inter-lab/institution collaborative projects between different institutions within the country. It is here that the “ invisible college ” like the Guha Research Conferences plays an important part in bringing the leading Indian scientists under a single platform and gives a meaning and a sense of national community. To what extent such professional networks and societies makes good of the weak interaction process between different groups within the country remains to be explored further.

Towards Biotechnology Network

Following Callon and Thomas Hughes and others, the perspective of networks in its varying forms been used by the STS studies. Drawing from the works of Callon et. al (1 990), a network is said to be operating when the links between the *Poles* of science, technology and the market are established ; and when there is a multiflow of information and sharing of resources for the constitution and production of novel knowledge, methods, products and services etc., by different poles of the network. As shown in figure 1, two additional Poles namely, the government pole and the international scientific community pole are included here compared to the original schema give by callon et al. Some salient features in the growth of biotechnology network in the Indian context are as follows :

i) Socio-historical growth of biotechnology network during the last few decades from 1960s to 1990s has progressed in mainly three phases : 1960s to late 1970s ; the period from 1980 ; and the period from the late 1980s. These phases by no means are watertight compartments ; they are only distinguished for analytical reasons. Whilst the first two phases are closely intertwined in their historical progression ; the third phase evolved distinctly from the late 1980s. It may be noted that the first two phases progressed in parallel from the 1980 ; and similarly all the three poles progressed in parallel from the late 1980s.
ii) The first phase (1 960s to late 1970s) reflects the institutionalisation and professionalisation of basic modern biology specialities relevant to the emergence of biotechnology as dealt in the first section. During this phase the institutions and research groups were constituted and this phase signifies the development of the *science Pole* relevant to biotechnology. As noted in the earlier sections (2 and 4), the international connectivity (another pole) of Indian scientists played a significant part in this process. More importantly, the science pole during this phase gained considerable politico-economic and scientific legitimacy for fostering the new field of biotechnology.
iii) The Second phase (from 1980) marks the emergence of biotechnology as a specialised field of activity in the Indian context. Towards the constitution and growth of this field, *three main actors or poles* were responsible. These are the *government* (creation of the Department of Biotechnology which ensured state funding), the *academia* (university chairs, courses in higher education and the development of relevant infrastructure etc.) and the *research and development* centres or *technology* pole (both in the universities and the national laboratories). The major feature during this phase as dealt in section 4 was the constitution of specialist groups in biotechnology numbering more than 28 ; and the establishment of specialised national laboratories devoted to this field or research and development activities. In this the part played by the poles of the first phase have been considerable.
iv) The third phase, which began from the late 1980s, signifies the emergence of a *market pole* with close interconnections to science. *academia. technology* and government poles. A good

example is the collaboration between the molecular biophysics group of the Indian Institute of Science and the Astra Research Centre India (subsidiary of the Swedish pharmaceutical MNCA.B. Astra) for the development of technological processes and products in the field of biotechnology which are commercially viable. Other examples are the new public and private sector companies in biotechnology which emerged with a close nexus with the academia and research groups. Rather many companies have emerged due to the work done in the national laboratories and academic units.

v) It is seen that the biotechnology network is overbearingly dependent on the basic research pursued in the relevant specialities of modern biology and it is here the relevance of scientific communities and the process of professionalisation assumes importance for its efficient functioning and sustaining linkages with the market pole.

vi) In the constitution of biotechnology network, the second stage particularly the establishment of research and development pole is seen to be associated with the problem of brain drain. In other words, a network with a strong research and development pole stands to check the process of brain drain and to some extent attract the return migration of scientists. However, to sustain the production of human resources from the academia it is essential that the market pole is developed to a considerable extent.

Concluding remarks

Going beyond the quantitative and input-out analysis vogue in the perspectives dealing with international scientific migrations, the present study sought to focus on the sociological perspectives, in particular, sociology of scientific communities and networks to explore the problems underlying the phenomena of brain drain and brain gain. The study is focused on a frontier speciality of science and technology - the biotechnology field in the Indian context. In this framework, the main question which concerned the empirical study is : What is the relationship between the concept of scientific communities and professionalisation of science with the problem of brain drain and brain gain ?

The exploration on the growth of biotechnology field in the Indian context lends considerable support to the hypothesis that the institutionalisation and growth of specialist communities over a period of time has a direct bearing on the problem to check the process of brain drain. what is also clear from this study on biotechnology is, it is not just sufficient to create institutions of research and higher training by inducing funds to foster a frontier field of science, it is essential that an intellectual climate is induced or created by the community concerned. What this entails is a certain viable number of research groups, university chairs and centres of higher learning with research infrastructure, professional societies or informal networks of collegiate pattern, local and national journals and above all sources of intellectual leadership who give a direction and leadership in the emergence of specialist groups and who can act as “ gate keepers ” to international connectivity in the relevant field of research. Closely embedded in this intellectual climate is the feature of professionalisation which points to a recognizable community or specialist groups who are involved in the fore front of the field and whose research contribution furthers the field with new frameworks, methods, areas etc. There are three aspects to this notion of professionalisation observed in the field of biotechnology in India. The first is the professional basic research base created in the areas directly related to the emergence of biotechnology in biochemistry, molecular biology, cell biology, immunology, genetics and virology. The second aspect is the underpinning of these basic stocks of knowledge for furthering the techniques and methods in biotechnology which related to genetic/protein engineering, enzyme engineering, hybrodoma, diagnostics and techniques of tissue culture - to name some prominent ones in which the Indian community developed recognizable competence. The third is the question of connectivities to the practical and production processes which are generally seen as the potential of commercialization and market development in the field of biotechnology.

Among these features, the growth of recognizable communities at the local-national level which sustain the field of research in terms of R & D groups is seen to be central to the process of professionalisation. As shown in the study, India began to embark on biotechnology from the late 1970s and more vigorously from the early 1980s. Over the last fifteen years or so, India witnessed considerable growth of the field in terms of R & D groups in the national laboratories and university departments. As Table3 shows there are over 28 centres where research groups in biotechnology have come up during these years. As indicated in this table on the position of fulltime equivalent research and teaching positions during 1982 and 1995, there has been a recognizable expansion of the centres and scientists or faculty positions. Whilst the research efforts of pioneers in modern biology gained tremendous political legitimacy for drawing the required funds for the institutionalisation and expansion of biotechnology, no less important was the part played by a governmental body - the Department of Biotechnology from 1982 in aiding the task of building the field of biotechnology in India. DBT not only sponsored post graduate and faculty positions during the last decade in about two dozen university departments but systematically planned to support programmes in various new facets of biotechnology. As one of the leading biophysicist commented, for a government outfit, DBT has been extraordinarily active, vibrant and forward looking' (See Padmanabhan 1992 : 541).

The point that trained intellectual human resources would have vanished without these specialised laboratories, leaders and R & D groups stands out glaringly in the Indian context. During the last half decade India is producing around 1200-1300 post graduates (ie M. Scs) and around 100 doctorates per year in biotechnology. It is seen that the country is able to retain about 50 % of the intellectual work force produced. Even though a significant percentage of this intellectual work force go abroad, the rate of return migration in the field directly related to biotechnology has not yet reached an alarming situation as reflected by several leading biologists. It is estimated that a high percentage (75 %) of the leading biologists responsible for the creation and strengthening the biotechnology related centres in India (see Table 3 and 4) have spent, on an average, between 3 to 5 five years abroad in one of the leading internationally recognized institutions in North America and Europe. This international connectivity in the growth of modern biology and biotechnology has been very strong during the last two decades or so. Interviews held with some leading members of the community reveals that the main reason influencing the decision of Indian scientists willing to come back to India in this field are the institutional growth of the field and a reasonable professional context created over the last decade. The return migration of established scientists and the strengthening of the field in the Indian context appears to be closely associated. As one of the leading molecular biologist recently commented, " with the development of several schools of molecular biology in different parts of the country and the return of a number of young enthusiastic, well trained molecular biologists from abroad the field of molecular biology is very rapidly widening " (see Burma 1992 : 224).

Since the growth of specialist groups and professionalisation were seen to have a bearing on the problem of checking brain drain, the factors sustaining the research groups assumes considerable importance. It is here the existence of invisible colleges like the Guha Research Conferences and the research communication channels such as the growth of local-national journals in the relevant field of biotechnology were also seen as factors related to the sustenance of research base and hence the problem of checking the process of drain.

From a sociology of science perspective, the feature of social organization of research groups was observed to have an important bearing on the sustenance of research groups. There are a host of factors in the ambit of social organization which relate us to the research traditions and excellence set by the pioneering leaders, the style of leadership, recruitment patterns, distribution of local-organizational rewards, avenues for mobility and participation in conferences etc. It was not possible to generate enough data to conclusively comment on these aspects in relation to the biotechnology field in this study but some interviews conducted with leading biologists reveal some insights. Tata Institute of Fundamental Research ; Indian Institute of Science ; Center for Cellular and Molecular Biology ; Madurai Kamraj University and the National Institute of Immunology are the five centers where the field of biotechnology and molecular biology witnessed considerable growth in terms of research groups and have gained recognition both nationally and internationally. The intellectual leadership and their recruitment patterns which laid emphasis on " selecting the best available talents in the country " principle appear to be the main factor. Another feature of the leadership in these national laboratories has been the emphasis on encouraging mobility of scientists to foster new ideas and arrest the process of " fossilization " in research.

India produces the largest number of post graduates and doctorates in the modern biological sciences compared to other developing countries. As noted earlier, a significant proportion of the trained personnel (about 50 %) go abroad and yet the Indian biological elite do not consider it as an alarming situation. Interviews held with some scientists reveal that since the west still dominates in the frontiers of molecular biology and biotechnology ; and that the developing countries continue to lag behind the west for many more years - India should evolve appropriate policies to tap this frontier constantly. The best way to do is to keep the outflow of scientific and technical human resources going but at the same time make efforts to bring back the potential ones back into the country. Even if the country is able to attract 15 to 20 % of the scientific " cream " every year from abroad, the scientists interviewed feel, it will give a good boost o the professional standing of the field. Towards mapping the biotechnology network between research, academia, industry and the market, three main phases are identified as dealt in section : 5 and depicted in figure 1. The way in which the network evolved over the last couple of decades from the disciplinary origins of modern biology in the late 1970s to constitute the poles of academia, R & D groups, government, international scientific community from the early 1980s to the evolution of biotechnology and industry pole from the mid 1980s - the network depicts an innovation or pipe line model of growth. Without the inputs from, and interconnectivities with, the basic research disciplines of modern biology - the biotech network could not have emerged. The industrial and the market segment of the network is highly knowledge intensive in that the pole needs recurrent inputs from the basic and applied research, on the one hand, and the academia (being a source of trained human resources) in modern biology, on the other hand. In other words, with the expanding biotech market, this segment of the network which constitutes about 175 enterprises (both small scale and medium size) is emerging as the main source of future employment for the skilled personnel. This segment also attracted foreign collaborations such as between the Indian Institute of Science and Astra India in Bangalore. Whilst the biotech network as a whole, from the mid 1980s, emerged to play a significant role in checking the problem of drain, the industrial segment has begun to attract Indian scientists from abroad in the 1990s. As in other areas and fields, there is a new category of scientist-entrepreneurs emerging in the field of biotechnology.

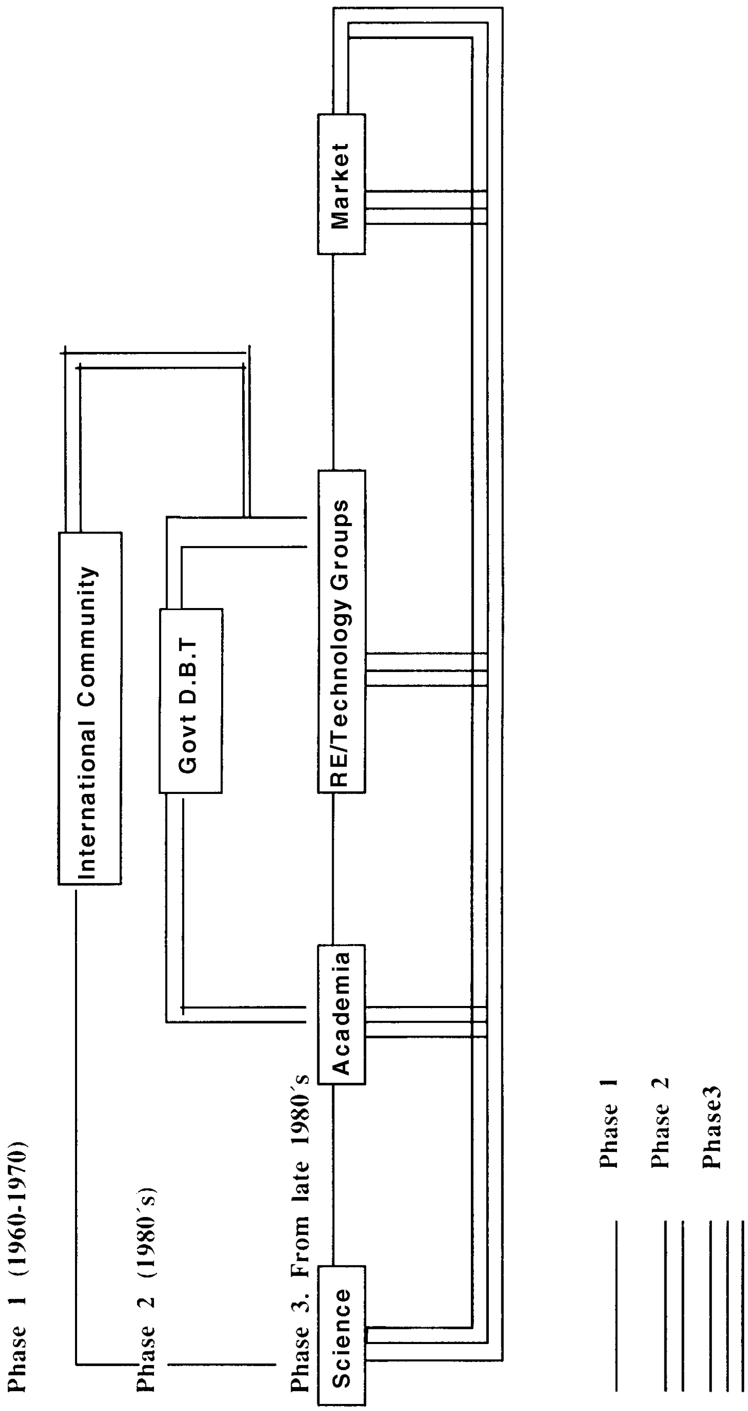

Figure 1. Biotech-Network

Table 3. Biotechnology and directly related research .and higher educational centres in M.Sc/Ph.D/Post.Doc in leading Indian institutions and full-time equivalent positions

University sector	Thrust of Activity	FESIF** Positions in 1982	FESIF Positions in 1995
Universities :			
Delhi University	M.Sc*1 Ph.D/ Post. Doct.	3	8
Calcutta University	-do-	2	7
Poona University	-do-	-	7
Banaras Hindu Univ.	-do-	2	3
Madurai Kamraj Univ.	-do-	2	6
Madras University	-do-	2	4
Jawaharl Nehru Univ.	-do-	4	12
Indian Institute of Sci.	-do-	3	11
Indian Agriculture inst.	-do-	7	23
M.S.University	-do-	2	8
Osmania University	-do-	1	5
Hyderabad University	-do-	1	5
Jadavpur University	-do-	-	4
Christian Med. College	Ph.D/Post.Doc	2	5
All And. Inst. Med. Sci.	Ph.D/Post.Doc	2	11
Ind. Inst. of Tech. (Khar)	M.Tech/Ph.D/Post.Doc	-	5
And. Inst of Tech. (Born)	-do-	-	5
And. Inst of Tech. (Del)	-do-	2	6
Anna University	-do-	-	7
		35	142

* Universities offering M.Sc courses admit 20-25 students per year
**(FES./Full-time) equivalent scientific/faculty

Table 3 contd

Research Institution	Thrust of Activity	FES/F Positions in 1982	FES/F Positions in 1985
CCMB	Full-time Res/Ph.D/P	27	52
Nat. Inst. of Immunology	-do-		49
Inst. of Microbial Tech.	-do-	12	30
Bose Institute	-do-	5	12
Tata Inst. of Fund. Res.	-do-	3	7
Nat. Chem. Lab	-do-	5	15
Nat. Inst. of Chem. Biol.	-do-	12	34
Bhabha Atom. Res. Cent.	Full-time Res	1	4
And. Vet. Res. Inst.	-do-		7
Cent. Rice. Res. Inst.	-do-		5
CSIR Compi. Palampur	-do-		6
Cent. Drug. Res. Inst.	Full-time Res/ PH.DIP.D	6	23
Nat. Inst. Heal. & Fly. Wel	-do-		6
Malaria. Res. Cent.	Full-time Res		4
Nat. Bot. Res. Inst.	Full-time Res/ Ph.D/P.O	8	40
P.G. Inst. of Med. Ed. Res	Full-time Res/ Teaching	1	5
Tam. Agd. Univ.	Full-time Res/ PH.DIP.D		4
Cnt. int. of Med.&Aro.Pits	-do-	3	12
Aligarh Muslim University	-do-		2
Tata Energy Research Cent.	Full-time Res/ PH.D		7
		84	324

Table 3 contd. Major private firms in biotechnology industry in India (Firms with R&D units)

1.	Astra Research Centre	11.	Spic
2.	Ranbaxy Laboratories	12.	Parry's
3.	Lupin Laboratories	13.	Hoechst
4.	Dr. Reddy's Laboratories	14.	ITC Agro Technology
5.	Span Diagnostics	15.	lndo American Seeds Corporation
6.	Unicon	16.	Harrison Malayalam
7	Torrant	17.	Rallis India
8.	A.V.Thomas	18.	Transgene Biotech
9.	Bicon	19.	Bangalore Genei
10.	Mailadi	20.	Hindustan Lever

Table4. Main leadership in biotechnology and related fields, the centres initiated and their foreign connectivity from the 1970s

Scientist who have the initial leadership	Foreign connection: collaboration/training	Emergence of a centre/ department/institutions
G.N.Ramachandran	n.a	University of Madras, 1960s;
Gopinath Kartha	n.a	Indian Institute of Science,1970
Sasishekharan	Stanford Univ., USA	Indian Institute of Science,
G.Padmanabhan	n.a	after 1970s
P.Bairam	Carneige Mellon, USA	
Obaid Siddiqui	Caltech Labs, USA	Tata Institute of Fundamental Research from 1960s
P.M.Bhargava	Max Plank Inst. Germany.	Centre for Cellular and Molecular Biology (1970s)
B.K.Bachawat	Univ. of illinois, USA	Indian Institute fo Chemical
Jyotirmoy Das	Rochester Univ., USA	Biology 1970s and Delhi Univesfty after 1980
G.P.Talwar f	Seagal Lab., USA Pasteur Institute, France	National Institute of immunology
M.Damodaran	n.a	National Chemical Lab.
John Bamabas	n.a	-do-
V.Mascamehas	n.a	-do-
Maharani Chakravorty	Cold Spring Harb. lab	Banaras Hindu Univ.
D.P.Burma	NIH, USA	-do-
B.B.Biswas	Abrams Lab.	Bose Institute
V.R. Muthukkarpan	Univ. Wisconsin, USA	Madurai Kamraj Univ.
K.Dharmalingam	Univ. of Boston , USA	-do-
V.V.Modi	Univ. of llinois, USA	Poona University
V.L.Chopra	Edinburgh Univ., U.K	Indian Agh. Res.institue

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[1] The division of biochemistry under P.M.Bhargava eventually led to the creation of CCMB in late 1970s ; and similarly the work of G.P.Talwar led to the creation of Nil in the early 1980s. B. Bachawat moved to Indian Institute of Chemical Biology and then to the Delhi University, South Campus.

[2] The quantitative data for this section is drawn from a report on Manpower sponsored by the Department of Science and Technology, New Delhi, see Visalakshi and Sharma (1995).

[3] The most notable names include : K. Dharmalingam, G. Shanmugam and Muthukkaruppan at Madurai Kamrai University ; P. Bairam, Sasi Shekharan, T. Ramasarma and G. Padmanabhan at the Indian Institute of Science ; P.M.Bhargava, Laiji Singh, C.R.Dass, among others, at the Centre for Cellular and Molecular Biology ; G.P.Talwar and others at the National Institute of Immunology ; V.L.Chopra and R.S.Paroda at the Indian Agriculture Research Institute ; B.K.Bachawat and S.C.Maheshwari at the Delhi University ; D.P.Burma and Maharani Chakravorty at the Banaras Hindu University ; Jyotirmoy Das at the Indian Institute of Chemical Biology ; V.V.Modi at the Poona University ; Cbaid Siddiqui at the Tata Institute of Fundamental Research and P.N.Bhatt at the Indian Veterinary Research Institute ; and John Barnabas and V. Mascarnehas at the National Chemical Laboratory.

[4] To have an idea of the international scene in the commercial importance of biotechnology, the following major events may be noted :
1973 - First cloning of gene
1974 - Recombinant DNA (RDNA) experiments first discussed in a public forum (Gordan Conference)
1975 - U.S. guidelines for RDNA research outlined (Asilomar Conference)
1976 - First firm to exploit RDNA technology founded in the U.S (Genetech)
1980 - Diamond V Chakrabarty won the case in the U.S Supreme court for patenting the live organism for the first time
1980 Cohen/Bayer patent issued on the technique for the construction of RDNA
1981 First monoclonal antibody diagnostic kits approved for use in the U.

[5] The first meeting of the GRC was organised in 1960 at Khandala near Pune and it was known as the " Khandala Type of Conferences ". The name of GRC came after the well known biochemist G.C.Guha. The idea of GRC was conceived in 1958 by a young group of biochemists who returned from abroad to pursue serious research in the frontiers of biology in India.

[6] As noted earlier, this national body was created in early 1930s. This society played an important part in the first few decades after its creation and still continues to play. The scientific society also publishes a journal. For the lack of space it is not possible to further elaborate the work and significance of this August body.

[7] This quote is taken from Burma (1992 : 221). Information for this section on symposiums and workshops on molecular biology is drawn from this source.

[8] The value of biotechnology market including the conventional fermentation based microbial products is estimated at 890,00 million rupees currently. The health care accounts for 60 % ; agriculture products 15 % ; and the balance is accounted by chemicals, alcohol and starch based products. Indian exports from the biotechnology products is estimated at 3000 million rupees currently.

[9] This emerges from an earlier study which explored seventeen research groups in physical, chemical and biological sciences during 1992-94. This study, to some extent, established a close association between the concept of communities and the phenomena of brain drain. See Mahanti et. al (1995).

[10] It maybe noted that the table is not theo outcome of an exhaustive exercise and possibly it misses out many leading personalities. The work on this still in progress and hence should be deemed an interim report.

[11] Interviews with leading biologists were conducted by the team involved in an earlier study (see Mahanti et. al 1995. The foreign connections is revealed from porsopographical survey of 25 leading biologists).