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Knowledge Production and Knowledge Transfer: A Study of Two Indian Institutes of Technology (IIT, Madras and IIT, Bombay)

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INTRODUCTION

Over the last decade, the links between academic research institutes (ARIs) and industry, generally known as University – Industry relations (UIS), has drawn substantial research and policy attention in science, technology, innovation policy and knowledge management related literature. A number of factors have culminated towards making ARIs in science and technology as important actors in the national innovation systems (NIS) for creating wealth from knowledge and as contributors to the economy as a whole. The impact of globalisation on trade, technology and economic growth generated a demand in industry for systematic knowledge in science and engineering, which in India, is increasingly becoming the domain of university system. The importance of human resource skills for a range of new technologies such as information and communication technology, biotechnology, nanotechnology, space and energy related technologies coupled with the rise of business enterprises and private industry in India including public sector enterprises is placing more and more demands on academia, particularly in premier institutes such as the Indian Institutes of Technology (IITs). Together with MIT as a reference model institution, Humboldtian values of teaching and research excellence have remained quite important in the establishment and growth of IITs.

Institutions of higher education engaged in teaching and research are now seen to occupy an important place in the knowledge production and knowledge transfer systems that are directly related to innovation and in capitalizing on their knowledge assets (research publications, processes and products and other research output), contributing to economic progress, and aiding in regional development and so on.

The IITs as a representative set of ARIs particularly in science and engineering education are known for their academic excellence[1], particularly for producing high quality engineering, science and management graduates and post graduates. Since their establishment, the primary objective for these institutions continues to be education and research, in both pure and applied science, in engineering, social science and humanities. The advancement and contribution of knowledge comes through knowledge products which are the academic and research outputs in the form of publications, conference paper presentations, and intellectual property which collectively can be called as the intellectual asset base of the institute. However, the mode of knowledge production in IITs which seems to be dominated by open science and research publications cannot be separated from the organisation of knowledge production. This draws our attention to the structure of student enrolments (both under graduate and post graduates including PhDs), structure of faculty and pattern of education finances and budgetary provisions. Emergence of IITs as research and knowledge producing institutions, over the last decade, is closely associated with increase in the post graduate students together with undergraduates. Lately, knowledge is being produced in the context of IITs increasingly getting involved as potential source of innovations for industry.

[1] IITs are recognised worldwide for the outstanding quality of engineers, scientists and managers they produce which is evident in the Times Higher Education (2006) where in the World's top hundred technology institutions they were ranked third after Massachusetts Institute of Technology (MIT) and University of California Berkley Source: http://www.timeshighereducation.co.uk/hybrid.asp?typeCode=163

The linear model of innovation which advances technology in several ways, has been conventionally considered as the basis for technological innovations that leaves academia spawned knowledge to find a logical way to commercialisation with minimal industry influence or interference. However, this pattern and perspective of innovation has undergone a radical transformation in the last decade since the 1990s in India. Perspectives such as 'Triple Helix', 'knowledge based economies' and national innovation systems on the one hand and the increasing demands for knowledge coming from both small and medium scale enterprises and large corporations and TNCs, on the other hand, have led to ARIs such as IITs in India to reorient and reorganise institutional and organisational structures to foster transfer of knowledge to industry and for societal consumption at a faster pace. The significance of knowledge institutions such as IITs is increasingly seen as the leading frontiers of innovation and technological change particularly concerning science based innovation. Creating intellectual property and its transfer has assumed enormous significance. Institutionalising proactive policies to patent intellectual property; license and transfer it for generating revenues; policies promoting incubation, spin-off firms for generating revenues have assumed enormous significance over conventional forms of technology transfers such as consultancy and sponsored research from industry to universities. This trend gained momentum in USA since the 1980s with the introduction of Bayh-Dole Act. However, in India particularly in the case of IITs the trends in knowledge transfer have assumed significance since the 1990s. This study is basically concerned with the exploration of knowledge production and knowledge transfer in two IITs, namely IIT Madras and IIT Bombay. IITs are an important part of a larger university system and hence constitutes as a key actor or an agency of the Indian national system of innovation. Before we get down to explore the case of IITs, it is pertinent here to briefly explore national innovation system in India with special reference to university system.

INDIA'S NATIONAL SYSTEM OF INNOVATION (NSI) AND ROLE OF UNIVERSITIES

Over the last decade, a very influential group of scholars (Freeman 1987, 1995; Lundval 1992; Nelson 1993; Edquist 1997, among others) have drawn our attention to the dynamics of innovation within and across different national boundaries or economies by identifying various actors and agencies which interact and determine the process of innovation. Varying perspectives culminate towards underpinning the importance of what has come to be known as the national system of innovation. Freeman (1987) is one of the earliest to define NSI 'as the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies'. Further, Lundval (1992: 12) also underlines the importance of organisations and institutions such as R&D departments, firms, technological institutes and universities which are crucial and 'the elements and relationships which interact in the production, diffusion and use of new and economically useful knowledge. These actors are either located within or rooted inside the borders of a nation state. Richard Nelson's (1993) study on *National Innovation Systems – A Comparative Analysis* further demonstrates how the conceptual framework of NSI can be used to compare and contrast different countries to identify critical factors or actors which determine innovation dynamics. Further elaboration and its relevance can be drawn from Metcalf (1995) who observes that institutions that contribute to the development and diffusion of new technologies also provide the framework that governments use in forming and implement policies to influence the innovation process. Extending this systemic basis of innovation in the national context, as Gu (1999: 9) stresses, the issue of innovative performance of an economy depends on the basis of both the performance of firms, research institutes and universities, individually, and on the basis of interaction as parts of a collective system. The collective system includes various other institutions and draws on their values, norms, legal frameworks and so on in the creation and diffusion of knowledge. In a different vein, Lundvall (1992) also underlines the importance of learning at various levels in the national system. Given the limited space, what we will do here is to briefly present the structure and main actors of India's NSI and focus on the role of universities.

Three Phases in the Evolution of Indian NSI[2]

The contemporary structure of NSI evolved through three interlaying phases. In a way Indian experience shows that building an infrastructure in science and technology institutions, developing national scientific communities, evolving appropriate science and technology policies and the evolution of firms and business enterprises are pre-cursors or building blocks to the contemporary structure of NSI. In the Indian context, role of government and public policies on science and technology institution building continue to be significant. Hence we begin to briefly trace its development as it progressed in its various phases.

1947-1970

This period reflects a phase of 'policy for the sciences' during which the main emphasis was on creating a basic infrastructure for science and technology in the country including the expansion of university sector for the supply of required S&T human resources. Major mission oriented science agencies were established during this phase. Compared to the main locus of Indian science in the academic settings during 1920-40s, the expansion and locus of science in the post independence period shifted to these mission oriented science agencies under the auspices of government. Scientific Policy Resolution (SPR) passed in the Parliament in 1958 provided legitimacy to the expansion of public sciences in India for the next three decades or so. Implicit in the policy for the sciences perspective was the view that once the infrastructure for modern S&T and congenial conditions for R&D is created, personnel trained and institutionalisation of science is completed, the S&T system will feed into solve developmental problems of India and tackle poverty. Gandhian model did have some influence in this phase but could not gain legitimacy as an alternative. This phase reflects the role of Jawaharlal Nehru, India's first Prime Minister and his legacy looming large in building S&T institutions. In fact, science-political nexus forged by Nehru with small group of elite scientists can be seen as the main actor for the evolution of Indian S&T system in this phase. The basic planning and its execution for the creation of main actors and science agencies of the current NSI began in this phase. From around 30 universities in 1950 the number increased to 105 by 1970s; and the out turn of university students increased about 20 times from 8774 in 1947 to150379 in 1975. The gross expenditure on R&D increased 126 times from 11 million rupees in 1947 to 1396 million rupees in 1971. By 1976, India was publishing about 1500 S&T journals and registered 13292 papers in various S&T journals at the national level. At the ISI based international level, India was the leading country in the entire Third World in terms of S&T publications.

[2] Data and figures for this section are drawn from an EU Report prepared on India. See http://www.proinno-europe.eu/extranet/upload/countryreports/Country_Report_India_2008.pdf

1970s to 1990

From the phase building basic infrastructure in S&T, Indian policies moved towards achieving certain national goals of development in this phase. However, much of the optimism of the earlier phase begun to erode during this phase with the 1973 oil crises and the rise of appropriate technology and people science movements (Krishna 1997). As the criticism from various quarters mounted to question the optimistic role of S&T for development envisaged during the earlier phase, the government geared to formulate appropriate responses. This phase could be called as 'science and technology in policy'. India's first Science and Technology Plan (1974-79) was announced which made explicit reference to attain indigenous technology capacities in various sectors. In an effort to protect local research and technology base, policies of self-reliance and import substitution were strengthened which had definite implications for public research institutions in S&T. These concerns were further articulated in the 1983 Technology Policy Statement which reiterated the need to strengthen institutions to give effect to endogenous technological capacity. In a way these policies characterised a some what 'inward looking' S&T and industrial policies. Exports promotion was not a major industrial policy platform in this phase.

The other main feature of this phase is that India entered nuclear and space 'clubs' by the 1980s demonstrating India's technological capacities in high technology areas. Not withstanding various criticisms, India achieved a relative success in 'Green Revolution' and 'White Revolution' which led to self sufficiency in food grain production. As the country entered the decade of 1980s, the country was entangled in a double bind situation. On the one hand, new technologies such as biotechnology and ICT and material sciences posed new challenges for their absorption and diffusion forcing the government to lift restrictions on international technology transfer. On the other hand, the critiques increasingly pointed to the failure of S&T for development and removal of poverty. As the basic needs agenda came into sharp focus, the government again responded this time with the new policy agenda of 'Technology Missions' around the mid 1980s. These were time bound regulated schemes for tackling the basic needs through redirection of science and technology inputs in water, immunisation, oil-seeds, telecommunications, leather and literacy. The period from the mid 1980s to the 1990 was one of considerable political instability coupled with the challenges of new technologies. The main industrial and S&T policy agenda toward the 1990s remained focused on how to open up and liberalise the Indian economy. In this phase, globalisation became a reality which mounted considerable pressure on the political system to embark on new economic reforms from the early 1990s. Some quantitative indicators of development of S&T institutions are shown in upcoming sections.

1991 – New Economic Reforms

The government embarked on what has come to be known as New Economic Reforms from June 1991. The main feature of this reform process was the New Industrial Policy (1991) with a major departure from the earlier era. Indian economic policies, compared to China's economic reforms from 1978, introduced a series of liberal economic policies with a focus on export promotion, selective privatisation, foreign direct investment and unprecedented encouragement to private industrial sector in power, transportation, mineral exploration, electronics and telecommunication, pharmaceuticals and ICT.

Main Actors Constituting Indian NSI

Publicly funded national laboratories under science agencies; universities and institutions of higher learning; business enterprises both public and private; public policies on science, technology and innovation; and civil society groups and institutions constitute main actors of India's NSI. India's gross national expenditure on research and development (GERD) in 2007-08 is around 368 billion Indian rupees, of which, the government accounts for 68% (down from 80% of 1980s era); business enterprises account for 30% (up from 21% in the 1980s); and the rest by others. University and higher education R&D, accounts for about 7.2% of GERD in 2007-08. As proportion of GDP, the R&D budget has been fluctuating between 0.8% and 1.13% between 1992-93 and 2004-07.

Laboratories under science agencies

As shown in the table-1 below, there are 12 main science agencies which constitute the main actor of India's NSI. This segment continues to draw considerable support from the government. Growth of R&D support given to 12 main science agencies in India during the decade of 1990s up to 2005-06 is shown in the table below. The strategic science related science agencies (DRDO, DOS and DAE) witnessed an almost five to seven fold increase in R&D expenditures. Other civilian science agencies also recorded increases with the exception of the science agency dealing with non conventional energy sources. As per data available, 391000 personnel were involved in R&D activities in both public and business enterprises.

Table 1: R&D Expenditure of Major Science Agencies 1990-91; 1998-99; 2000-2001; 2005-06 Figures in millions rupees

Science Agency	1990-91	1998-99	2000-01	2005-06
DRDO (defence)	6810	23002	20228	52000
DOS (space)	3862	15155	16423	25000
DAE(atomic energy)	2755	8367	na	17500
ICAR (agriculture)	2762	8440	14988	17500
CSIR(industrial research)	2491	7133	8778	17500
MOEF(environment & forest)	1620	3780	8500	1900
DST (all S&T)	1198	2990	7314	10000
DBT (biotechnology)	413	945	1415	2000
DOD(ocean)	278	848	1688	Na
ICMR(medical)	445	862	1470	2000
MIT (ICT)	330	621	760	Na
MNES(non conventional energy)	160	90	na	Na

Source: DST, Ministry of Science and Technology Reports

Universities

Higher educational institutions witnessed considerable growth in the post-independence period after 1947. From 20 universities in 1947 the number increased to over 361 universities.

There are now 20 Central Universities, 217 State Universities, 106 Deemed to be Universities, and 13 Institutes of National Importance established through Central legislation and 5 institutions established through State legislation. The number of colleges increased from 500 in 1947 to 17,625 in 2005, indicating twenty-six-fold increase.

In the technical education sector there were about 1749 colleges comprising: 1265 engineering and technology collages; 320 pharmacies; 107 architecture; and 40 hotel management colleges. In addition to these figures, there were 958 post-graduate in management institutions and 1034 master in computer application based institutions in the country by 2004.

The government through the University Grants Commission accorded special recognition of deemed university status to science agencies such as in space, atomic energy and other specialized agencies to train human resources. In May 2008 government made budget provisions to set up 4 new Indian Institutes of Technology, 6 Indian Institutes of Management and 14 more Central Universities. Among the new HEIs, mention may be made of the Rajiv Gandhi Centre for Biotechnology (RGCB), Indian Institute of Science, Education and Research (IISER) and the Institute of Space Science and Technology (IIST) all three institutions created in Kerala. These centres of higher learning are created to meet the increasing demand in high technologies and science based innovation in space, nano and biotechnologies and related areas.

Currently the Gross Enrolment Ratio (GER) in higher education is relatively low at 12 (that is 10.481 million students in HEIs in about 360 universities and 17625 colleges affiliated to these universities in 2005-06). The target is to achieve GER of 15 in the 2007-2012 XIth Plan Period.

Historically research and development in science and technology has been concentrated only in about 15% of the Universities and partly their affiliated colleges. The top 20% of the universities account for bulk of the R&D output from the university sector. As the table 2 below shows, there has been considerable increase in the overall publication of papers in all sciences from 52120 in 1999 to 89297 in 2005. Universities constitute more than 50% of the total papers published from India, though it accounts for mere 7.2% of GERD. Tables 2 and 3 below show that from 1980 there was considerable increase in the growth of S&T human resources from 1.7 million graduates to 8 million in 2004. About 14% of 391000 R&D personnel are in the university sector.

The human resources for India's S&T system primarily come from the University Grants Commission (UGC) under the Ministry of Education. While general higher education is governed by UGC, technical education is governed and controlled by All India Council for Technical Education (AICTE). The four layers of vocational and higher education consists of a) UGC which has more than 381 universities and accredits private universities and deemed universities; b) All Council of Technical Education which controls the technical, business management and other educational institutions such as hotel management etc; c) Medical education is governed by the Medical Council of India (MCI); and d) Vocational training through 5000 Industrial Training Institutes (ITI) under the Directorate of Employment and Training in the Ministry of Labor, Employment and Training. Some trends in the publications and human resources are shown in the tables below.

Table 2: Research Papers Published* from India during 1989-2005

Subject/ Year	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2005
						Number of papers						
Agriculture	11660	11382	11014	10903	11264	11025	11575	11739	11700	12782	11702	16526
Biological Sciences	8041	8012	8131	9244	10071	9987	9992	9537	9226	8880	8948	12491
Chemical Sciences	11670	11372	12449	13510	12964	13125	12569	13448	13467	14237	13384	23668
Earth Sciences	1848	1602	1492	1399	1355	908	1390	1078	923	1102	890	1212
Engineering	3798	2778	2921	2421	3477	4292	3658	4540	4696	3755	4550	11945
Mathematics	1337	1384	1463	1548	1352	1486	1841	2271	2247	2109	1318	1739
Medical Sciences	4273	5327	4396	4209	4068	4215	3988	4132	4490	4637	5633	12142
Physical Sciences	5545	5192	5312	5778	5453	5652	5709	5655	5642	5725	5695	9574
Total	48172	47049	47178	49012	50004	50690	50722	52400	52391	53227	52120	89297

Source: Department of Science and Technology (DST) 1999: 42; DST 2002: 46); and R&D statistics at glance, DST, New Delhi 2008.* In international databases

Table 3: Growth of the total Scientific and Technical Manpower 1970-2000
Figures in 000

Fields	1970	1980	1991	2000	2004**
Engineering Degree Holders	185.4	221.4	546.7	969.5	1011.7
Engineering Diploma Holders	244.4	329.4	873.9	1456.0	1514.3
Science Post graduates	139.2	217.5	482.0	767.1	795.6
Science Degree Holders	420.0	750.5	2430.3	3837.7	3978.4
Agriculture Post Graduates	13.5	96.5*	168.4*	231.2*	237.5*
Agriculture Degree Holders	47.2	-	-	-	-
Medicine Degree Holders	97.8	165.4	310.3	403.4	412.7
Others	na	na	na	68.1	74.9
Total	1147.5	1780.7	4811.6	7733.0	8025.1

Source: Department of Science and Technology. 1999 & 2002.
*includes first degree holders
** Estimation based on the decade (1990-2000) average.

Universities constitute an important part of the Indian NSI for the supply of highly skilled human resources and in knowledge production. However, the major challenge in the coming decade is to enhance the higher education enrolment ratio from 11% to at least 15% in the XIth Five Year Plan Period 2007-2012. One of the major weaknesses of Indian NSI is the weak linkages between universities and industry. However, IITs are an exception which we will explore in this report.

Business enterprise

Even though the government dominates in both R&D effort (research activities) and expenditure to the extent of over 68% per cent currently, the share of business enterprise R&D has been increasing over the last decade. While it increased from 13.8% in 1990 to around 21.6% in 2000, it further increased to 30% in 2007-08. In the business enterprise sector, R&D expenditure and performance is concentrated by biotechnology, pharmaceuticals and chemicals, telecommunications and ICT, electrical and electronics equipment, textiles, transportation and metallurgical industries. The innovation potential of Indian business enterprise sector (both public and private) can be examined through its patenting activity in the US. Some trends by the business enterprise are shown in the table below for the period ranging from 1999 and 2003-06:

Table 4: Trends in Indian Patents 1999 to 2003

Science Agencies/ Others	Indian Patents 1995-98	Indian Patents 1999-02	Foreign Patents (USPTO) 1995-98	Foreign Patents (USPTO) 1999-02	Foreign Patents (USPTO) 2003-06
CSIR	532	814	71	278	521
DRDO	14	31	na	na	na
ISRO	10	3	na	na	1
IITs	26	40	na	na	na
Universities total	75	173	na	8	na
Hindustan Lever	184	189	na	na	na
Ranbaxy Labs	7	23	9	32	40
Dr.Reddy Labs	7	29	3	32	25
Dabur Research	Na	Na	na	15	19
Panacea Biotech	Na	Na	2	11	3
Lupin Labs	13	1	7	4	7

Source: xxxx

Let us look into two sectors briefly. Pharmaceuticals have been one of the most dynamic sectors in India over the last two decades. According to estimates given by the Indian pharmaceutical industry and WTO, in 1974 drug production in India was barely US$10-12 million. This increased dramatically to about US$2.75 billion by 1994 and to US$ 6.5 billion in 2003 (sees Jayaraman, 2005).

Another important feature of the pharmaceutical sectoral system has been the evolution of technological capabilities. The first stage of technology support involved the development of R&D base in national laboratories. This capability enabled reverse engineering under the policy regime, which protected patents for about seven years. A second stage enhanced the capacity to exploit the innovation base for new drug discovery, development of vaccines and use new technologies such as biotechnology knowledge for value addition in the production of high technology pharmaceuticals and health related industry products (see Krishna 2007). Another sector which is a key component of NSI is ICT software. From 1990, the ICT sector emerged as India's leading knowledge sector registering a CAGR of above 26% for the last decade. It is contributing 5% of GDP and currently employing about 2 million professionals with demand projection of about 1 million for the next five years. In 2006-2007 the software and services exports have increased by 32% with the revenue aggregate growing by nearly 10 times in 10 years. The Indian ICT sector (in IT services, BPO, IT enabled services and engineering services and R&D Products); performance witnessed a tenfold increase in the last ten years. From 15.2 billion US$ in 2004 the sector generated total revenues through sales of 36 billion US$ in 2007 of which exports constitute approximately 78% and the rest 22% domestic market in 2007. The sector has set a milestone of 54 billion US$ by 2010.

BRIEF THEORETICAL AND LITERATURE OVERVIEW

The approach in this paper builds on the view that the essence of the relationships between institutions and associated actors can be captured from among the different concepts on innovation including the 'triple helix' framework[3]. This framework is pertinent because 'triple helix' observes academic institutions to be playing a dominant role in the innovation system. 'triple helix' has evolved gradually from a simple understanding of university-industry 'double helix' to trilateral reciprocal relationships between academia, industry and government and lately to a more intricate adaptation of innovation and sustainability as 'triple helix twins' working together as a dynamic yin/yang pair that advance sustainable economic and social development[4]. Etzkowitz et al. (2000) argue that there is a widespread movement among the academic research institutions to adopt a more complex entrepreneurial model, one that emphasises the commercialisation of knowledge and the fuelling of private enterprise in the local and regional economies.

Broadly speaking, this paper builds upon the theoretical premise of Etzkowitz et al (2000); Etzkowitz and Leydesdorff (1997, 2000); Lundvall (1992, 2004) wherein we examine how IITs as representative set of ARIs particularly in engineering and science whether or not fit into the entrepreneurial model in the Indian context. Specifically, we attempt to fill in the knowledge gap by empirically examining how IIT Madras and IIT Bombay (two of the five IITs that have existed for nearly six decades) have sought to reform the institutional and

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[3] The other important theoretical concepts are: the NSI framework (Nelson, 1993; Lundvall, 1992, 2002) which emphasizes how innovations are introduced and spread in the context of a country and attempts to explain as to why national economies differ. To a certain extent, it also explains why certain actors are important to the overall dynamism in the system of innovation. *The New Production of Knowledge* (Gibbons et al., 1994) explain two distinct ways in which knowledge is produced: 'Mode 1' and 'Mode 2'. In 'Mode 1', knowledge is generated in an autonomous university: in self-defined and self-sustained scientific disciplines and specialities, and is governed by peer group scientists who have a say in telling what constitutes science and truth and what does not (also see Gibbons, 1998, 2003).

[4] For details see Etzkowitz and Zhou (2006)

organisational structure since 1990s, considering the impact that such developments have had on the ARIs changing role in knowledge based economic development of India.

The changing role of academia towards contributing to economic and regional development has been addressed by several US and European scholars largely in their country context. Some of the important contributions looking at the transformation of ARIs are seen in the contemporary literature such as the 'enhanced role of university' (Leydesdorff and Etzkowitz, 1996); 'movement of knowledge from the academic institute to the marketplace' (Slaughter and Leslie, 1997); 'the place of universities in the system of knowledge production' (Godin and Gingras, 2000); 'capitalization of knowledge' (Etzkowitz et al., 1998); 'universities in national innovation systems' (Mowery and Sampat, 2005); 'new production of knowledge' (Gibbons et al., 1994); 'the changing rationale for European University research funding' (Geuna, 2001); 'new university roles in a knowledge economy' (Tornatzky and Gray, 2003); 'university research programs designed to contribute to economic development' (Rosenberg and Nelson, 1994; Mowery and Rosenberg, 1989); 'the university in the learning economy' (Lundvall, 2002), 'universities in the market place' (Bok, 2003), 'the university in ruins' (Reading, 1996). There are limited studies in the area focussing on Asia and even fewer undertaken in the Indian context. To name a few, there are studies by Fujisue (1998), Hicks (1993) and Kneller (1999) on the challenges facing academic institutions in Japan; Wong Poh-Kam's study of Singapore's national systems of innovation (1996, 2007); Shulin Gu's paper (1999) on the implications of national innovation systems for developing countries; Kim's book (1993) on the Korean experience and Sharif and Baark's (2005) study on understanding Hong Kong's innovation system and innovation policies.

However, many of these studies do not focus exclusively on the role of universities. Further, there are limited numbers of studies addressing innovation system in India that focus on academic institutions. Chidambaram (1999) focuses on patterns and priorities in Indian R&D. Gupta and Dutta (2005) give a macro picture of innovation system in the Asia Pacific region; Krishna (2001) looks at the changing status of academic science in India; Abrol (1983) addresses the issue of scientific research in Indian universities and Menon (2002) focuses on technology incubation systems in India. Even though history of science and technology and social sciences including history and economics of education, among other sub-disciplines, are well developed in India with substantial research contributions. However, these studies have given little or residual research attention to the subject of changing role of universities and particularly on IITs, there are rather very few studies. In view of the available literature, most of them are written by decision makers and heads of institutions. Mention may be made of Indiresan and Nigam (1993), and Indiresan (2000) who address the challenges faced by IITs in general and in mobilizing resources. While Raju (1995) in his paper focuses on building bridges between IITs and Indian industry, Swaminadhan (1995) looks at how engineering education can be made relevant to industry. Sengupta (1999) looks at the aspect of marketing technological competence of ARIs in technology transfer. There are however exceptions with focus on IITs - such as the recent paper by Basant and Chandra (2007) looking at the role of educational and R&D institutions in city clusters, another by Nath (1992) who shares the experience of IITs with industry and some others. Despite the growth of IITs and their significant position in the Indian economic and intellectual structure, very little attention is given by social science research in India to these institutions, except for some studies like Chandra and Krishna, (2006) and Chandra (2007). It may also be noted that most of the IITs have management schools and our cursory exploration of research from these schools also indicate that innovation based studies on IITs and their contribution and IIT's relations with industry are rather rare. In other words, social science and management research has not been given the kind of research attention that IITs deserve in the emerging era of knowledge based economies.

ORIGIN OF IITS AND THE IIT SYSTEM

The origin of IITs in late 1940s is an era which signified the end of World War culminating towards the end of colonialism and its control over higher educational institutions. It was indeed the beginning of an era when independent governmental efforts were devoted towards building higher science and engineering institutions. The IITs were born at a time when the First Prime Minister, Jawaharlal Nehru's vision clearly held that science and technology are key factors for the transformation and modernisation of India. The policy discourse initiated by Indian political and scientific leadership over the need for engineering and technical personnel for economic development and growth of India led to the formation of an *adhoc* committee under N.R.Sarkar in 1945. This committee consisted of scientists and businessmen with a view to advice on the provision of higher technical education facilities in India towards the end of Second World War. In the meantime the All India Council for Technical education (AICTE) which was also set up by the colonial government in 1945 upheld three primary objects in view to survey the whole field of technical education in India; to consider the desirability of establishing high-grade technical institutions in India on the lines of MIT; and thirdly to promote inter-provincial coordination in all India schemes of technical education.

The adhoc committee submitted their interim report (Interim Report: Sarkar Committee, 1946) recommending the establishment of not less than four higher technical institutions (HTI) in different parts of India (east, west, south and north), which would serve as models of scientific and technical education, particularly of a high order. This document known as the Sarkar Committee report[5] was submitted in 1946 and is considered as the blueprint for the establishment of IITs[6]. Jawaharlal Nehru, who ardently facilitated the setting up of IITs, acknowledged the views of Sir Ardeshir Dalal (Viceroy Executive Council member) in recognising that technology would play a critical role in building a free India. The government after independence in fact established five IITs in Kharagpur, Madras, Delhi, Bombay and Kanpur.

Even though Indian inherited a number of colonial scientific organisations, India opted to emulate The Massachusetts Institute of Technology (MIT) as a 'model' institution and was taken as a 'reference model' for setting up of a chain of Five IITs. There were certain features in this 'MIT model' that inspired the planners of these higher technical institutions, the prominent of which were: strong science base; course structure that integrated teaching and practical training; recognition to humanities and social science in engineering curriculum; characteristics of land-grant university committed to local/regional economic and social development; and most importantly the co-operation with industry. MIT was one of the most

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[5] This committee was set up with N R. Sarkar as chairman and S R Sengupta as Secretary and had 22 members. In its introduction the representatives of the committee expressed that the existing facilities for higher technical education in India were inadequate both in quantity and quality, to satisfy India's post-war needs for high grade technologists. The committee came to the conclusion that in view of the size of the country and the location of her industries, the provisions of several HTI's on regional basis was the solution most likely to satisfy the post war requirements.

[6] L. S. Chandrakant and Biman Sen in the Education Ministry also played significant role in producing a blueprint for a truly autonomous academic institution.

prestigious institutes at that time that was set up on large-scale government support of research concentrations. This reason appears to be pragmatic and dominant wherein through the demonstration effect, the ‘‘MIT Model’’ was perceived as a solution to the lack of high-level engineering training in India (as has been noted by several scholars also mentioned in previous sections) and possibly also as a means to promote an institutional research model in which science and engineering education and research will have a major impact on the regional development.

The IIT System

The IITs have been in existence for over six decades making significant contributions in terms of knowledge production, creating highly skilled, well educated graduates and post graduates particularly in engineering and sciences as also in social science and management disciplines. As Table 1 shows, the five initial IITs were established in a decade from 1951 to 1961. Even though the underwriters of IITs drew inspiration from the MIT model in their educational structure and course modules, five different countries assisted the government through aid and infrastructure in establishment in their formative years. After the creation of Five IITs during 1950s and 1960s, two more were established in 1994 and 2001 (at Guwahati and Roorkee respectively) and three new IITs have been set up in 2008[7]. These institutions have played an important role in imparting quality teaching and undertaking scientific and engineering research. However, the involvement of IITs in making use of their intellectual assets for economic development and also for generating revenue has gained considerable attention in the last one decade or so.

IITs are a unique system for two important reasons that find relevance in this study. First, they represent a subgroup of India’s premier academic researchers, spanning a broad range of disciplines which serve as a model for other ARIs in India, both in knowledge creation and in knowledge transfer. Second, we presume that IIT’s mission (at the time of their establishment) was not explicitly focused on research, contrasting to the homogeneity of missions in the five IITs dispersed geographically. The IITs focused more on teaching, education and training in the initial years of their establishment. Keeping in mind the objective of producing highly skilled scientists and technologists, the emphasis on post-graduate education and research was rather subdued in the beginning till 1970s. Many scholars have also pointed out this trend in IITs. For instance the former director of IIT Bombay, Prof. S P Sukhatme observes, “*In 1965, the teaching programs at IIT Bombay were already probably the best in India. The course-work and course content were fairly up to date but research wise, IIT Bombay was nowhere*”[8]. Balaram (2003) notes that thus far IITs have emphasized quality undergraduate education in engineering, and their success has been predicated on two factors: rigorous selection of students and a proven recipe for training. The IIT Review Committee (2004) also suggested that the IIT brand has to be moved up the value ladder from the undergraduate to post-graduate and PhD levels and even beyond post-doctoral level to more mature heights of research.

[7] Three more IITs have been established in 2008 in the states of Andhra Pradesh, Bihar and Rajasthan.

[8] Source: http://www.iitbombay.org/info/ypoint/InsIghT_Vol_10_2_old.pdf accessed on May 03, 2008.

Table 5: Five IITs: Year of establishment, foreign assistance, students and faculty on rolls

IITs--- (year of establishment)	**IIT Bombay (1958)**		**IIT Delhi (1961)**		**IIT Kanpur (1961)**		**IIT Kharagpur (1951)**		**IIT Madras (1959)**	
Countries Assisted in Establishment	Soviet Union		UK		USA		-		Germany	
Student (S) & Faculty (F) Strength	F	S	F	S	F	S	F	S	F	S
Engineering Departments	250	3225	248	3812	190	2395	297	3049	244	4023
Science Departments	92	620	109	674	88	542	92	466	77	487
Interdisciplinary Centre/Others	36	205	84	134	8	79	54	150	5	44
Humanities & Social Science including management	32	202	27	211	22	88	31	132	29	177
Total	410	4252	468	4831	308	3104	474	3797	355	4731

More than any other aspect, IITs have earned a big name globally for producing highly skilled engineering graduates. The IITs as a representative set of academic research institutes (ARIs) particularly in science and engineering education are known for their academic excellence[9]. It is not surprising that admission into IITs is rather a highly competitive exercise in the country with nearly 250000 students competing for 5500 students' positions in all IITs combined together. The competition is the toughest to get admission in an IIT than any other prestigious institution of engineering and technology in the World (IITDAA, 2004). This study shows that the acceptance rate to undergraduate program in IIT is one in sixty applicants, one in seven in Stanford, USA while it is one in ten applicants in MIT, USA. For, postgraduate admissions, in 2003, about 159000 students (out of approximately 350000 engineers produced in India) appeared for General Aptitude Test in Engineering (GATE) out of which 28877 (18%) were qualified to take admissions in IITs.

[9] IITs are recognised worldwide for the outstanding quality of engineers, scientists and managers they produce which is evident in the Times Higher Education (2006) where in the World's top hundred technology institutions they were ranked third after Massachusetts Institute of Technology (MIT) and University of California Berkley Source: http://www.timeshighereducation.co.uk/hybrid.asp?typeCode=163 accessed on 24 August 2007.

Enrolment of students

Table 6 shows the snap shot profile student enrolment/graduation of Five IITs during 1999 and 2005. At IITs there has been an overall increase in the enrolment of students and in degrees awarded to them, which is reflected in the visible growth in number of teaching disciplines and programmes of study[10]

Table 6: Students Enrolment/Graduation on an Average per Year in IITs (1999-2005)

Enrolment	B.Tech	M.Tech	PhD	M.Sc.	MBA	Dual Degree	Others	Total Average/ Year
IIT MADRAS	**381**	**568**	**176**	**90**	**41**	**107**	**0**	**1362**
IIT BOMBAY	**335**	**536**	**191**	**112**	**64**	**172**	**13**	**1423**
IIT DELHI	499	710	246	84	64	0	10	1613
IIT KANPUR	407	361	111	61	35	73	10	1057
IIT KHARAGPUR	431	540	197	55	55	134	26	1437
TOTAL	2053	2715	920	401	259	485	58	6891

Source: Calculated from Annual Reports of respective IITs (1999-2005)

Table 7: Increase in Student Enrolment (1999-00 to 2004-05)
figures in brackets give % growth

All Five IITs	B.Tech	M.Tech/M.Sc/MBA	PhDs	Others	Total
1999-2000	2295	3506	541	18	6137
2004-2005	2699 (17.6)	3624 (3.4)	1003 (84)	115 (505)	7441 (15.7)

B.Tech includes 5 year integrated M.Sc program and dual degree; M.Tech includes 2 Year M.Sc, MBA, M.S. (Research) & M. Design; others include diploma, post graduate diploma; others include diploma students

Looking at the data of five years (1999-00 to 2004-05) as shown in Table 7, there has been a relatively higher growth in research students as compared to UG. Ideally the UG: PG ratio at the time of the establishment of IITs was recommended by Sarkar Committee to be 2:1 (Interim Report: Sarkar Committee, 1946). The present UG: PG ratio computed for all five IITs is 1:1.72[11]. Thus the most striking feature of IITs in terms of student output is the reversal of trend in the ratio of undergraduate students to postgraduate students in over five decades of their existence. Other outstanding change is seen in the enrolment of PhD students, which has almost doubled in just five years, from 541 to 1003 (Table 7).

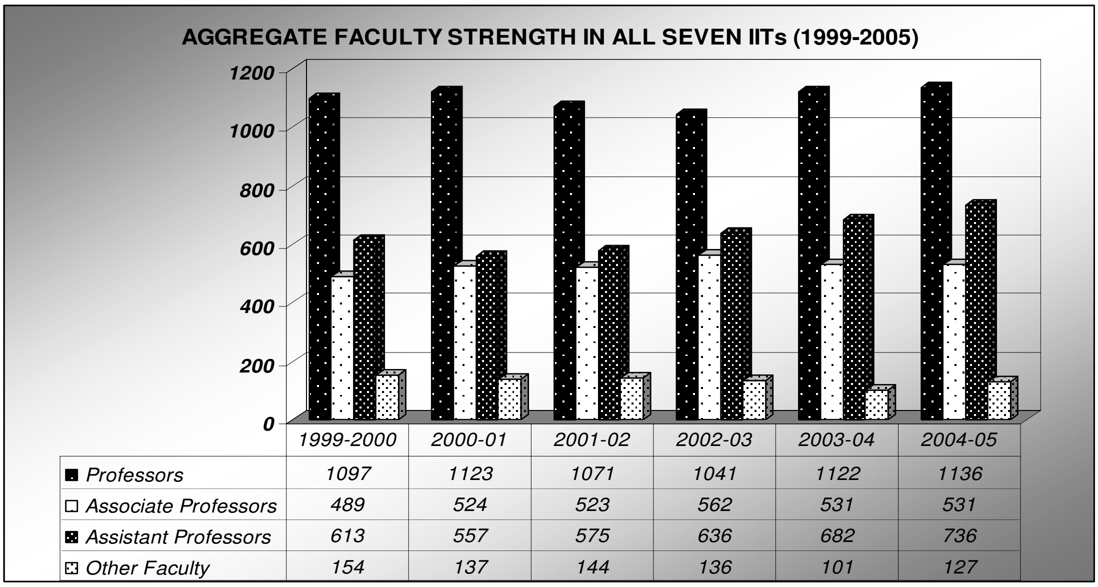
[10] Knowledge production at IITs is organised through the number of courses offered at the undergraduate UG) and postgraduate (PG) level. There are in all 3537 UG and 3797 PG courses at the five IITs offering 22 degrees in 409 disciplines (IIT Review Committee, 2004: 94).

[11] Based on computing data on student enrolment from Annual Reports of respective IITs in 2004-05. The total number of B.Tech students in five IITs were 2699 while M.Tech/M.Sc/PhD students were 4627

Faculty status at IITs

Faculty members and their academic stature constitute the core calibre of IIT system and it is their intellectual value that drives output (IIT Review Committee, 2004). The figure 1 suggests that the total faculty strength in the period 1999-2005 has been stable and has not increased significantly. The faculty break-up shows that the numbers of professors are nearly equal the total number of associate and assistant professors. The growth in number of faculty members has not been relatively significant while comparing the proportional increase in number of students.

Figure 1: Aggregate Faculty Strength in Seven IITs (1999-2005)



Source: Annual Reports of IITs and IIT Review Committee (2004)

The IITs however face a critical challenge to maintain faculty base. There is a critical shortage of faculty in all the IITs.[12] The faculty: student ratio is given in Table 8, which shows that taking into account all five IITs for 1999-2005 period, there are ten faculty members for each student at IITs, with maximum at IIT Madras.

Table 8: Faculty-Student Ratio at IITs (2004)

Institution	Faculty	Student	Student: Faculty Ratio
Bombay	410	4252	10:1
Delhi	468	4831	10:1
Kanpur	308	3104	10:1
Kharagpur	474	3797	8:1
Madras	355	4731	13:1
All 5 IITs	2015	20715	10:1

Source: IIT Annual Reports (2004)

[12] For instance in the seven IITs, the total number of vacant positions is 866

Finance and budgetary provisions for IITs

The Sarkar Committee, in 1946 had recommended that in their initial years of establishment, since the IITs would not be in a position to generate funds of their own immediately, the government should, as an interim measure, meet the entire balance of costs incurred (Indiresan, 2000). However the committee did not specify how long that interregnum should be, nor did it suggest in what manner, and how fast, state support should be scaled down to suggested levels. Indiresan further draws our attention to the Sarkar Committee report recommendation that the costs should be shared equally between the government, the student and the institution. However within the government, this idea of a three-way share was never taken seriously.

By and large IITs are now (were they not earlier) publicly funded institutions. The Indian government gives grants to them through the Department of Higher and Secondary Education, Ministry of Human Resource Development. Latest figures of 2007-08 (Budget and Revised Estimates: Table 9) also show a significant rise in allocation to IITs as a proportion in the total allocation to higher education sector given in the Union Budget 2008-09.

Table 9: Allocation to IITs in Union Budget-2007-08
(Revised & Budget Estimates in Million Rupees)

2007-08	Plan (BE)	Non Plan (BE)	Total (BE)
All IITs	11117	4420	15537
New IITs	800	-	800
Total Technical	29290	9410	38700

Source: Union Budget 2008-09: Expenditure Budget, Vol. II as shown in Tilak (2008: 54)

In 1993-94, with the introduction of a ‘block grant system’ for non-plan funding for IITs, a significant shift in the funding policy of the government was seen. This policy targeted reducing expenditure and encouraged internal resource generation. While the grant from government accounts for the maximum share; the earnings in 2002-03 from student tuition fees accounted for about 6% of the total expenditure and the revenue generated through sponsored research and industrial consultancy ranged between 15 to 22% of the total expenditure at different IITs.

AN OVERVIEW OF IIT MADRAS AND IIT BOMBAY

IIT Madras

IIT Madras[13] was opened on July 31 1959 and it was located at Guindy, Madras. The IIT Madras was surrounded by other higher educational institutions such as the Government College of Engineering, the University College of Technology, with its advanced study in chemical engineering and textile technology, and the Central Leather Research Institute (CLRI). The Government of Germany as well as its universities gave generous support to the institute in the form of valuable equipment, instruments, books and powerful computers totalling a value of nearly DM 50 million during its inception, making it one of the largest German-aided educational projects in late 1950s.

Professor Humayun Kabir, Minister for Scientific Research and Cultural Affairs, at the time of inauguration of SHTI stressed on the need for active co-operation of the industries in the country stating that the impact of these higher Technical institutes on industries would be decisive and important. A Lakshmanaswami Mudaliar, Vice-Chancellor of the Madras University and the chairman of the governing body of SHTI hoped that in future the industries in India would realise more and more, as industries had realised in the more advanced countries, that unless opportunities were given to students and post-graduates to be in touch with the industrial establishments and for those working in the industries occasionally to get in touch likewise, with the more theoretical but nonetheless important aspect of technical education in our institutions, the desired progress could not be maintained (*The Hindu*; August 1, 1959). At SHTI too, the course structure was debated and the extent of adaptation of German model was discussed. The first Director of the institute, Professor B Senugupto observed that while German students entered four or five year technical institutions at the age of nineteen plus with adequate preparation in science combined with two years of practical experience, the Indian student at IIT would come at the age of sixteen-plus with little workshop experience and inadequate preparation in basic sciences. Thus he pointed out that fundamental sciences and mathematics consequently had to be taught more intensively in the first two years of the courses in IITs (Sebaly, 1972: 75). Moreover the academic pattern emphasised on course work during the first three years on basic sciences while specialisation through a system of electives would be offered in the fourth and fifth year[14].

German influence apart from the equipment and expert support was seen in the course structure, where students could opt for German language and Indo-German politics and economic relations particularly in the humanities department. Similar to the western HTI (that is IIT Bombay), where problems of industries were considered, the Madras institute gave importance to problems peculiar to the southern region through its focus on tropical

[13] The institute was notified as the Southern Higher Technical Institute (SHTI), in the Sarkar Committee Report (1946) which recommended the establishment of IITs in India. The Co-ordinating Committee of All India Council of Technical Education (AICTE) recommended the location of SHTI for which the Madras Government offered over 407 acres of land free of cost at Guindy in the city of Madras (*The Hindu*, May 18, 1958).

[14] Complaints were made during the first five years of assistance program stating that German experts had limited role in academic development of the SHTI. It was reported that efforts were made without considering developments taking place in comparable German technical institutes. In order to resolve the issue, an informal committee was formed known as the 'Madras Committee' in which a German expert at SHTI would maintain a closer liaison with Indian counterpart (Sebaly, 1972: 77).

technology, agro industries, and economics of development. Another important aspect of this institute was the research programme that emphasised on technological development and industry cooperation and included developing expertise on erection of pilot plants, testing of products, provision of computer facilities, facilities for basic research, emphasis on practical training and guest lectures on industry specific issues[15]. This feature perhaps explains a culture of large scale industry cooperation and sizeable number of start-up firms and technological development projects in the contemporary period in IIT Madras.

Table 10 provides a summary overview of the key changes that IITM has undergone during 1999-2000 to 2007-08. In essence, this table shows that although there was only a moderate expansion of IIT in terms of conventional/traditional dimensions of education and research output, a more dramatic change can be observed in the new dimensions of entrepreneurship promotion, technology commercialisation, and collaborative research and development in the upcoming sections.

Table 10: Key Indicators of Change at IIT Madras
Government grant and value of sponsored research and industrial consultancy in Rs million

Indicator	1999-2000	2004-05	2007-08
UG Students Enrolled	465	550	518
PG Students Enrolled	633	761	690
PhD Students Enrolled	115	255	204
Government Grant to IIT Madras	814	1100	1330
Number of Sponsored Research Projects	42	79**	139
Value of Sponsored Research Projects	45.0	351.6	669.27
Number of Consultancy Assignments	833	452	549
Value of Consultancy Assignments	67.8	83.9***	177.26
Number of Research Publications #	317	555*	
Number of Conference Presentations	391	881	881
Number of Patents Filed	1	12	23^
Number of Patents Issued	1	2	14
Number of Spin-offs	4	14	28^^

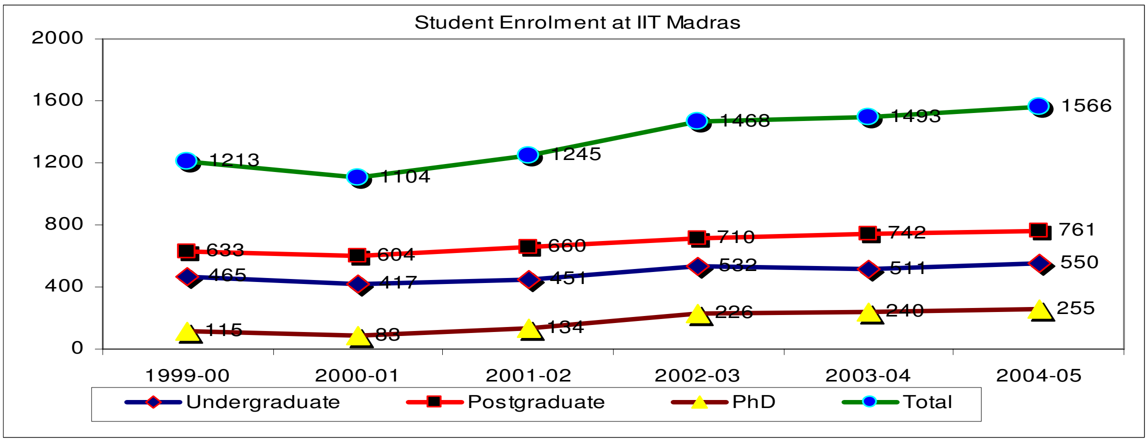
\# Thomson (ISI Web of Knowledge)
* In 2007, the publication count was 664 (~110% increase since 1999)
** In 2006-07, the number of sponsored research projects increased to 112 valued at Rs 450 mn
*** In 2006-07, the number of industrial consultancy assignments increased to 639 valued at Rs 220 mn
^ IPR includes 2 PCT applications and is computed for the calendar year 2007
^^ This includes 16 incubatee units from TeNeT group and 12 from Rural Technology Business Incubation Unit (RTBI) formed in 2006

[15] This viewpoint has been pointed out by several scholars like Professor S Sampath in his address "Aims and Tasks of IIT Madras" delivered at the DAAD seminar on January 20, 1968; p.4; like Professor B Sen Gupto, the first director of IIT Madras in his report on a visit to the Federal Republic of Germany; April 22 to May 16, 1967; like Professor Dr. Ing. H A Havemann in an interview to K P Sebaly on September 24, 1969 as per Sebaly, 1972: 79)

Skilled graduates/PhDs at IIT Madras

IIT Madras has witnessed a gradual increase in the post-graduate and research students which has enabled the institute to increase its research and innovation base. The Number of PhDs awarded at IIT Madras in 2004-05 was 255. The emphasis on research is more pronounced if we compare the ratio of undergraduate (UG) to postgraduate (PG) student enrolment at the time of the establishment of IITs and now. Ideally the UG: PG ratio at the time of the establishment of IITs was recommended by Sarkar Committee to be 2:1 (Interim Report: Sarkar Committee, 1946).

Figure 2: Student Enrolment at IIT Madras



Undergraduates include B.Tech and Dual Degree; Postgraduates include M.Tech; M.Sc. and Management

IIT Bombay

The institute celebrated its golden jubilee this year in 2008. The planning for the institute began in 1957 and IIT Bombay (IITB) was established in 1958 with the cooperation and participation of the UNESCO, and funding from the erstwhile Soviet Union (R&D Spectrum, 2005: 20)[16]. Indian Prime Minister Jawaharlal Nehru sought Soviet assistance to set up the institute in Bombay (now Mumbai). Brigadier Bose to be appointed as its first Director.[17] As fallout of the prevailing Cold War, the Americans offered to help to set up yet another IIT at Kanpur.

The IITB campus at Powai extends over 200 hectares and is situated in picturesque surroundings with Vihar and Powai lakes on either sides and green hills. In 1961, by an act of Parliament, the Institute was declared an institution of national importance and was accorded the status of a university with power to award its own degrees and diplomas.[18]

[16] The Institute received substantial assistance in the form of equipment and expert services from USSR through the UNESCO from 1956 to 1973. The Institute received several experts (59) and technicians (14) from several reputed institutions in the USSR. The UNESCO also offered a number of fellowships (27) for training of Indian faculty members in the USSR. Under the bilateral agreement of 1965, the USSR Govt. provided additional assistance to supplement the Aid Program already received by the Institute through UNESCO.

[17] Krishna Menon, the then Defence Minister under Prime Minister Nehru, recommended this appointment.

[18] See the brief history of IITB on its website.

IITB is a residential campus with 2,200 undergraduate and 2,000 postgraduate students. IIT Bombay also has schools in management (Shailesh J. Mehta School of Management) and information technology (Kanwal Rekhi School of Information Technology) on its premises. Despite a change in the name of the city, the IIT retains the original name.[19] Over the last decade, as other IITs, IITB has received a good deal of encouragement and support from its alumni. It is said that the largest overseas concentration of alumni can be found in USA. It is however not surprising that the most prominent celebrations of IITB golden jubilee celebrations were organised in New York in 2008. Romesh Wadhwani, founder of the Foundation and an IITB alumnus of the class (electrical engineering) of 1969 donated 5 million US$ at this event for the research and innovation in the area of biosciences and bioengineering and for setting up the Wadhwani Research Centre in Biosciences and Bioengineering at IIT B.

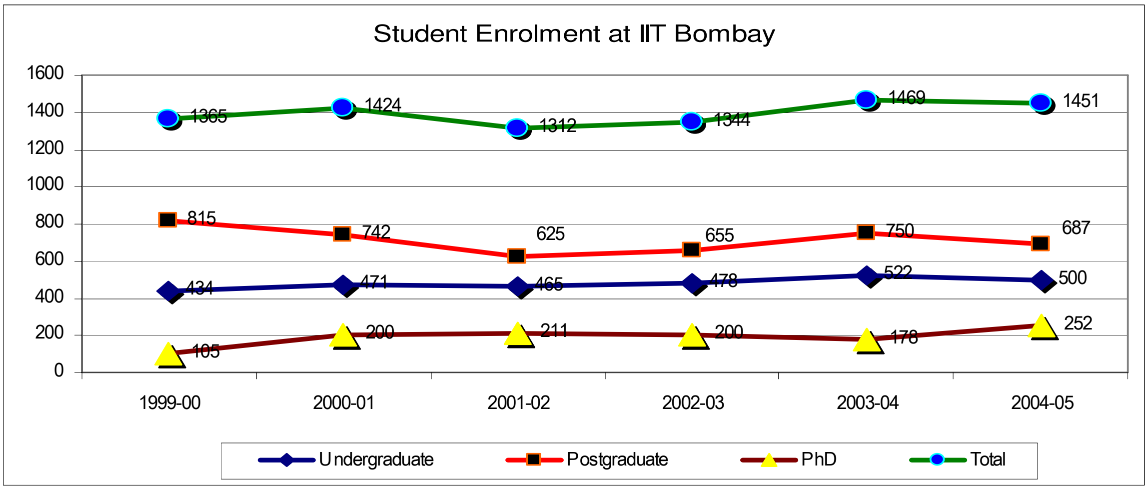
Table11: Key Indicators of Change at IIT Bombay
Government grant and value of sponsored research and industrial consultancy in Rs million

Indicator	1999-2000	2004-05	2007-08
UG Students Enrolled	434	500	553
PG Students Enrolled	815	699	863
PhD Students Enrolled	105	252	263
Government Grant to IIT Bombay	839.5	1024	1073.9
Number of Sponsored Research Projects	140 (2001)	200 (2003-04)	180
Value of Sponsored Research Projects	145.6	280	560
Number of Consultancy Assignments	506	950	na
Value of Consultancy Assignments	52	100	167
Number of Research Publications #	238	552	
Number of Conference Presentations	233 (2001)	514	604 (2006)
Number of Patents Filed	9	12	13
Number of Patents Issued	1	-	14
Number of Spin-offs	Na	7	33

Thomson (ISI Web of Knowledge)
* In 2007, the publication count was 664 (~110% increase since 1999)
** In 2006-07, the number of sponsored research projects increased to 112 valued at Rs 450 mn
*** In 2006-07, the number of industrial consultancy assignments increased to 639 valued at Rs 220 mn

[19] See Wikipedia and the website of IITB

Figure 3: Student Enrolment at IIT Bombay



KNOWLEDGE PRODUCTION AND KNOWLEDGE TRANSFER

Knowledge Production

Research publications

Attaining teaching and research excellence, core values underlying both MIT and Humboltian University models, remained an important objective for IITs from the beginning[20]. From an overall national perspective, the publication record of IITs (at the international level as seen through the count of publications in SCI extended data base) shows that IITs figure among the top ten universities in India. To have an international perspective of the publication output from IITs, we take into account those publications that are listed in the *Web of Science*–Science Citation Index Expanded Version (SCI–Expanded) and the Social Science Citation Index (see Table 12).

Table 12: International Publication Profile of IIT Madras

IITs	1999	2000	2001	2002	2003	2004	2005	2006	2007	% increase (1999 – 2007)
IIT Madras	414	395	351	382	467	510	639	750	834	101
IIT Bombay	342	424	413	476	503	604	635	743	798	133
Total 5 IITs	1650	1708	1693	1864	2261	2639	2928	3498	3652	121

Source: Science Citation Index – Expanded accessed on 28 February 2008 and 24 June 2008.

[20] As early as 1947, at the second meeting of AICTE proceedings in 1947 it was highlighted that the consideration of the establishment of high grade technological institutes in the country was on the lines of MIT–an institution known all over the world where technology is studied and where the advantage of training in technology is appreciated (AICTE 2nd Proceedings, 1947: 20 – address by Sir A Ramaswami Mudaliar, Dewan of Mysore)

Quality of publications and impact factor

From the understanding of scientometric perspectives, quality of research publications is generally examined from citation counts, impact factor etc. Notwithstanding the direction (positive or negative) citation counts are generally recognised in scientometric literature for giving some indication of quality profiles. To get an indication about the nature and quality of publications, the publication profile of the five IITs is given in Table 10 in terms of total number of publications, average impact factor, average citations per paper, total collaborative papers and total collaborative papers at international level.

The citations to these papers indicate the transfer and utilisation of published knowledge. In analysis of citations, a frequently cited paper is considered to have a greater probability of influencing subsequent research activity than a paper with no or few citations. The average impact factor per paper shows the potential of a paper to win citations and is based on the average impact factor of their publishing journal. It is computed by summing up the impact factor values of journals publishing a given set of papers and dividing it by the total number of papers in the given set. The obtained value is useful in assessing and comparing the quality of research outputs of institutions, sectors, and geographic regions etc. Average citations per paper is an absolute measure of the citations impact of the research output by institutions and is computed by summing up the total citations won by a given set of papers dividing it by total number of papers in the given set.

Table 13: International Publication Profile of Most Prolific Academic Research Institutes in India in (2001-02)

Institutes	Total Publications	Average Impact Factor	Average Citations per Paper	Total Collaborative Papers	Total Collaborative Papers at International Level
IIT Bombay	699	1.22	2.575	388	193
IIT Delhi	690	0.94	1.812	333	130
IIT Kanpur	667	1.32	2.813	296	166
IIT Kharagpur	688	0.96	1.737	380	140
IIT Madras	575	0.96	1.550	300	136
IIT Guwahati	81	1.36	2.469	27	7
IIT Roorkee	270	0.96	1.763	138	45
AIIMS	902	1.72	2.080	406	103
IISc	1719	1.87	3.510	912	364
Delhi University	577	1.24	2.166	324	135
Jadavpur University	513	1.24	2.347	311	96
BHU	402	1.04	3.095	166	67

Source: Adapted from Gupta and Dhawan (2006: 115, 116, 165)

Disciplinary Trends of Publications

At an aggregate level, the engineering departments score above the science departments, research centres and departments of humanities and social science/management (see figure 4). Although the data sources are from the Annual Reports of the respective IITs, the trends should not be very different from the SCI databases. The publication contributions from the centres at IIT Kharagpur and IIT Delhi (that include multidisciplinary disciplines) are more as compared to the centres at other IITs. The publication count from science departments at IIT Kanpur is the highest which is nearly 0.7 times the number of publications in journals in the engineering discipline. The disciplinary trends on conference presentations by IIT personnel at IIT Madras are shown in the next section.

Evaluating the subject profile of IIT Madras, it was found that chemistry is the dominating area of research publication, followed by mechanical, civil engineering and metallurgy and material science. Subjects like physics, electrical engineering and chemical engineering also accounted for most prolific fields where publication count was high (see figure 4). In the case of IITB, chemical and physical sciences seem to indicate the main focus of research (see figure 4a)

Figure 4: Discipline-wise Publication Spread at IIT Madras

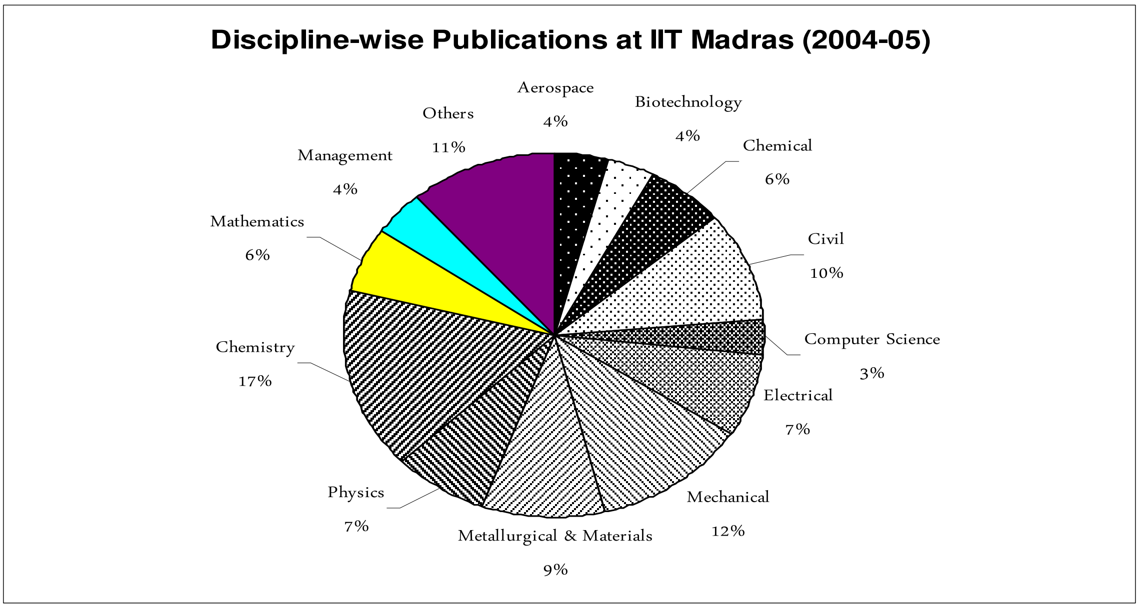
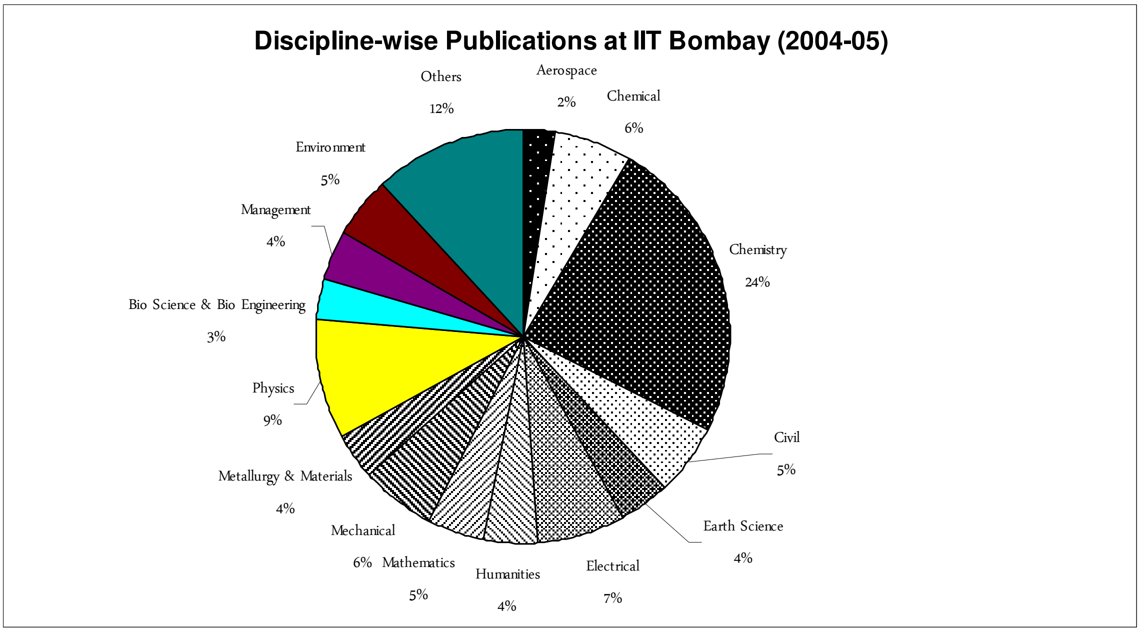


Figure 4a: Discipline-wise Publication Spread at IIT Bombay

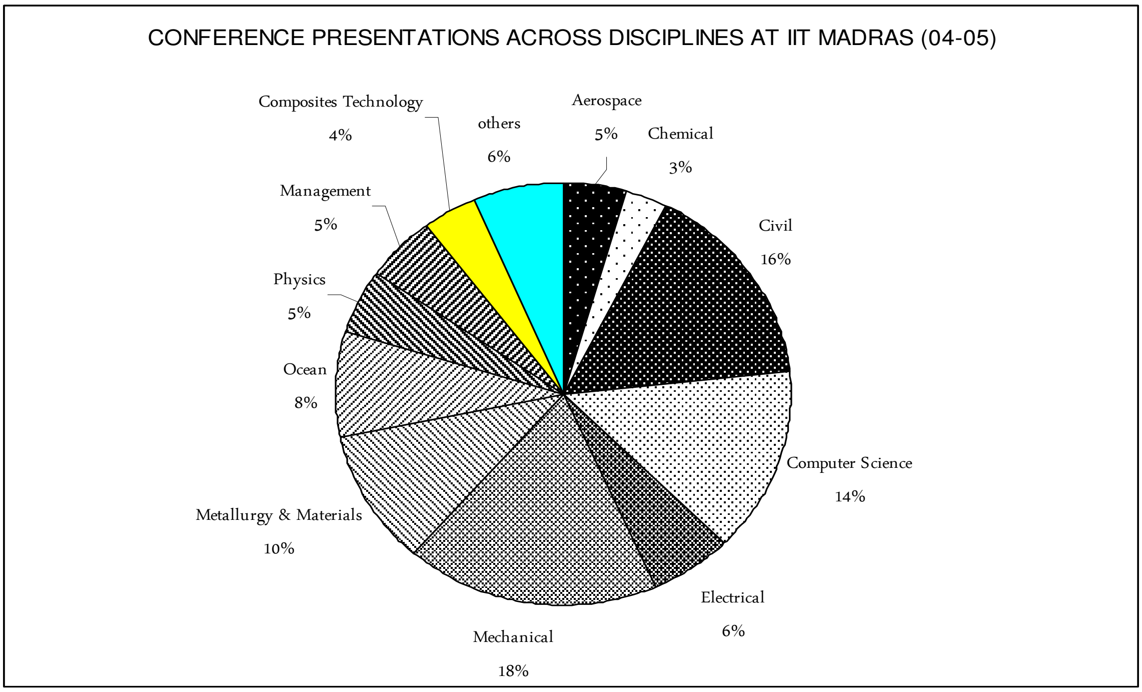


Conference Presentations

While publications in an institution are a direct indicative of their intellectual base, the representation of faculty members and other scholars in international and national seminars and conferences are also symptomatic of the knowledge that is created in an academic setting. Paper presentations in conferences have increasingly shown a direct impact on knowledge sharing and advancement in the form of publication of special issues or collaborative projects or a greater possibility of talent search. According to Merton (1957), a primary motive of university scientists is recognition within the scientific community, which emanates from publications in top-tier journals, presentations at prestigious conferences, and federal research grants. The study by Siegel et al (2004) also highlighted the result of their survey wherein 80% university administrators acknowledged the importance of conferences to display new technology and meetings on university-industry technology transfer issues.

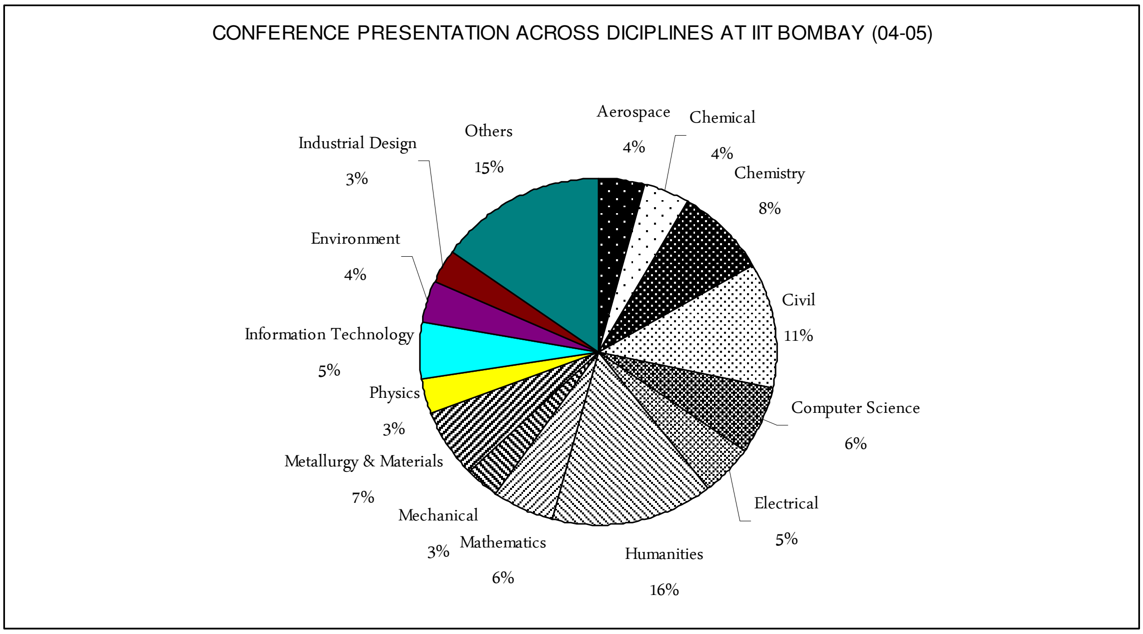
In view of the national conferences dominating the landscape of IITs, the IIT Review Committee (2004) has noted that the IITs may be playing a critical role in facilitating knowledge dissemination within the country. In IITs there has been a significant rise in participation of personnel in both national and international conferences (see Figure 5 and 5a)

Figure 5: Conference Presentations across disciplines at IIT Madras



Source: Compiled from Annual Reports of the respective IITs

Figure 5a: Conference Presentation at IIT Bombay



Patenting Activities

The technology transfer offices at IITs are involved in protecting Intellectual Property (IP) mainly in the form of patents, copyrights and designs. The filing of IP applications from academic institutions is gradually increasing, which is evident from figure 7a and 7b. The availability of data for the number of invention disclosures is unclear but the trend shows that it is increasing. As per talks with the TTO personnel, the number of invention disclosures received annually by a typical IIT is 60.

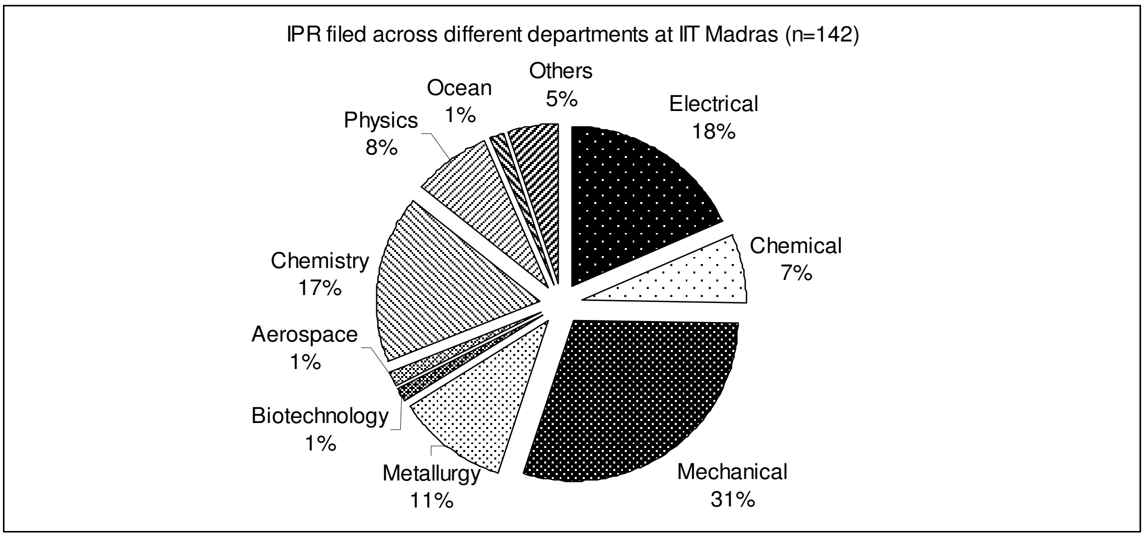
Table 14: Intellectual Property Filed at IIT Madras and IIT Bombay

Institute		2000-01	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08
IIT Madras*	Filed	1	2	3	11	12	12	18	23
	Issued	1	-	-	3	2	-	15	14
IIT Bombay	Filed	10	13	13	22	18	15	13	13
	Issued	1	4	2	-	-	3	18	14

IPR filing includes Indian and foreign patent applications, copyrights, designs and trademarks
* IPR Filed in the calendar year

The usual time lag between filing of a patent and getting granted varies from two years to as long as eight years. The average time lag works out to be 61 months or a little over five years. In IIT Madras, till March 2006, out of 190 patents that had been filed, 86 had been granted[21].

Figure 6: Intellectual Property Filed by different departments at IIT Madras



Source: Compiled from IIT Madras Annual Reports and Official Documents at IC&SR, IIT Madras

[21] This also includes the patents/copyrights that were granted but were not renewed after expiry of their term.

At the risk of a simple analysis in attempting to establish a link between patents and publications, we find that there is a linkage. One presumes that researchers at IIT must be patenting in areas in which they are good in publications. We have taken the five most prolific departments at IITs in publication count as well as in filing patent applications (see table 11). The figures within brackets are the publication/patent application count.

Figure 6a: IPR filed across different departments in IIT Bombay

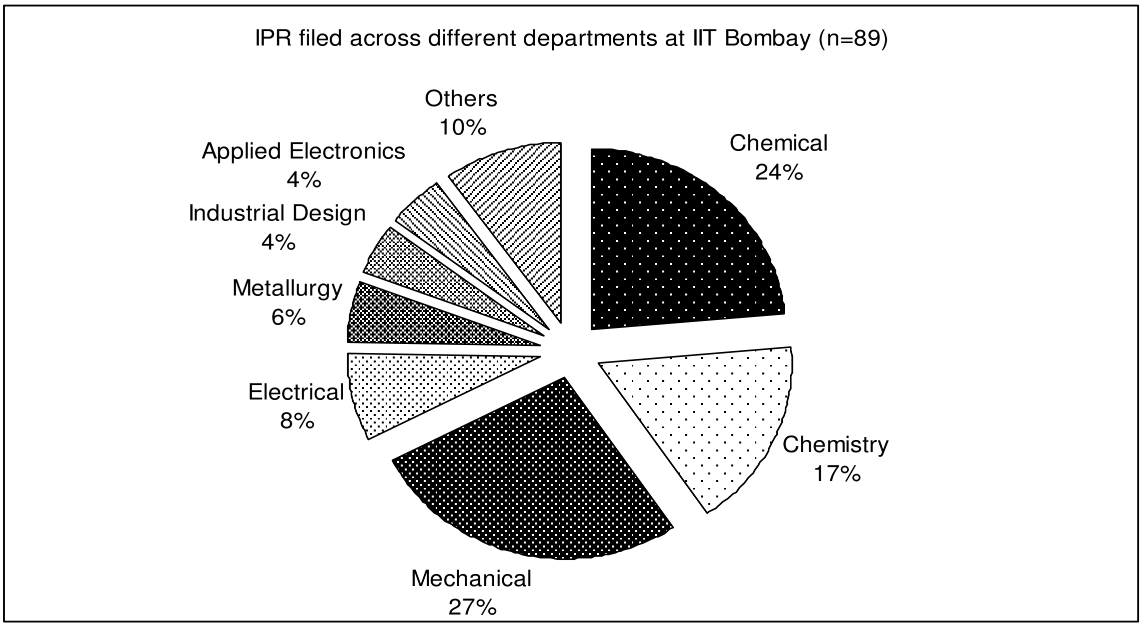


Table15: Publications vs Patents at the Two IITs Knowledge Transfer

IIT Bombay		IIT Madras	
Publications (1999-2005)	***Patents Filed***	***Publications (1999-2005)***	***Patents Filed***
Chemistry (139)	Mechanical (24)	Chemistry (81)	Mechanical (37)
Physics (53)	Chemical (21)	Mechanical (47)	Chemistry (26)
Chemical (51)	Chemistry (15)	Civil (39)	Metallurgy (23)
Civil (44)	Electrical (7)	Physics (36)	Electrical (21)
Electrical (43)	Metallurgy (5)	Maths (36)	Chemical (11)

INSTITUTIONAL ARRANGEMENTS FOR KNOWLEDGE TRANSFER

The institutional framework, consisting of policies, practices and appropriately trained human resources, are essential for meaningful knowledge transfer to occur between ARIs and industry. While ARIs get direct economic benefits stemming from their involvement in sponsored research projects and consultancy assignments, from their intellectual property (protected or not); there are also high spill-over advantages germinating from the public-private collaborations in the form increased economic activity, such as start-up firms and job creation. Often the intellectual assets developed by researchers in academic institutions – their inventions, technologies and know-how – are not transferred to industry and are rarely put to any practical or commercial use such that they can be employed in activities to stimulate economic growth. However, the institutional framework necessary for transfer of technologies/know-how from academia to the private sector is not well developed in many developing countries including India. IIT Madras too has developed such institutional arrangements, more so in the last decade for facilitating knowledge transfer.

Industrial Consultancy To Technology Transfer

IIT Madras

In the early 1970s, in some IITs (Kharagpur and Madras), efforts were made to formalise industry interaction through research projects and consultancies and as a result industry liaison agencies were established. In other IITs, such functions were carried on by other departments as the quantum of research collaboration with industry was not large. In last two decades, as the Indian industrial growth witnessed considerable growth and technological sophistication the demand of knowledge and know how from leading institutions such as IITs increased. This has led IITs to build institutional processes and mechanisms to promote knowledge transfer. Before we see the impact of knowledge creation and transfer at IIT Madras and IIT Bombay, let us also look at the organisational and institutional support structures that facilitate innovations at IITs. One of the organisational innovations that became very common, particularly in the United States, was the establishment of technology transfer offices (TTOs) or technology licensing offices (TLOs) or industry liaison offices in universities. Here the marketing model introduced a business element into the academic institutions which exemplified an aspect of the triple helix model of one institutional sphere 'taking the role of the other'.

In the past the R&D department of IITs normally undertook the task of commercialising intellectual property generated within the institute but now new systems have evolved. The establishment of TTOs, some of which are autonomous bodies; framing of innovation specific guidelines and policies (for instance licensing policy, revenue sharing policy, intellectual property policy); technology business incubation units are such dynamic formations that have compelled the academic institutes to evolve or start attempting in evolving innovation strategies. At IIT Madras, industry interaction and other functions of a technology transfer office is undertaken by Centre for Industrial Consultancy and Sponsored Research (IC & SR), established in early 1970's. This centre is headed by the dean, while the key personnel involved are the chief techno-economic officer, who is supported by senior technical officers and research staff. The entrepreneurial infrastructure at IIT Madras has been developed since 1990s. The Centre has facilitated the M.S. programme in Entrepreneurship and successfully coordinated technology development and management projects. The creation of C-TIDES: the Cell for Technology Innovation, Development and

Entrepreneurship Support at IIT Madras is a student focused establishment primarily to develop the spirit of entrepreneurship and provide mentorship from industry to young entrepreneurs.

Even though IIT Madras established a formal IC&SR unit which manages sponsored and consultancy research, The Telecommunication and Computer Networking (TeNeT) group, which has been constituted from different science and engineering faculties, has been the focal point of the institute for incubation and enterprise creation through spin-offs in the last decade. It may be said that IC&SR and TeNeT operate at IIT Madras in a complimentary mode. The TeNeT group which promotes incubation and enterprise creation at IIT Madras is described as an un-conventional model[22] or can be considered as non-formal model as its members, faculty and students are drawn from engineering, electrical and computing departments and housed in close proximity to the Department of Electrical Engineering. It is headed by Professor Ashok Jhunjhunwala, Department of Electrical Engineering, who has given leadership and directed its research and incubation for the last 12 years. The other leading actors at TeNeT is Professor B.Ramamurthy. There are over 200 professionals, engineers, technicians and other staff including 14 core IIT faculties - who form the TeNeT group at IIT Madras. These professionals are working in diverse areas and fields of research from 8 to 10 dedicated laboratories of the institute engaged in wireless communication, computer networking, fibre optics, digital systems architecture, integrated voice, video and data communications, computing and translations for rural development in India.

Research park at IIT Madras

Besides knowledge and technology successful ventures require vision, understanding of market, venture and working capital, organisation building capabilities, and managerial skills. A quality research and development ecosystem like the IITs have faculty who encompass vast knowledge and expertise, students, R&D personnel and entrepreneurs. Research/Technology Parks combine quality R&D ecosystem with the above mentioned requirements of a successful venture. These Parks have a significant role in promoting research and development by the ARI in partnership with industry, assisting in the growth of new ventures, and promoting economic development, as also it has an important role in aiding transfer of technology/know-how and business skills between ARI and industry tenants.

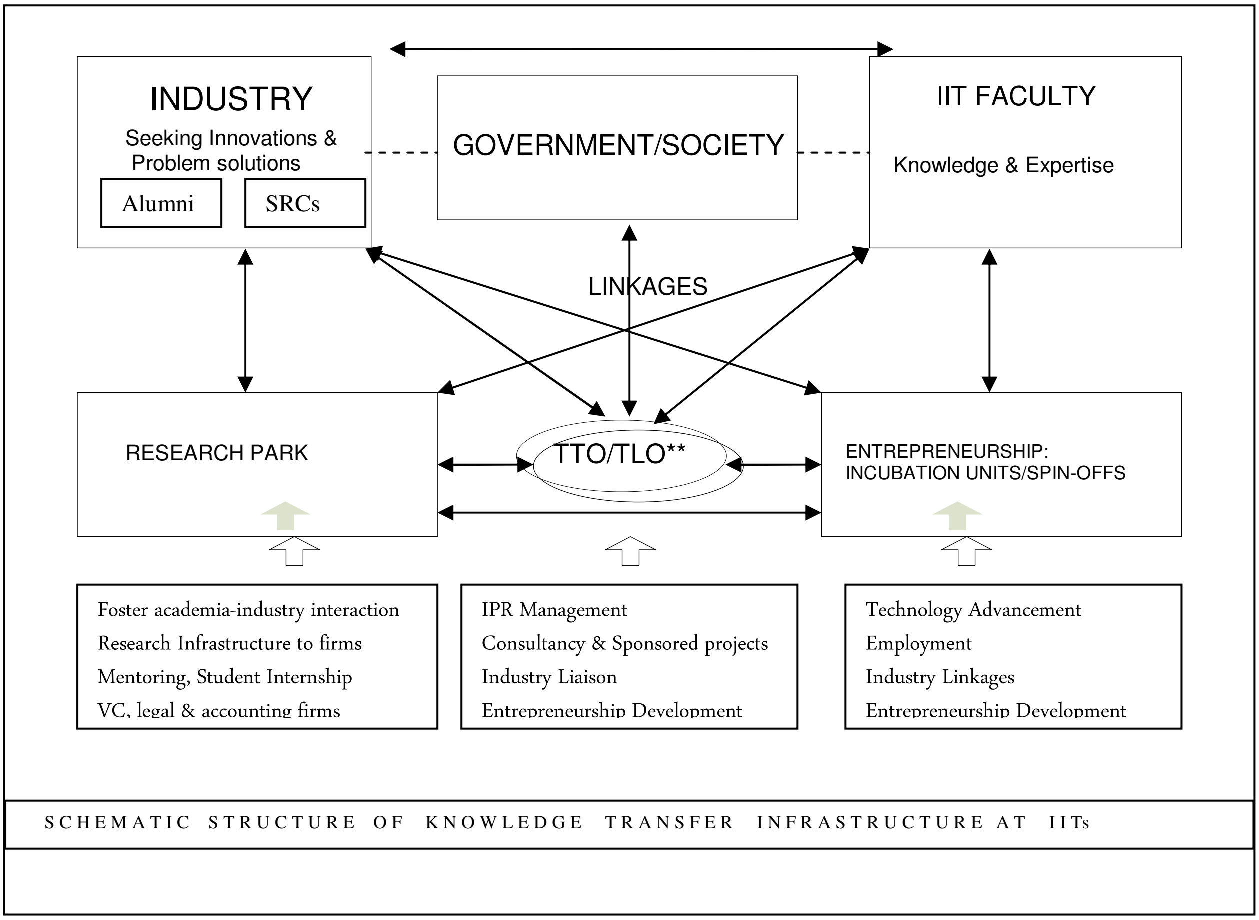
IIT Madras Research Park, a recent initiative has been promoted by IIT Madras and Alumni with the mission of creating a collaborative environment between industry and academia to enable; encourage and develop cutting-edge technology and innovation that exceeds global standards. The Research Park intends to leverage IIT Madras's technological capabilities to innovate and promote entrepreneurship by navigating research into ideas, developing the ideas into products/processes, incubating products/processes into ventures, and nurturing ventures into enterprises[23]. This is expected inter-alia, to enable companies mentioned by IIT Madras to realize the commercial value of their intellectual property.

[22] See Basant and Chandra (2006)

[23] IITM Research Park will have a built-up space of 1.5 million sq.ft., one Innovation cum Incubation Centre (IIC) that will be the fountainhead of R&D and Entrepreneurship Development, three R&D Towers housing about 100 Companies and Organisations pursuing serious R&D activities which would be large, medium and small industries and enterprises from India and overseas. The park also plans to have over 10,000 engineers, scientists, researchers, innovators in diverse technologies. The finishing school at the IIC plans to groom around 5000 new entrepreneurs in the future. The research Park would start operations in late 2008.

In short, the knowledge transfer from IITs can be understood through the schematic diagram (figure 7). However, there will be some variations among different IITs.

Figure 7: Schematic Diagram of Knowledge Transfer Infrastructure at IITs



IPR: Intellectual Property Rights; VC: Venture Capital; S&T: Science & Technology; SRCs: Strategic Research Coalition; TTO/TLO: Technology Transfer Office/Technology Licensing Office

IIT Bombay

The Industrial Research and Consultancy Centre was set up in IIT B in the 1970s, to foster the overall R&D growth of the institute and promotes and manages academia-industry interaction, and all externally funded research and development projects. It undertakes financial management and recruitment of researchers to work on funded projects as well as handles activities related to intellectual property protection/management and technology transfer. The IRCC has an advisory committee with some faculty as members of the committee. The activities undertaken at IRCC are spread across its technical, administrative and accounts sections. The technical section is primarily concerned with technical management of sponsored and consultancy projects, industrial interface and technology transfers, intellectual property management, and MoU/agreements with industries and other external agencies. The administrative section is responsible for the recruitment and administration of all project staff working on funded projects. The accounts section oversees all the financial matters of sponsored research and consultancy projects. The Dean (R&D) who is assisted by an associate dean heads the IRCC. The technical section has a Chief

Technical officer and two technical officers along with other supporting staff. The accounts section has an administrative officer, while a deputy registrar heads the administrative section. The institute also has an Information Management Cell, the main objective of which is to assist performance evaluation and internal decision-making through collection of data and through trend analysis.

IIT Bombay set up a incubator in 1999 at the Kanwal Rekhi School of Information Technology. This incubator, more than any other achievement in its initial years, was an important source for creating an environment for entrepreneurship.[24] This has further catalysed the institute's effort to set up a full fledged incubator covering other areas of science, engineering and technology. This effort received supports from the government policies via Department of Science and Technology which had a created a 'window' for incubation support schemes in institutions. In an effort to further boost the transfer of technologies and commercialise R&D, IIT Bombay set up an independent Society for Innovation and Entrpreneurship (SINE) in 2004. On behalf of IIT B, SINE manages equity in incubated firms or spin-offs.

The policy of revenue sharing

One of the key policies in knowledge transfer is the policy that specifies distribution or sharing of revenue earnings from intellectual property of the academic institute. When any inventor(s) realises that his/her idea or invention can have (or already has) commercial potential, they get an incentive in the form of a share in the revenue earnings arising from the venture that has to be (or has been) commercialised. The most common formula in sharing of revenues in academic institutes is the equal sharing formula where the inventor, the department and the academic institute get 33 percent each. The other fairly common alternative is an equal 50-50 sharing between university and the inventor (Graff et al., 2002). Interestingly the sharing patterns for the five IITs are different and at IIT Madras, the revenue sharing policy states: "50% of the revenue is credited to IIT Madras while remaining revenue is divided equally among inventors as per the royalty sharing agreement. Out of IIT Madras share, 5% is transferred to the concerned department development fund and 2% to IC&SR overhead and balance to the institute corpus fund". In the case of IIT Bombay, as the table below indicates, inventors get a share of 70% and the institute receives the rest 30%.

Table 16: Revenue Sharing Policy of IITs from institute owned intellectual property

Institution	Revenue Sharing
IIT Bombay	Inventor(s) get a share of 70 percent while IIT Bombay receives 30 percent. This holds if the net earnings do not cross a threshold amount for any inventor.
IIT Madras	Fifty percent of the revenue is credited to IIT Madras while remaining revenue is divided equally among inventors as per the royalty sharing agreement. Out of IIT Madras share five percent is transferred to the concerned department development fund and two percent to IC&SR overhead and balance to the institute corpus fund.

[24] See Basant and Chandra (2006)

Consultancy and Sponsored Projects

Institutions of higher education engaged in teaching and research are now seen to occupy a place in the knowledge production system that distinctly reflects a shift towards playing other significant roles in capitalizing on their knowledge assets, contributing to economic progress, and aiding in regional development and so on. One of the most important channels that drive knowledge generation is the sponsored research and industrial consultancy projects. The trend in IITs is apparently seen to embrace such activities and programs that in effect give them a clear competitive advantage over other knowledge producing institutions in creating and fostering innovations. Consultancy services, and sponsored research projects have an exchange value that earns revenue for IITs. The recognition of an exchange value for such projects and assignments is generally referred to as capitalisation of those assets.

Table 17: Combined Earnings of Sponsored Research and Industrial Consultancy Projects (SRIC) as a Percentage of the Total Grant Given to IITs
All values of Earnings and Grants in Rs million

IITs	Earnings through SRIC (99-00)	Government Grant to IITs in 1999-2000	Earnings through SRIC as a percentage of total grant (99-00)	Earnings through SRIC (04-05)	Government Grant to IITs in 2004-2005	Earnings through SRIC as a percentage of total grant (04-05)
IIT Bombay	197.6	671.5	29	380.0	1024.0	37
IIT Madras	112.8	943.7	12	435.5	1100.0	40
All Five IITs	701.3	4066.2	17.2	2291.2	5154.0	44.4

*IIT Kharagpur, grant-in-aid in (2000-01); Source: Computed from the Annual Reports of respective IITs

The combined SRIC earnings have increased from as low as 12% in 1999-2000 to 60% in 2004-05 of the total government grant-in-aid in the case of IIT Madras and from 29% to 37% in the case of IIT Bombay for the same period. If we add the income from other sources (tuition fees, endowments), this share will decrease slightly, but the important thing to note is that the earnings through SRIC, technology transfers, licensing and spin-offs has witnessed growth in a short span of five years and this trend is likely to continue. However one should also note that the majority of earnings are from government sponsored research projects funded through national agencies.

Table 18: Increase in Sponsored Research Projects
(all values in Rs million)

	1999-2000	2004-2005	Percentage Increase (%)
IIT Madras	45.0	351.6	681
IIT Bombay	145.6	280.0	92
All Five IITs	576.9	1669.5	189

Source: Compiled from Annual Reports of respective IITs (1999-2005)

Sponsored Research Projects

In addition to the primary objective of teaching and research, the faculty members and research personnel of IITs undertake several sponsored research projects. Sponsored research includes research in areas of current relevance, new investigations, products or system development and so on, usually proposed by faculty. These projects are generally funded by government agencies, national research councils and both public and private industry (national and international). These projects provide for bringing in new resources to the institute and also permit technical staff to be employed for specific durations to carry out the research (see figure 8).

Figure 8: Sponsored Research Projects at IIT Bombay and their Value

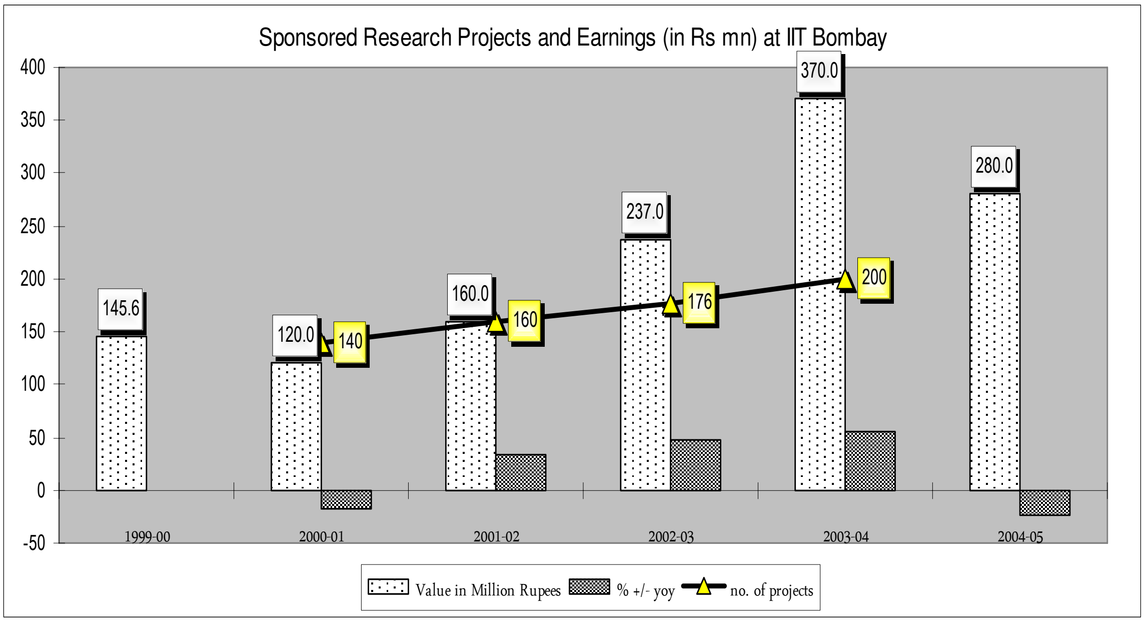
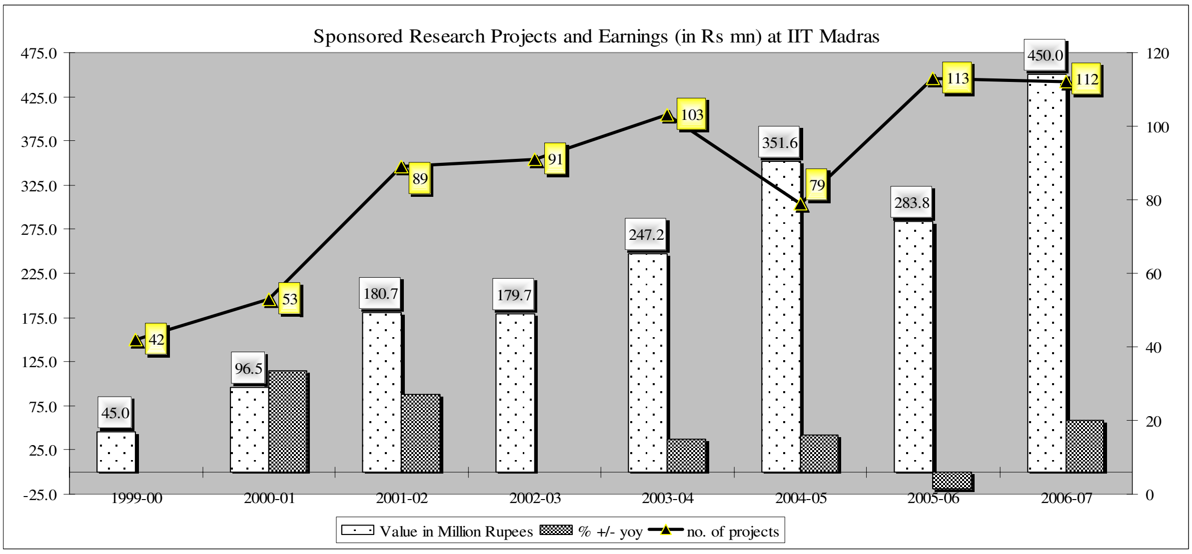


Figure 8a: Sponsored Research Projects at IIT Madras and their Value



Source: Compiled from IIT Madras Annual Reports and Official Documents at IC&SR, IIT Madras

The EPP at IIT Madras was the maximum for Electrical Engineering at Rs 3.3 million while for Chemical Engineering the EPP was Rs 1.5 million. In the five year period from 1999-00 to 2004-05, on an average out of the total 388 faculty/researchers at IIT Madras, 214 were involved in sponsored research which is nearly 55% of the total faculty.

Industrial Consultancy

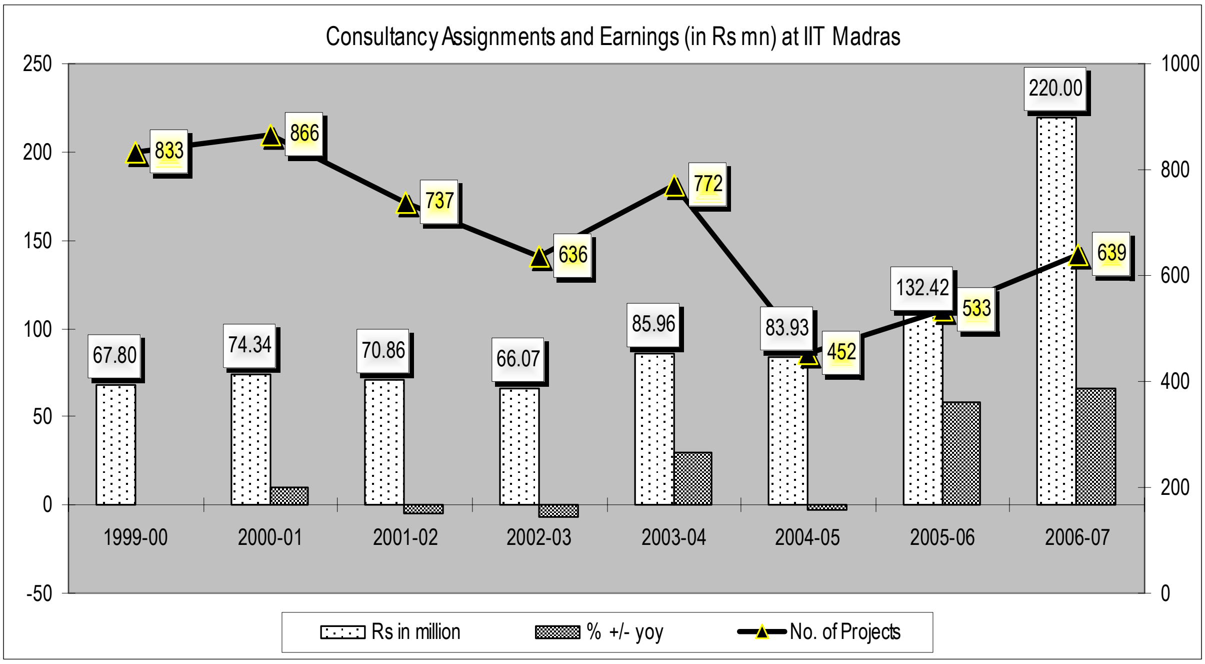
The assignments of direct relevance to industry, offered in the name of industrial consultancy include testing and certification of industrial products; development of prototypes and their testing; exploring new approaches to design and manufacturing; helping in development of new products; investigating/problem solving; and offering specialized programs to industry and keeping them abreast of latest developments. Undertaking consultancy jobs has been an effective way of making available the expertise of the IIT personnel for the benefit of industry, government and others. Its value to IITs in stimulating further interactions and research collaborations has been well recognised, in addition to the professional and financial benefits obtained by the academics themselves. The consultancy jobs also show a significant rise at all the IITs (see figure 9 and table 15), though not as significant as in sponsored research.

Table 19: Increase in Consultancy Assignments
(all values in Rs million)

	1999-2000	2004-2005	Percentage Increase
IIT Madras	67.8	83.9	24
IIT Bombay	52.0	100.0	92

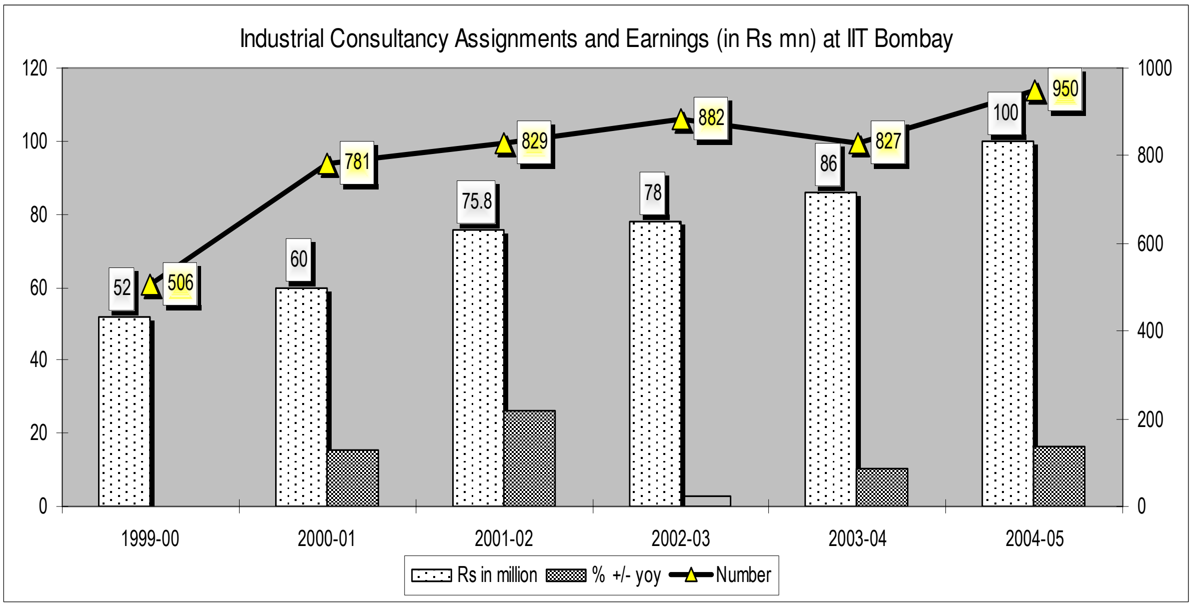
Source: Compiled from Annual Reports of IIT Madras (1999 and 2005)

Figure 9: Industrial Consultancy Assignments at IIT Madras and their Value



Source: Compiled from IIT Madras Annual Reports and Official Documents at IC&SR, IIT Madras

Figure 9a: Industrial Consultancy Assignments at IIT Bombay and their Value



Incubation and Enterprise Creation or Spin-offs

Incubation and enterprise creation or what is known as spin-offs (we define spin-offs as companies that evolve from academic institutions through commercialisation of intellectual property and transfer of technology developed within academic institutions) has come into prominence and sharp focus in the literature on Triple Helix. It is regarded as one of the main indicators for entrepreneurial universities. In our study, while IITs at Kanpur, Delhi and Bombay have adopted the conventional approach of creating formal incubation units, the spin-offs at IIT Kharagpur and IIT Madras have been created without a formal incubation setup. This phenomenon of enterprise creation without the benefit of formal structures may be regarded as unconventional mode of spin-off creation (Basant and Chandra, 2007). However, in October 2006, a formal incubation unit was set up at IIT Madras – the Rural Technology Business Incubation (RTBI) that promotes such ventures that have a rural development focus. Up to March 2009, 12 companies have been residents of RTBI and 3 are about to complete their residency tenure and graduate successfully. IIT Madras has been quite active in incubation and enterprise creation at par with other IITs. The Telecommunication and Computer Networking (TeNeT) group at IIT Madras comprises of faculty members from electrical and computer faculties who came together about 14 years back in 1994. Even though the main objective of TeNeT group is to fulfil socio-economic agenda of innovation in ICT for development, the group has incubated over 15 enterprises from the knowledge generated at the institute (see Table 20, figure 10).

Most of the firms incubated from IIT Madras have been formed by the students and partners from outside the institute. Among the earliest firms incubated is Midas Communications which designed integrated circuits (ICs) and in collaboration with Analog Devices, USA manufactures and supplies to the consumers all over the world. Midas has offices and outlets in some 25 countries of the world. Other incubated firms from IIT Madras collaborated and partnered with global ICT firms such as Polaris Software, Intel Corporation and national firms such as Electronics Corporation of India.

In the case of IIT Bombay, among the most success stories include Geosyndicate Power Private Limited. The technology transferred to the firm which markets currently involves the use of non-conventional energy mechanism like Geothermal to deliver high efficiency and low cost electricity to Indian power sector. Other firms created fall in the category of software solutions such as creative ideas portal technology to M/s Voyager2 Infotech; wireless gateways and connectivity bridges technology to M/s Myzus Technologies; Information Rights and Firewall solutions technology to M/s Seclore Technology Pvt Ltd; and broad band based technologies to M/s Eisodus Networks Pvt Ltd. Up to March 2009, in all 33 SINE companies have been formed, of which 14 have graduated; 15 are residents at the IITB campus while four incubation units could not succeed.

Table 20: Incubation and Entrepreneurial Infrastructure at IIT Madras and IIT Bombay

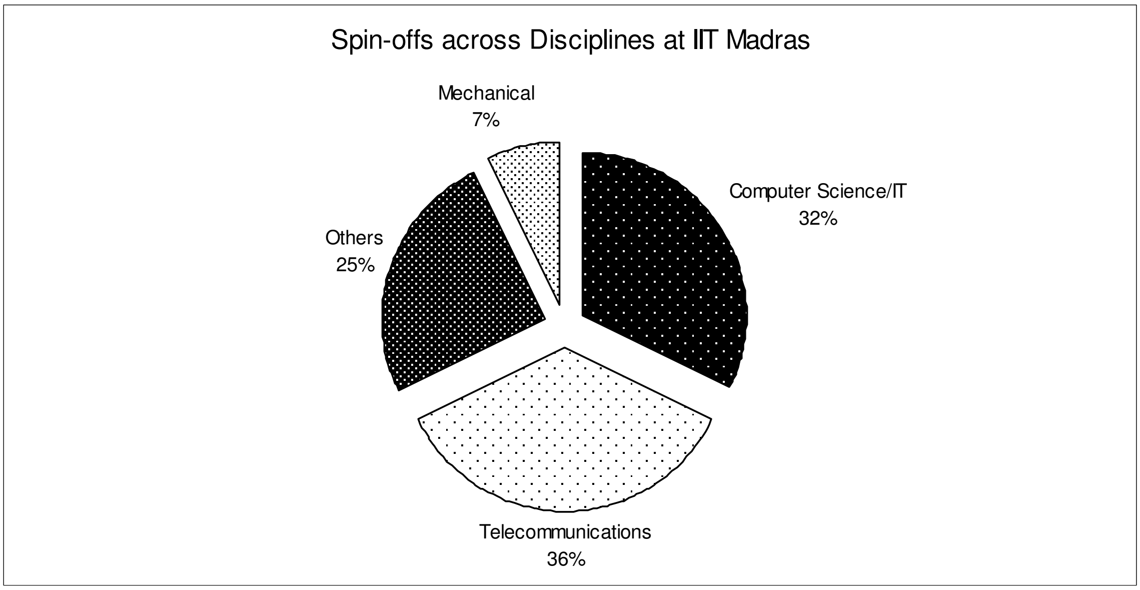
Institution	Incubation Unit & Year	No. of Incubatee /spin-offs (from 1994 till 2008)	Prominent Areas of Expertise of Incubatee Units	Other Entrepreneurial Infrastructure*
IIT Bombay	Incubator at Kanwal Rekhi School of ICT (1999) & Society for Innovation and Entrepreneurship (SINE); 2004**	33	IT, computer science, electronics, design, earth sciences, energy & environment, electrical, chemical, aerospace	Entrepreneurship Cell
IIT Madras	Rural Technology Business Incubation (2006) and non-formal dynamic group like Tele-communication Network Group (TeNeT); 1999	12 16 Total: 28	Telecommunications; Information Technology; Computer Science; Physics	C-TIDES; Research Park

Source: Compiled from official documents & newsletters at Sponsored Research & Industrial Consultancy Centre, IIT Madras

The concept of a research park near IIT Madras however also has additional features. The Rural Technology Business Incubation unit would also be relocating with its twelve companies to the Research Park. Apart from the pattern of incubation, maturation and relocation which is seen to be a key element in the strategy for the expansion of the Research Park, there is a 'real estate' component of attracting established businesses and laboratories to the park. The businesses housed in the research park also propose to offer internships to students.[25]

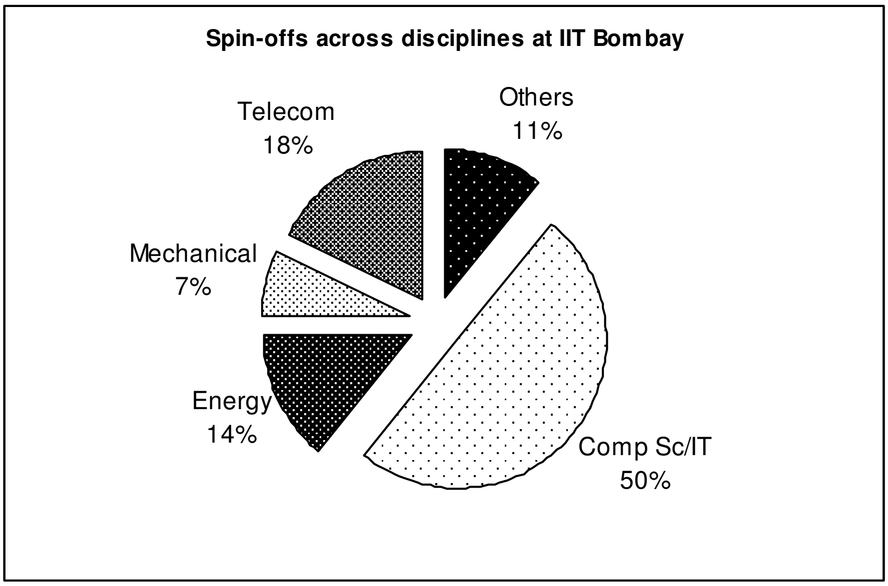
The establishment of spin-off firms is seen as is an important commercialisation mechanism to hold and develop intellectual property where a high return is foreseen from future sales. A comprehensive analysis of the firms which have begun life within IITs, provide an interesting picture.

Figure 10: Spin offs across disciplines at IIT Madras



[25] We can draw a parallel with the University of Cambridge which has indirectly played a key role in the development of the area through the Science Park since it has been at the origin of virtually all the new companies in one way or another. Some 17 per cent of the firms were formed by people coming straight from the university, while others were indirect spin-offs of research conducted at the university. Other start-ups owe their existence to the presence of the university nearby. Most of those companies are very small, with an average of 11 employees. The success of the Cambridge Science Park is widely recognized and is part of what has come to be known as the "Cambridge phenomenon," which is regarded as a symbol of the innovative milieu.

Figure 10a: Spin offs across Disciplines at IIT Bombay



In case of start-up firms, it is observed that serious consideration is given to the nature of the technology in terms of its applicability to several markets and the availability of firms that are capable of bringing the technology to the market place. At IITs, there is an increasing eagerness among the academics with substantial research performance in seeing the potential outcomes of their research being realised. For some incubators in the campus, it was possible to realise revenues directly, while for others, the economic return was indirect, but for both categories, it was reportedly found that the social return was considerable.

CONCLUDING REMARKS

IITs in India have evolved as country's leading engineering institutions over the last six decades. The structure of teaching courses and research in IITs, right from the beginning, has drawn inspiration from the MIT model. Over the last six decades, Indian IITs have acquired international recognition and a 'brand name' for excellence in teaching and producing quality engineering and science graduates. However, only since the last decade that IITs have come to be recognised for their research and development (R&D) potential with the increasing graduate and post-graduate and doctoral programmes. Through 'human capital' and research contribution, IITs have come to occupy a significant position in the Indian national innovation system, particularly during the last decade. The two institutions explored in this study, namely IIT Madras and IIT Bombay, are clear examples of the IIT system as whole.

Our exploration of knowledge production and knowledge transfer in these two institutions mainly concerned the ways in which the institutional structures have progressed over the last decade or so to foster and promote university-industry linkages and enterprise creation. Secondly, our concern has been to explore the extent to which the Indian IITs have embraced or even reflect the emergence of entrepreneurial university 'culture' or style. Thirdly, to explore how the two institutes differ in the processes of knowledge transfer and enterprise creation.

From an overall perspective of IITs, specifically the two cases considered here, it is rather apparent that the two IITs assign rather greater importance to teaching, research (open science, peer reviewed publications and advancement of science and engineering knowledge) compared to the objective of transferring knowledge to industry and entrepreneurial activities. Given the long standing tradition of emulating MIT as the main reference model, it appears that IITs have some how focused more on attaining excellence in teaching and research compared to knowledge transfer. In a way, this also shows the pre-eminence of upholding Humboldtian values. However, this does not mean to suggest that the latter dimension is not important. Our interviews with several IIT faculty reveals that the supply of highly skilled and excellent engineering graduates to industry both in India and abroad, mainly USA is indeed seen as an indirect contribution to the industry in that it is non-targeted through institutionalised mechanisms.

The concepts and innovation policies which promoted and popularised Triple Helix, university – industry relations and that of knowledge based economies did not emerge until the 1990s. India begun to liberalise its economy in 1991 and the impact of globalisation and emerging discourse of knowledge based economies coupled with the importance of new technologies (biotechnology, ICT based technologies and more recently nano and material sciences) drew attention to science based innovation in universities. IITs and some other leading Indian universities, such as, Indian Institute of Science, Jawaharlal Nehru University, Delhi University, Madurai Kamraj University, among others, begun to respond in the 1990s to this new policy discourse. Even though the two IITs begun to institutionalise some form of TTOs from as early as 1970s to promote consultancy and sponsored research, it was only since the late 1990s the signs of a shift towards embracing entrepreneurial university became apparent with the dynamic institutional and organisational factors. The formation of incubator at the Kanwal Rekhi School of Information Technology in 1999 and subsequent creation of SINE in 2004 at IIT Bombay; and the establishment of TeNeT group at IIT Madras as also the RTBI to promote enterprise creation (spin-offs), are clear indicators of this development. It is observed that the two IITs are no longer content merely to provide human resources and new knowledge as a traditional ARI but have in addition assumed a more visible and pro-active role in knowledge commercialisation through increased sponsored research and industrial consultancy assignments, number of spin-offs generated and a moderate rise in IPR activities.

With new initiatives given to faculty and research staff for technology commercialisation, with the institutionalisation of certain IPR policies, and with the establishment and strengthening of organisational mechanisms, there has been a significant increase in knowledge transfer activities from IIT Madras and IIT Bombay in the 1990s compared to earlier decade. However, these institutes are still facing the challenges towards its new role particularly in faculty attitude towards engaging in entrepreneurial activities in an academic environment.

Knowledge transfers at IIT Madras and IIT Bombay have shown considerable increase through two modes. The first is through the traditional form of knowledge transfer comprising of sponsored research, industrial consultancy, training of industry/government personnel, and such activities. Secondly, the mode of building an entrepreneurial culture via incubation and entrepreneurship programmes and training as noted above which have fostered and promoted enterprise creation and spin-offs. The first mode has been by far the most successful mode as it involves many faculty members and researchers at the two IITs. More than 70% faculty in both the IITs are involved in industrial consultancy and sponsored research in departments such as ocean engineering, ICT, composite technology centre, civil, mechanical and electrical engineering and applied mechanics[26]. Our empirical research and quantitative data reveals that the traditional forms or mode of knowledge transfer via sponsored research and industrial consultancy are considered more important compared to patenting and licensing. The other important finding that is clearly revealed from the two case studies of IITs is that the IPR and patenting are not critical for enterprise creation and spin-offs. It may be the case that the two institutions in our study are rather focused more on engineering sciences and ICT based disciplines rather than biotechnology and biomedical where IPRs assume rather greater significance.

Our comparison of IIT Bombay and IIT Madras has also revealed an important finding for the role of enterprise creation and spin-offs. While the IIT Bombay institutionalised a formal incubation and TTO and was responsible for a cumulative 33 SINE companies, the TeNeT group and RTBI at IIT Madras reflected a mix of non-formal and conventional source of incubation and enterprise creation. It is now responsible for 28 spin-offs. In a large measure the two IITs reflect two different patterns or 'models' of enterprise creation. Closely associated with these different patterns, is the development of indirect spin-offs from IITs. In other words, there are several leading Indian software firms such as TCS and Infosys which are either managed or owned by engineers trained in IITs and who have spent several years abroad in Silicon Valley before coming back to India to establish such firms. However, despite such indicators it is rather too early to suggest that IIT Madras and IIT Bomay are emerging as entrepreneurial universities. IITs are rather a special case of Indian university system of having institutionalised knowledge transfer modes as compared to other universities. We can thus say that the triple helix based entrepreneurial mode is emerging and is seen as a special case in the Indian academic system in IITs.

From an overall policy perspective which fosters entrepreneurial culture and enterprise creation in ARIs, we may say that IITs and other universities in India lack appropriate 'innovation ecosystem' and a well developed venture capital support structure as is seen in the case of MIT, Stanford and Silicon Valley in USA. The government has evolved several schemes to promote university – industry relations but again it will take few more years before they could have any visible impact. Further, India is still in the process of framing a national regulation and law equivalent to Bayh-Dole Act of USA which governs IPR in universities.

[26] As per our study, taking into account the number of faculty involved in consultancy projects across departments from 1999 to 2005. Similar is the case with sponsored research where the composite technology centre, department of physics and metallurgy have over 75% faculty involved in such projects.

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