Changing Landscape of Innovation Systems in India: Collaboration and Entrepreneurship in Emerging Technology

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Abstract Engaging with emerging technology and harnessing its potential benefits requires a well functioning innovation system. The increasing complexities of emerging technology in conjunction with their convergence demands a systemic interaction of various actors in the innovation system and a greater need for S&T collaboration at various spatial scale. Also, emerging technology throws entrepreneurial challenges and demands entrepreneurs as 'technology champions' to facilitate the use of frontier technologies. With increasing global interdependence the various spatial dimensions of innovation systems are not expected to act in an isolated manner. The paper attempts to capture the changing dynamics of innovation systems in India by drawing the interlinkages between various spatial scales of innovation systems and gain insights into the nature of collaborations and entrepreneurship in emerging field of nanotechnology. The paper draws a conclusion that despite a weak innovation system in India, collaborations and entrepreneurship in the exploitation and generation of emerging technology would provide opportunities to an developing country like India to catch-up. However, the countries ability to adopt to the changing demands posed by emerging technology will determine the efficiency of the innovation system.
Key words innovation system, emerging technology, incremental innovation, radical innovation, technology capabilities

1 Introduction

Science, in its simplest form, means the creation of knowledge and technology is the application of that knowledge towards the betterment of humankind. Innovation on the other hand is the complete process through which new ideas are created and implemented particularly through the process of commercialization. The presence or absence of innovation system characterized by the level and range of university research, the presence of science-industry bridging mechanisms, vertical and horizontal links among local firms, user-producer interaction, and the types and levels of firms innovative efforts (Nelson, 1993) enables a country to generate and exploit the opportunities posed by scientific and technological developments.

Emerging technology, such as information and communication technology, biotechnology and nanotechnology, may lead to a paradigmatic shift in the Indian innovation system. The new technology may need redefinition of existing strategies by the firm as it leads to a different level of dynamism in the industry and transform the very settings under which the industry operates. The challenges posed in engaging with emerging technology may demand shift in strategies such as product differentiation based on incremental innovation to that of radical or major innovation. In this context it becomes important to understand the preparedness of institutions to undergo such shifts and thereby prepare a framework for identifying the specific measures that are needed to strengthen innovation systems in the context of emerging technology.

2 Snapshot of Indian Innovation System

The evolution of Indian innovation system can be classified into three stages: 1) The initial growth phase; 2) The restrictive phase/inward looking phase; and 3) The liberalized phase/outward looking phase.

2.1 The initial growth phase

Having started the industrial growth in 1948 with the announcement of Industrial Policy Resolution 1948, India pursued an inward looking policy of import substitution across all sectors with a particular emphasis on basic and heavy industries. To meet the technological requirements of heavy industries FDI and technology licensing were encouraged and foreign collaborations over wide range of industries were promoted. Till 1968 the adoption of non-discriminatory policy between Indian enterprises and its foreign counterparts resulted in financial as well as technical collaborations. The average annual number of foreign collaborations increased from 35 during 1948-55 to 210 during 1964-70. FDI stock witnessed a more than two-fold increase from Rs 2560 million in 1948 to Rs 5660 in million in 1964. Payments related to technology increased from Rs 12 million in 1956-57 to Rs 190 million in 1967-68 (RBI, 1992).

Measures were also undertaken to strengthen scientific and technological capacity. The Ministry of Scientific Research and Cultural Affairs was created in1948. The Science Policy Resolution announced in 1958 adopted a linear approach for the development of science and technology and considered the creation of scientific base as a pre-requisite for development of domestic R&D capacity. Focus on building S&T infrastructure during this phase resulted in the increase of the number of universities from 25 in 1947 to 80 in 1969. There was also a spurt in the number of engineering colleges from 38 to 138 in 1970. Scientific agencies such as Council for Scientific and Industrial Research (CSIR), Defence Research Development Organization (DRDO), and the Department of Atomic Energy (DAE) were established to increase the scientific base besides the establishment of consulting, engineering and design organizations. All these effort resulted in the building of a relatively substantial scientific and research base. However, there was a disjoint in the process of industrialization, which proceeded on the basis of imported technologies, and the effort to build R&D capabilities by focusing on a strong scientific and research base.

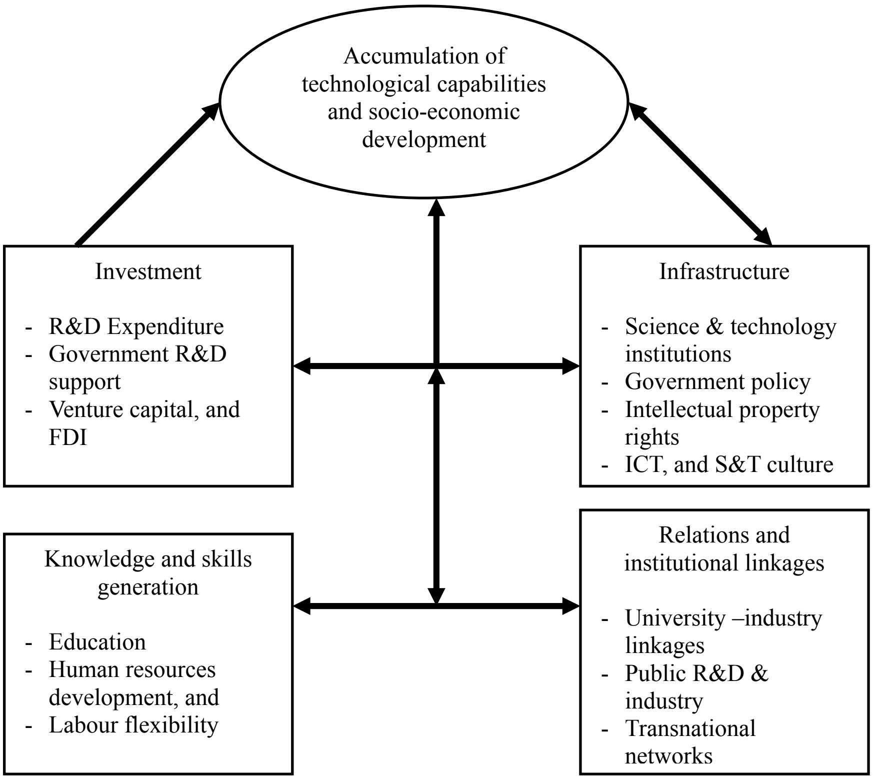

Figure 1 Major Elements of the Indian Innovation System
Source: Baskaran and Muchie 2007

2.2 The restrictive phase/inward looking phase

The evolution of Indian innovation system by the late 1960s was driven by the defensive and inward-looking policy of self-reliance and emphasis on strengthening the scientific and technological capacity for economic and political independence. Building up of local technological capabilities was emphasized upon so as to meet domestic demands and to reduce foreign dependency. Towards ensuring ‘self-reliance’ and ‘social justice’ government tightened the industrial licensing sector and the foreign trade sector and imposed numerous restrictions on foreign collaborations. FDI was however allowed only in core industries wherein little progress had been made nationally. As a result there was a development of indigenous R&D capabilities and local machine tools and industrial equipment suppliers as little or no technical assistance was received from foreign technology suppliers (Cooper, 1988, p. 117).

The policy of self-reliance necessitated a re-examination of R&D policies and strengthening of the S&T infrastructure and planning process. Creation of a separate Department of Science, making S&T planning an integral part of the overall planning process with the creation of the National Commission on Science and Technology (NCST), and including a separate chapter on S&T in the Fifth-Plan document (1974-79) were some of the steps undertaken during this phase. To promote R&D in industry the following major policies were adopted - the introduction of the Patent Act, 1970; the introduction of the scheme of recognizing in-house R&D units and; the promotion of industry-institution linkages.

Notwithstanding the development of indigenous technological capabilities Indian firms mostly made minor innovations producing cheap and reliable products to cater to the domestic market. There were hardly any major innovations to their products that could be exported. Further, the creation of a strong scientific research base often did not contribute directly to solve the pressing socio-economic problems of the country (Mascarenhas, 1982). Also the policy of self-reliance leading to the distribution of scarce resources to all the sectors resulted in resource constraints in all sectors.

Although India witnessed the creation of S&T capacity in the first phase, its focus on technology generation to harness S&T capabilities could not meet with much success as evident in industrial stagnation during this phase. This was mainly because of inconsistency or neglect in various aspects of the technology policy viz., technology acquisition, technology generation and diffusion and an inability to maintain a balance between technology and industrial policies. Absence of a strong competitive pressure on the domestic firms from other domestic firms, importers, foreign companies or export markets, the mismatch between manpower requirements and the output of higher education system, weak linkages between universities and institutes, and the lack of access to foreign technology when most of the R&D was adaptive in nature led to the underutilization of research capabilities and resulted in a weak innovation system.

2.3 The liberalized phase/outward looking phase

In the 1980s with the deceleration in economic performance India adopted an outward looking innovation system approach and an export promotion strategy. This was evident from the industrial policy resolution of 1991 leading to the liberalization of Indian licensing policies, foreign technology agreements, Monopolies and Restrictive Trade Practices Act. This reform process continued in the years to follow with the continuing liberalization of financial, infrastructure, telecom, information technology and foreign trade sectors.

The liberalization policy made a significant impact on the performance of innovation system. More than 80 per cent of the industrial sector was de-licensed and the number of industries reserved for the public sector witnessed considerable reduction. Foreign technology import, manufacturing operations, and investment increased since the 1990s (Goldar and Ranganathan, 1998; Kumar and Agarwal, 2000). Looking at developments in Indian science and innovation, India seems to be a scientific powerhouse in the making. Table 1 in the Appendix bring together some key scientific indicators for India. However, the issue of scientific power is a partial treatment of the large and complex problem of linking science to economic development and well being of the nation.

The need for effective linkages between scientific, technological and financial institutions so as to promote technology transfer was felt and this led to the announcement of Technology Policy Statement in 1983. Several important policy measures have been undertaken since then to promote industrial R&D efforts and enhance domestic R&D capacity. These include - strengthening of administrative infrastructure with the creation of the Ministry of Science and Technology in 1985 and the creation of Technology Information Forecasting and Assessment Council (TIFAC) in 1987; strengthening of in-house R&D units through introduction of quality system management (QSM); strengthening of fiscal incentives and provision of financial support for technology development and absorption through Technology Development Fund (TDF); the creation of patent information centres; the restructuring of public institution; and the fostering of international linkages and technological upgradation of Indian industry. To meet the present national needs in the new era of globalization the government announced the Science and Technology Policy in 2003 with a major objective of advancement of scientific temper and full integration of S&T into all spheres of national activity on a sustainable basis. This involves among others the promotion of innovation and support for national innovation system, forecasting, prevention and mitigation of natural hazards, generation and management of intellectual property and international S&T cooperation[19].

Despite the initiatives that were undertaken to build appropriate linkages between different actors of the innovation system much needs to be accomplished in India on this front. However, the liberalization of policy regimes demonstrated the potential of the Indian innovation system and its contribution to the growth process. This was observed in the IT sector, which emerged as a major sector in the 1980s and 1990s due to the policy of liberalization and intensive R&D support by Indian companies and supplemented with the presence of a strong basic research capability.

3 Emerging Technology: Opportunity to Catch up Despite Weak Innovation System

There has been a change in the context of 'production of knowledge'[20]. Furthermore, advancements in knowledge in the emerging areas of biotechnology, information technology and nanotechnology and the emergence of new institutional forms - intellectual property regimes of the WTO and the policies of liberalization being adopted by countries around the world - have all created new conditions for industry, R&D institutions and the government to come together and create productive alliances so as to become competitive in the globalizing world. Developing countries like India is showing a growing interest in the emerging area of nano science and technology with a large number of universities, academic institutes and research centres engaged in nanotechnology R&D[21]. This changing pattern demands a reconfiguration of the various agents that are at work. Under such circumstances the nation's capability would be reflected in the ability of the institutions and agents to adapt to the new environment created by the forces of globalization. Furthermore, systemic interaction of various organizations and procedures may occur at different spatial scales (Oinas and Malecki, 1999) viz, international, national and regional scales. The accumulation of knowledge through dynamic and systemic processes of production and diffusion, thereby promoting technological change is the core of national systems of innovation (NSI) approach (Freeman, 1987; Lundvall, 1992; Nelson, 1993; Edquist, 1997). The notion of regional systems of innovation (RSI) perceives innovation system as a collaboration network of R&D organizations, innovating firms and public support agencies and considers that the region "may be the most appropriate scale for understanding the dynamics of, and organizing policy interventions directed towards, integrated innovation systems" (Cook et al., 1997). An extended view of innovation that increasingly depends on international information exchange and collaboration could be captured in the international system of innovation (Fromhold-Eisebith, 2006).

Given the increasing global interdependence, more so in the case of emerging technology, as manifested in terms of global flow of technology, manpower, finances and institutional interdependence, the various spatial dimensions of innovation systems are not expected to act in an isolated manner and therefore seem to affect each other's performance. In this respect exploring the missing links and the interdependencies of the multi scalar innovation system taking emerging technology as an entrance point may provide valuable insights in understanding innovation system especially in the context of developing countries (Figure 2).

The degree of interdependencies along spatial scales would vary across emerging technologies and the phases of the product life cycle. For example in the electronics industry building international connections may be a top priority, whereas biotechnology based industries would rather rely on a favourable national framework (Bunnel and Coe, 2001).

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[19] See < http://dst.gov.in/stsysindia/stp2003.htm>

[20] Implies shift from Mode-1 (disciplinary knowledge production) to Mode-2 (interdisciplinary and contextualized knowledge production) as proposed by Gibbons et al., 1994.

[21] For details see, www.indiananotechnology.com/uploads/Nanotechnology_Research_in_India_By_U-Shu_Nanotech_rev_B.pdf

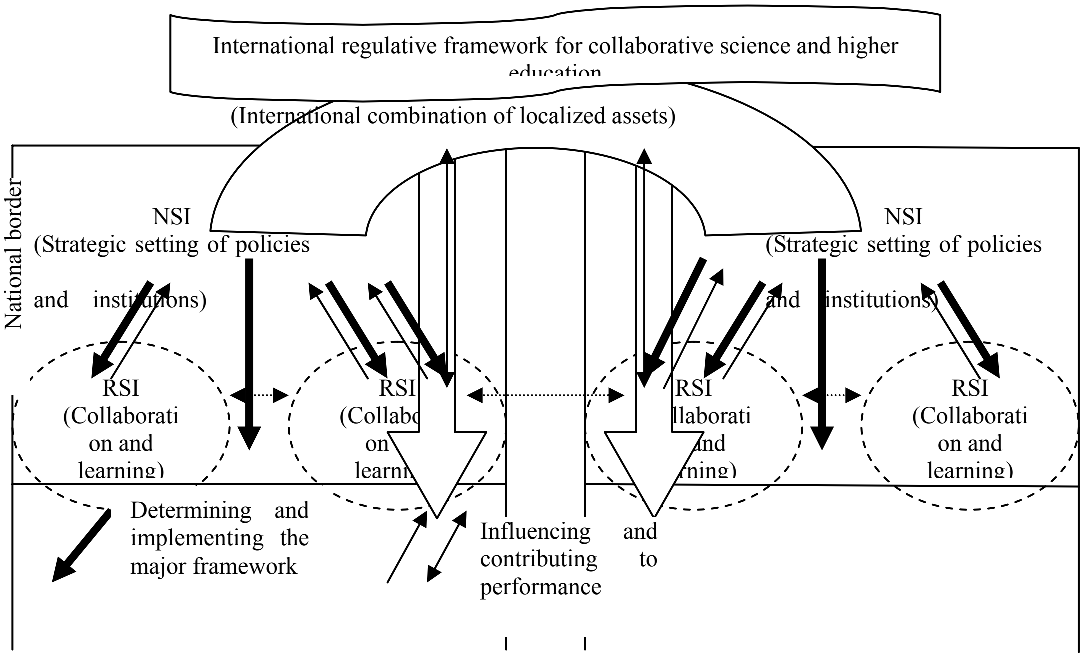

Figure 2 Interdependencies of National, Regional and International Systems of Innovation (NSI, RSI and ISI)

(Source: Fromhold-Eisebith, 2006)

As discussed earlier, the strategy for scientific development in India in the first four decades of independence was based on the policy of self-reliance and import substitution. As a result there were little international influence on industrial development and the national and regional system of innovation evolved in the background of building indigenous technological capabilities. India missed the semiconductor revolution in the 1970s due to protectionism and interdepartmental turf (*Commerce,* 1983; Khandelwal, 1981). Although there was dependence on foreign technology, foreign transnational corporations were restricted to investment, location, import and other allowances. Information and communication technology industry, concentrated in specific regions of India, provides a successful example of the multi-scalar interdependencies with a strong reliance on the combination of inward transnational corporation investments and the use of regional human capital to forge greater international connections (Fromhold-Eisebith, 2006). Similar geographical concentration of nanotechnology industry as witnessed in the information and communication technology and biotechnology industry have started emerging in India.[22] The emergence of regional technology based collaboration wherein laboratories, academic institutions and firms are co-located and facilitated by central authorities, have led to a well-networked RSIs which may help in the growth of domestic and foreign firms thus, building bridges between RSI and ISI. In the federal set up of Indian democracy which provides authority to the states to formulate their own regulatory policies in relation to human resources development and location of private industries, the states which will take proactive steps and allow for the combination of ISI and RSI potential may be able to harness the benefits of emerging technology pushing India on to the path of technological development.

[22] An analysis of the geographical location of the nanotechnology companies reveals that Mumbai and Bangalore are emerging as favored destinations by the industry. These two locations offer differing advantages. Mumbai is preferred for its concentration of Indian industries and corporate houses. The IT and biotechnology hub of the country, Bangalore, offers access to superior technical talent. It is also the seat of premier academic and research institutions such as Indian Institute of Science, the leading centre for nanotechnology research in the country, Jawaharlal Nehru Centre for Advanced Scientific research, Raman Research Institute etc.

Although there are some elements of functional interdependencies visible in some sectors led by emerging technologies in the Indian context there is a need for effective linkages between the various components of the innovation system at various spatial scales. Also, emerging technologies which share different timelines in their penetration and development, with some of them like nanotechnology have not yet reached the stage of product maturity, studying the nature of collaborations emerging among the academia, government and industry and thereby forming an important component of innovation system can provide valuable insights and help in the formulation of policies with respect to these technologies.

4 Efficiency of Innovation Systems: Understanding Collaboration and Entrepreneurship in Emerging Nanotechnology

The increasing complexities of emerging technologies in conjunction with their convergence demands a greater need for S&T collaboration at various spatial scales as well as between the different actors in the innovation system. With globalization the share of foreign R&D sites has increased from 45 to 66 per cent between 1975-2004 (Doz et al., 2006). Wide geographic dispersion has been noticed in the recent past, with India emerging as a major destination center. According to a study, India accounts for 9 per cent of global R&D sites in 2007 (7 per cent in 2004). Further, the global growth of R&D employees in India witnessed a jump from 14 per cent in 2004 to 23 per cent in 2007 (Appendix - Figure 3 and 4). Low cost skill base, highly qualified human resources and opportunities for university collaboration are important factors for such developments (Kauffman, 2006). Further, looking at the sectors in which R&D partnerships are taking place it could be observed that most of the research alliances worldwide are in the high-tech sectors with 574 new technology or research alliances worldwide in the year 2000 being reported in information technology, biotechnology, advanced materials, aerospace and defense, automotive, and non-biotechnology chemicals (National Science Board, 2002). Thus emerging technologies have started influencing the process of collaboration and the unfolding of globalizing forces. In the context of multi-scalar innovation systems the ISI impulse, which was largely de-emphasized in the NSI approach, has resulted in knowledge accumulation. This is evident from the various statistics relating to FDI and technical collaboration, shown in the Tables 2-7 in the Appendix, contributing towards the performance of Indian innovation system.

4.1 Relationship between academia, government and industry

Bringing the benefits of new products, new processes, and new knowledge into the market is a key challenge for an innovation system. Collaborations among universities, industry and government can play an instrumental role in accelerating the development of emerging technologies from idea to market. Collaborations facilitate the transfer of scientific knowledge to real products and may further contribute directly towards global competitiveness of the industry. Further, collaborations offer a means to integrate the diverse participants in the innovation system and provide an institutional structure with financial and policy initiatives within which companies, universities, research labs, and research institutes can cooperate to accelerate the development of promising technologies (Nelson, 1993).

There has been a change in knowledge production over time. Institutional and national boundaries are transcended in the course of creating new innovation environments. The public, private, and academic sectors, which formerly operated at arms length, are increasingly working together, with a spiral pattern of linkages emerging at different stages of the innovation process. What is called the "knowledge economy" has created a climate in which the ability to assemble and exploit knowledge has become a key competitive factor (Vanderburg, 2000). There is involvement of actors in an increasing number of networks to support their different roles, as well as the increasing numbers of actors from outside universities and established research centers, and these actors play a growing role in teams (consortia) as a new structure working on a temporary (project) basis. In addition, there has been a shift from hierarchical, disciplinary and division of labor-based knowledge production to a mode in which research problems are set across disciplinary boundaries, with applicability of the research outcomes counting as much as scientific innovation (Etzkovitz, 2002; Gibbons et al., 1994; Nowotny et al., 2001).

In young and highly dynamic fields such as nanotechnology[23], many research breakthroughs are stimulated in the intersection of established scientific disciplines and across fundamental and applied

[23] Nanotechnology is among the most prominent emerging technologies. It includes components that have at least one dimension between 1 and 100 nm, and display unique characteristics due to being at this scale.

technological research[24]. It is in such fields that new scientific sub-fields emerge, and where there is considerable potential for technological innovation to emerge. Therefore, inter-institutional collaboration is an important dimension of performance in the emerging field of nanotechnology. The growing interdisciplinary character of scientific and technological knowledge in the process of production, manifests itself in the emergence of a new division of labour that are generated with increased collaboration between institutions, the increasing withdrawal of the State from support for academic research, and the increasing emphasis on the State to use the industry-academia interaction to achieve regional development (Webster and Etzkowitz, 1991). A network, in this context, serves as a locus of innovation because it provides timely access to knowledge and resources that are otherwise unavailable, while also testing internal expertise and learning capabilities. The networks of government-

Box: Collaborations in nanotechnology

Various institutional collaborations are taking place in the field of nanotechnology. For e.g., Veeco Instruments, which makes atomic force microscopes and other nanotechnology research equipment opened a nanoscience center in Bangalore in partnership with the Jawaharlal Nehru Center for Advanced Scientific Research. Also collaborations between academia are taking place in nanotechnology in India. For e.g., Ajay K. Sood and his student Shankar Ghosh from the Indian Institute of Science (IISc), Bangalore, and N. Kumar, Director of the Raman Research Institute (RRI), Bangalore, have discovered an interesting property of carbon nanotubes — slender tubes of carbon about a nanometre (nm) or a billionth of a metre (10 -9) in diameter. Similarly, IISc works in collaboration with institutions like IIT Bombay, JNCASR, Raman Research Institute in the area of nanotechnology. Some of the major current academic collaborations in India are as follows:
i) IIT Bombay, Mumbai - Umbrella collaboration between the two centers for Nanoelectronics under the institutional MOU between IISc and IIT Bombay.
ii) IIT Kharagpur, IIT Madras, NIT Suratkal, NIT Trichy and NIT Warangal - collaboration under the NPSM Programme for National MEMS Design Centres.
iii) VTU Karnataka - Educational programme between CEN and Visveshwaraya Technological University under NPSM for developing undergraduate curriculum on nanotechnology.

Various international collaborations are taking place India in nanotechnology. For e.g., Indian Institute of Sciences international collaborations are:

- NUS Singapore: Research collaboration in micro and nanotechnology under the umbrella MOU between IISc and NUS Singapore.
- IMEC Belgium: Research collaboration in nanoelectronics under the umbrella LOI between IMEC Belgium and IISc.
- EPFL Lausanne: Research collaboration under the Indo-Swiss collaboration project.

academia-private R&D institutions highlight two key observations: (a) inter-organizational collaborations are not simply a means to compensate for the lack of internal skills; and (b) nor should they be viewed as a series of discrete transactions. A firm's value and ability as a collaborator is related to its internal assets, but at the same time, collaboration further develops and strengthens those internal competencies (Powell et al. 1996).

Recently, the Government of India has come out with the Science and Technology Policy in the year 2003[25]. Earlier, the State was almost the sole sponsor of the scientific research in the country. Prior

[24] For instance, consider that organizational infrastructure dedicated to the fundamental understanding of certain nano-scale properties (basic research) is institutionally separated from the organizational infrastructure for modifying and fictionalizing certain nano-scale phenomenon (applied technological research). Therefore, in the field of nano science and technology, and apparently in other research fields too various researchers have found it useful to pool these different competencies.

[25] The main aim of the S&T Policy of 2003 was *to encourage research and innovation in areas of relevance for the economy and society, particularly by promoting close and productive interaction between private and public institutions in science and technology*.

to 1990s the industry in India did not seem to be interested in collaborating with the universities to find solutions to their problems, as the industry was able to import technology from other countries. The adaptation of imported technology to achieve the goals of import substitution also led to the enhancement of their indigenous technological capabilities. The industrial R&D except in a few cases largely remained a tax saving device. Also universities and national research centers worked in isolation (Figure 5).

This lack of synergy and cooperation between the two sectors prevented the growth of inventive technology. Private companies, at the most, worked with university labs in a consulting mode where a short-term interaction was sought for solving a well-defined problem, mostly of trouble-shooting nature. The weak links between R&D performing institutions and industry could not lead to a long-term vision for research driven product or technology development resulting in a weak innovation system.

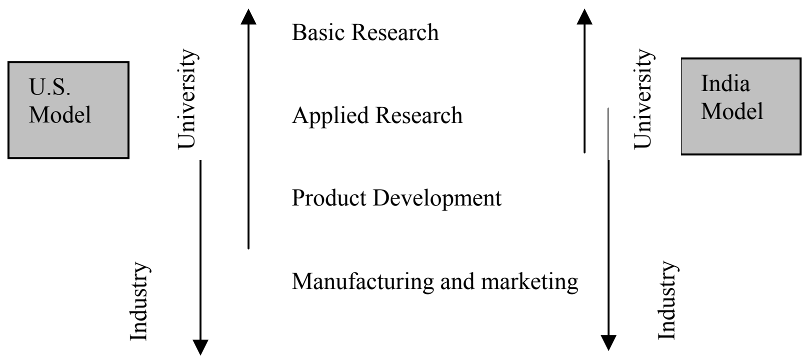

Figure 5 University-Industry Role in the Innovation Process

In the changing context of production of knowledge in the Indian scenario slowly the R&D institutions, both private and public, see the necessity to network for learning and generation of knowledge that has application potential and the eventual commercialization. The process of institutionalization of networking has to overcome barriers arising out of the interests and meanings that R&D scientists and managers located in different kinds of R&D institutions hold. At this stage one can only say that some elements of networking between various agents of innovation in emerging technology have started evolving. However, there is a need to examine the dynamics in the Indian context by looking at the kind of norms that government, R&D institutions, both public and private evolve over time in different sectors and for different kinds of activities relating to the process of innovation and how they resolve clashes arising out of their interests and meanings.

4.2 Entrepreneurship and innovation systems in the emerging technology

Knowledge generated in the academic institutions that helps in technological advancement may possess business potential. Witt and Zellner (2007) have argued that the transfer of knowledge from scientific research to the commercial part of the innovation system is essentially an entrepreneurial process. However, there are various obstacles to this entrepreneurial process such as, barriers to entrepreneurial entry, lack of qualified resources, and/or organizational rigidness. Such difficulties varying with different national economies may impede the entrepreneurial commercialization of new technologies (Henrekson and Rosenberg, 2001).

Emerging technologies such as nanotechnology having wider applications in various fields have garnered the attention of various economic enterprises. There are number of start-ups, which have sprung up in this field[26] besides the existing firms who have tried to incorporate nanotechnology in their

[26] A handful of start-up companies have emerged in India in the last 4-5 years. Out of about a dozen start-ups founded since 2002, 50% of them are providing consultancy, market research and training, while product development efforts are directed towards chip design and development, nanomanipulation, nanomedicine, and nanomaterials (e.g. carbon nanotubes, silica and alumina). Almost all these start-ups are at product development stage with limited commercial success. Lack of seed capital is hampering these product development efforts. Indian venture capital firms, especially after the IT bust at the turn of the century, are risk averse and are reluctant to provide seed funding to unproven businesses.

production processes. There may be replacement of the incumbent firms by new firms leading to what is termed as the Schumpeterian waves of *creative destruction* or, it may happen so that the incumbent firms are able to successfully engage with the new technology resulting in *creative accumulation*. The ability of the incumbent firms to harness the potential of emerging technology and the emergence of successful start-up firms will require entrepreneurship which may play an important role in economic growth and improving the efficiency of the innovation system. The Information Technology sector, which witnessed a series of waves of creative destruction during 1970s and 1980s, provides valuable insights into the factors causing creative destruction of firms. Bresnahan (2007) draws the following important conclusions for the IT sector with respect to the wave of creative destruction:

- The most economically important use of a general purpose technology (GPT) need not be determined by the inventors of GPT, but rather by the inventors of complements, and applications.
- A vertical disintegrated structure and openness of the industry enables creative destruction while, a vertically integrated and proprietary system act as an impediment.
- Changing nature of technology and demand over time leads to replacement of existing firms and products with new ones.

Entrepreneurs perform an important role and may contribute to a well functioning innovation system. In the case of emerging technologies where scientific research is creating new knowledge rapidly, having both tacit and codified components, the role of entrepreneur becomes very crucial in monitoring and tapping new knowledge, networks and markets into concrete actions and thereby generate and take advantage of new business opportunities. The codified technological knowledge emerging in the international innovation systems needs to be traced thus demanding entrepreneurship engagement at the various spatial dimensions of the innovation system. Further, entrepreneurs play an important role in overcoming the uncertainties prevalent in the early stage of development of a new technology. Their function can be analysed by mapping the number of new entrants, the number of diversification activities of incumbent actors and the number of experiments with the new technology.

Thus, new scientific and technological knowledge in the emerging areas throws entrepreneurial challenges and demands entrepreneurs as "technology" champions to facilitate the use of frontier technologies and emerging areas such as nanotechnology.

5 Concluding Remarks

Indian innovation system, which has helped to create a high level of human resources in terms of qualified and skilled labour, is also facing serious problems and challenges resulting in an overall weak innovation system. Globalization process has further aggravated the complexities of Indian innovation system and to realize the full potential of the innovation system, liberalization of policy regimes may not be enough.

Collaborations in the exploitation and generation of emerging technology and entrepreneurship will increase the efficiency of the innovation system. Advancements in knowledge in emerging areas such as molecular biology and biotechnology, information technology and nanotechnology and the new institutional context of the IPRs of the WTO, policies of liberalization have all created new conditions for industry, R&D institutions and the government to come together and create productive alliances in the highly competitive globalizing world. This changing pattern demands a reconfiguration of the various agents and under such circumstances the nation’s capacity would be reflected in its ability to adapt to these changes.

In Indian innovation system the boundary between the academic and the commercial sphere is not equally permeable and the knowledge transfer between these two spheres is an entrepreneurial process. Entrepreneurs perform an important role and may contribute to a well functioning innovation system. In case of emerging technologies where scientific research is creating new knowledge rapidly, having both tacit and codified components, the role of entrepreneur becomes very crucial in monitoring and tapping new knowledge, networks and markets into concrete actions to generate and take advantage of new business opportunities. Further, emerging technology and the peculiarities of scientific knowledge poses considerable challenges and opportunities to the entrepreneurial process operating within the institutional and political conditions of the national economies. A well functioning innovation system may provide a suitable environment for the operation of entrepreneurial process and facilitate the commercialization of new technologies.

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APPENDIX

Table 1 Key Scientific Indicators for India

	Figure	Source
Inputs		
GDP growth rate	– 8.2%	Dahlman and Utz, World Bank, 2005
	– India has 17% of the world's population but only 2% of global GDP and only 1% of world trade	ITPS (Swedish Institute of Growth Studies), 2005
Percentage GDP on R&D	– 0.8% GDP	NSTMIS, Department of Science and Technology, Government of India, 2002/03
Annual science budget	– $4.5 billion	Department of Science and Technology, Government of India, 2006
Human capital creation		
Annual enrolments at the level of graduate and above	– 6.6 million in 1995/96 – 9.84 million in 2004	National Council for Applied Economic Research (NCAER), India Science Report, 2005
Within this, the percentage studying engineering has almost doubled	– 6% in 1995/96 – 11.2% in 2003/04 (= 8.2% growth from 1995 to 2000, risen to 21.9% growth from 2000 to 2004)	
Pool of young university graduates (those with 7 years or less of work experience)	– Roughly 14 million – This is 1.5 times the size of China's, almost twice that of the US, and is topped up by 2.5 million new graduates in science, engineering and IT every year	Farrell et al[9]
Engineering graduates per year	– Approximately 350,000[10] – Predictions claim there will be as many as 1.4 million by 2015	A study by UGC and CLSA Markets
Science PhDs per year	– 5000–6714	Mashelkar,[11] ITPS, NSTMIS
R&D staff at work in science or industry	– 21 researchers per 1000 employed	OECD, 2001/02

	Figure	Source
Inputs cont.		
Size of R&D infrastructure	– 229 universities – 96 deemed universities – 13 institutes of national importance – 400 government research labs – 1300 (approx) industrial R&D units	Ministry of Human Resource Development, Government of India, 2006
Quality of broadband infrastructure	– Urban India has only a 3 per cent adoption rate among its top three socioeconomic classes	Forrester research published in SDA[12]
FDI as a % of GDP	– 0.07	World Bank WDI (World Development Indicators), 2005
Comparative FDI	– India is the fifth most preferred investment destination for foreign money in Asia, attracting $6.6 billion in 2005 (compared with China's $72.6 billion in 2005)	UN Conference on Trade and Development (UNCTAD), World Investment Report 2006
Outward FDI	– India's *outward* FDI has grown at an average of over 50% on a three-year moving average, between 1992 and 2004	UNCTAD, World Investment Report 2006
Growth competitiveness index, 2005	– India is ranked 50th, one place below China. India is up five places from 2004, whereas China is down three.	World Economic Forum (WEF), 2005

	Figure	Source
Outputs		
US patents	– 341 US patents granted in 2003 (China 424) – 1164 US patent applications in 2003 compared with just 54 ten years earlier	US Patent and Trademark Office (USPTO)
Indian patents	– Nearly 23,000 applications in 2005/06 compared with 17,266 in 2004	Indian Patent Facilitation Centre[13]
Peer-reviewed articles	– 12,500 scientific papers were published and included in the Thomson ISI database in 1999, rising to 15,600 in 2003	Science and Development Network, 2005

Source: Bound, 2007

Table 2 Sectoral Distribution of the FDI Inflows in India (1991-2007)

Sl No	Sector	Percentage Share
1	Electrical Equipments (Incl comp. software & electronics)	19
2	Service Sector	17
3	Telecommunications	9
4	Transportation Industry	8
5	Fuels (Power & Oil Refinery)	6
6	Chemicals (Other Than Fertilizers)	5
7	Drugs And Pharmaceuticals	3
8	Food Processing Industries	3
9	Cement And Gypsum Products	2
10	Metallurgical Industries	2

Source: *SIA Newsletter*, Ministry of Commerce and Industry, Government of India, February 2007

Table 3 Number of Cumulative Foreign Technology Collaborations (FTC) Approvals

No. of Cumulative FTC approvals (from August 1991 to August 2007)	7886
No. of FTC approvals during 2006-07 (from April 2006 to March 2007)	81
No. of FTC approvals during 2007-08 (from April to August 2007)	40

Source: <http://dipp.nic.in/fdi_statistics/india_fdi_index.htm>

Table 4 Sector-Wise Technology Transfer Approvals (1991-2007)

Rank	Sector	Number of Technical Collaborations	Percentage Share
1	Electrical Equipments (Incl comp software & electronics)	1253	15.89
2	Chemicals (other than fertilizer)	883	11.20
3	Industrial Machinery	869	11.02
4	Transportation Industry	730	9.26
5	Misc. Mach. Engineering Industry	441	5.59
6	Other sectors	3710	47.04
Total of all sectors		**7886**	**100.00**

Source: <http://dipp.nic.in/fdi_statistics/india_fdi_index.htm>

Table 5 Country-Wise Technology Transfer Approvals (1991-2007)

Rank	Sector	Number of Technical Collaborations	Percentage Share
1	U.S.A.	1750	17.30
2	Germany	1103	8.24
3	Japan	861	7.64
4	U.K.	856	4.49
5	Italy	484	3.96
6	Other Countries	2832	58.37
Total of all Country		**7886**	**100.00**

Source: <http://dipp.nic.in/fdi_statistics/india_fdi_index.htm>

Table 6 State-Wise Technology Transfer Approvals (1991-2007)

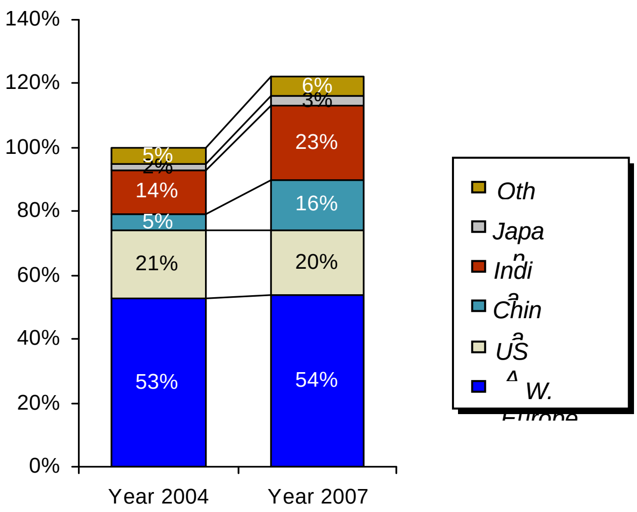
Rank	Sector	Number of Technical Collaborations	Percentage Share
1	Maharashtra	1364	17.30
2	Tamil Nadu	650	8.24
3	Gujarat	602	7.64
4	Haryana	354	4.49
5	Delhi	313	3.96
6	Other States	4603	58.37
Total of all States		**7886**	**100.00**

Source: <http://dipp.nic.in/fdi_statistics/india_fdi_index.htm>

Table 7 Imbalance in State-wise FDI flow to India (2000 - 2007)

Rank	State(s)	FDI Inflow (Rupee billion)	FDI Inflow (US$ billion)	% of FDI Inflow (in Rupee terms)
1	Maharastra, Dadra Nagar Haveli, Daman & Diu	345.91	7.65	23.9
2	Delhi, Part of Uttar Pradesh and Haryana	336.45	7.46	23.3
3	Tamil Nadu, Pondicherry	106.90	2.36	7.70
4	Karnataka	93.61	2.07	6.48
5	Andhra Pradesh	52.81	1.16	3.65
6	Gujarat	44.35	0.97	3.07
7	Punjab, Haryana, Himachal Pradesh	15.65	0.34	1.08
8	West Bengal, Sikkim, Andaman & Nicobar	15.33	0.33	1.06

Source: Reserve Bank of India, *Fact Sheet on Foreign Direct Investment (FDI)* 1991-2007



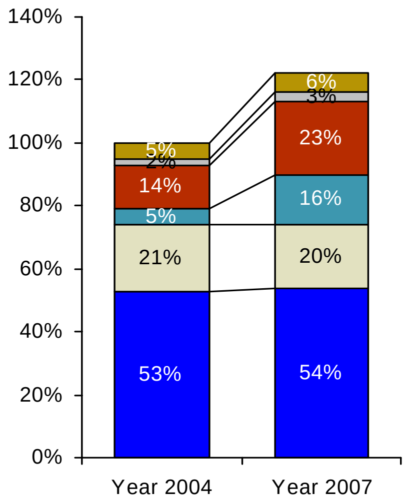


Figure 3 Growth in Global R&D Sites 2004 – 2

Figure 4 Growth in Global R&D Employees 2004 – 2007

Source: Booz Allen / INSEAD Global Innovation Network Study, survey of 186 global companie