The Evolution of a Developing Country Innovation System During Economic Liberalization: The Case of India

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Abstract

Among developing nations, India has one of the strongest bases of scientific and technical manpower and infrastructure for research and development. This base was built largely by the government and resulted in significant achievements in strategic sectors such as atomic energy and space. However, in the over-regulated and internally-focused economic policy regime that was in place till the late 1980s, this scientific and technological base did not, barring a few exceptions, translate into significant industrial innovation. Existing firms did not feel the pressure to, or see any benefit in, making serious efforts at technological innovation, and technological capabilities remained localized in research laboratories that were isolated from the system of industrial production.

This paper looks at what happens to such an innovation system when the economy is deregulated. Specifically, we identify the major changes that have occurred in the Indian innovation system following the commencement of deregulated and liberalized economic policies in 1991.

Post-1991, the most significant development in the industrial sector has been the significant growth of the Indian software services industry that today accounts for 2% of gross domestic product and 15% of exports. While the software services sector has seen spectacular growth, its evolution has been based on a distinct role in the global production system that involves relatively low value-added work, "locked-in" to the global division of labour. The software services sector has attracted India's best talent and spurred a tremendous growth of technical education, much of it in the private sector. While the software sector has both Indian and multinational firms, multinational firms appear to be doing more advanced software work; however, their links and spinoffs to the local innovation system have so far been limited. The growth of the software sector appears to have done little to enhance productivity in other sectors of the Indian economy though it has provided alternate organizational paradigms and management models that have influenced companies in other industries.

The impact of economic liberalization on innovation in the rest of the economy has been mixed. In the two-wheeler and pharmaceutical industries, regulatory changes, demand conditions, competitive forces and entrepreneurial initiative have resulted in the development of innovative capabilities as reflected in a number of successful products. Government support and links with government research laboratories have facilitated the process of innovation in the pharmaceutical industry. However, in many other industries, changes in the innovation profile have been limited. The reasons for these differences are investigated.

This paper explores the implications of these trends for the future evolution of the innovation system in India. In conclusion, we identify the implications of the Indian experience for innovation system research and raise questions for further investigation.

The Evolution of a Developing Country Innovation System During Economic Liberalization: The Case of India[1]

Introduction

In spite of being a poor country, India had, since its independence in 1947, devoted scarce resources to the development of a science and technology infrastructure and a high quality system of higher technical education. While this enabled the country to make significant progress in strategic sectors such as space research and atomic energy, the benefits did not percolate into the industrial sector. A major reason for this was that in a protected and inward-looking economy there was little need or incentive for innovation. The objective of this paper is to describe how the Indian innovation system has evolved during the twelve years since India moved from a highly regulated mixed economy to a much more open market economy. In this process we will attempt to answer the following questions: Has economic liberalization facilitated the translation of India's technological capabilities into goods and services, and economic growth and competitiveness? Has the innovation system become more dynamic and strong, or has greater integration with the world economy weakened the innovative capabilities of the Indian economy? What are the future challenges faced by the country in strengthening its potential for innovation? Can it hope to transform itself into a knowledge society?

We start by describing the Indian innovation system as it existed before the start of the process of economic liberalization in 1991. We then briefly describe the economic policy changes introduced by the government since that watershed year. We then describe some of the key changes in the innovation system that have taken place and identify broad trends. We analyze the implications of these trends for the future growth and competitiveness of the country. We end by raising some questions regarding (a) the relevance of the Indian experience for other countries and (b) further research on national innovation systems.

The Indian Innovation System before Economic Liberalization

Before economic liberalization, India's dominant economic philosophy was one of self-reliance. The objective was to produce the country's requirements, to the extent possible, within the borders of the country. This self-reliance became an end in itself, leading to a very broad production base, but insufficient attention to efficiency and productivity (Forbes, 1999).

[1] My first attempt to understand the new Indian innovation system was presented at the R&D Management Conference 2001 organized by the Council of Scientific & Industrial Research at New Delhi in December 2001. I have benefited from the feedback of the participants in that conference, and later seminars at the Indian Institute of Technology Kanpur, Jawaharlal Nehru University, Hong Kong University of Science & Technology, and the Hebrew University of Jerusalem. I am also indebted to Richard Nelson, Nasir Tyabji and Morris Teubal for useful advice.

The public sector was seen to be the fountainhead of industrial development and accounted for as much as two-thirds of the fixed capital investment in the factory sector. Public ownership was particularly stressed in those sectors where technology acquisition was expected to involve the evaluation of a range of non-commercial considerations (Tyabji, 2000). However, with a few exceptions, the public sector failed to drive the Indian industrial sector on to a higher growth trajectory and got bogged down by cost and time overruns, high costs, and a lack of technological dynamism.

Though private industrial activity by both Indian firms and multinational companies went on in parallel, there were tight regulations on inward capital flows, expansion, diversification and the import of capital goods, intermediates, and technology. Technology imports were regulated on a case-to-case basis, and companies permitted to import technology were often required to commit to progressive indigenization through a "phased manufacturing programme." The high effective rate of protection (through physical constraints on imports and high import duties) coupled with industrial licensing (that constituted a major barrier to entry) meant that local industry felt little need to innovate (Forbes, 1999; Krishnan and Prabhu, 1999). Constraints on growth also acted as a disincentive to innovative behaviour. (Forbes, 1999). With a protected market, and a high cost structure, very few firms pursued exports or targeted external markets aggressively. Such R&D as was done by industry was concentrated on import substitution and the creation of local sources for inputs.

The small scale sector was provided reservation in many sectors and implicitly encouraged to make imitative products through reverse-engineering and improvisation (Tyabji, 2000). Since small scale industries enjoyed fiscal benefits like lower rates of excise duties and were largely outside the purview of industrial regulation, there was a tendency to fragment capacities and no incentive to grow to exploit economies of scale or scope.

The government dominated research and development activity. Over 80% of the R&D done in India was financed by the government of India and conducted within government research laboratories (Forbes, 1999). Much of this was in the strategic sectors of atomic energy, defence and space research, resulting in some of the most advanced capabilities in these areas in the developing world. The government also created a network of forty laboratories under the aegis of the Council of Scientific & Industrial Research to do work of relevance to industry; however the links of these laboratories with the industrial sector remained limited and such technological capabilities as were created remained largely confined to the laboratories themselves. An effort was made in the early 1970s to formulate a national science and technology plan that would dovetail with the economic planning process and help integration of the government's technology development efforts with industrial development, but this was short-lived.

A later government initiative in the 1980s to develop the technology for small digital electronic telephone exchanges under a separate Centre for Development of Telematics (C-DOT) was more successful, largely because this was viewed as a technology mission with clear objectives. C-DOT was given the requisite resources, considerable flexibility to operate outside the government administrative framework and had the advantage of politically-supported visionary leadership (Meemamsi, 1993; Krishnan, 2003).

Starting in the later 1950s, the central government created a strong infrastructure of institutions of higher technical education through the Indian Institutes of Technology (IIT) and the Regional Engineering Colleges (REC). At the state-level, many governments created and funded government colleges of engineering. Private involvement in higher technical education was limited and restricted to a few states that experimented with "capitation fee" colleges. The IITs recruited good faculty, typically Indians who had obtained doctoral degrees from the United States, and provided a good environment for academic pursuits. A very competitive entrance test ensured that the IITs got very bright students. The quality of IIT education is excellent, the research output from its faculty good but not outstanding but, as in the case of the national research laboratories, IITs had limited interaction with Indian industry. IIT graduates found few opportunities to use their technical knowledge in the industrial sector and tended to emigrate in large numbers, principally to the United States. Those that stayed behind went into the government research establishments or to management positions in the private sector.

By the end of the 1980s, India had perhaps the strongest scientific and technological infrastructure among developing countries, but little benefit of this was accruing to the industrial production system. The economy was largely stuck in the historical "Hindu rate of growth" of about 3.5% and India had fallen significantly behind countries such as Korea that at one time had comparable per capita incomes.

The Economic Policy Reforms

Though the trigger was an economic crisis caused by a serious decline in foreign exchange reserves due to the flaring up of oil prices, the new Indian government that took office in June 1991 attempted to address the structural problems underlying the crisis. While the broader objective was to stimulate economic growth by attracting foreign investment, removing licensing and "monopoly" controls, allowing imports and encouraging exports, an explicit focus of the new polices was the development of an innovative capability in the economy. The Industrial Policy Statement of the Government of India of July 24, 1991 had among its objectives "injecting the desired level of technological dynamism in Indian industry", and "the development of indigenous competence for the efficient absorption of foreign technology" and expressed the hope "that greater competitive pressure will also induce our industry to invest much more in research and development than they have been doing in the past...."

Successive governments have carried forward the reform process. Today, most industries do not require industrial licencing. Automatic approval is given for foreign investment, even up to 100%, in many industries (see Rathinasamy, et. al. 2003 for details). Physical constraints on imports like actual user conditions have been removed and duties have been reduced considerably though they are still higher than in many other countries. Similarly, restrictions on technology imports have been removed. The focus of economic liberalization has shifted to the states, the co-called "second phase of economic reforms" including the creation of industrial and urban infrastructure, removal of barriers to use of land and movement of goods, environmental clearances and rationalization of local taxation. State governments have responded by competing for investments by multinationals and large industrial groups.

In the subsequent sections of this paper, we investigate the evolution of the Indian innovation system in response to these changes. Adherents to dependency theory might expect the existing Indian innovation capabilities to decline and be subordinated to the interests of the "centre", i.e. the multinational corporations headquartered outside India. Others might expect the Indian innovation capabilities to benefit from both the spillovers resulting from increased foreign direct investment and innovative activity undertaken by local industry to survive increased competition. The Indian experience gives us a unique opportunity to study what happens when an "independent" becomes more of an "integrationist" (Amsden, 2001).

The Indian Innovation System after 1991

Before we look at the innovation system, let us look at how the macro-picture of the Indian economy changed over the 1990s. Today, India's manufacturing sector accounts for approximately 17 per cent of real GDP, 12 per cent of total workforce and 80% of merchandise exports. Total manufacturing gross value added showed a trend growth rate between 1980 and 2000 of 6.8% (compared to 12.8% in China and 11.2% in Malaysia). More interestingly, the industrial growth during the 1980s and 1990s were roughly the same. The share of manufacturing in GDP also remained roughly the same between 1990 and 2000 (Nagaraj, 2003). The service sector grew at about the same rate as industry, 7.6%, during 1992-97, but in 1997-2001 services grew at an annual rate of 8.1% compared to the 4.8% growth of industry (Acharya, 2002). The service sector in India is larger than either the agriculture sector or the industrial sector. It has been growing at least as fast as the industrial sector, and faster than the agriculture sector, reinforcing its dominance.

The importance of the services sector is reinforced by its strong share of foreign direct investment post-liberalization. Subsequent to the government's deregulation of foreign investment in India, investment to the extent of Rs. 2776 billion (approximately $75 billion) was approved until March 2002 (Table 1). The actual inflow is about Rs. 1157 billion (a little under $30 billion) during the same period (*Economic & Political Weekly*, 2002). FDI inflows into India are believed to be less than 10% of those into China during the same period,

Basic goods account for the largest proportion of the FDI approvals accounting for almost 39%. Within the basic goods category, about one-third is in the power sector. The second largest category is services, accounting for about 37%. Telecommunications accounts for a little over half of this category and computer services a little under a sixth of the services FDI approvals.

Table 1 Foreign Direct Investment in India Since Liberalization (Approvals) August 1991-March 2002.			
	Category of Industry	Amount Rs. billion	Per cent
1.	Basic Goods	1075.76	38.8
2.	Capital Goods	251.17	9.0
3.	Intermediate Goods	49.93	1.8
4.	Consumer Non-durables	276.23	10.1
5.	Consumer durables	93.57	3.4
6.	Services	1029.28	37.1
	Total	2775.97	
Source: "Foreign Investment Approvals and Actuals: A Profile" *Economic & Political Weekly*, August 31, 2002, p. 3567.			

To understand the contours of the new innovation system, we have to understand the dynamics of both the industrial and services sectors during liberalization. Before exploring these dynamics, we look at the government support available for innovation.

Government Support for Technological Innovation

Before liberalization, the Government of India's involvement in support for R&D and technological innovation was largely through the direct funding of government research laboratories and establishments. While R&D in some public sector industrial enterprises received budgetary support, there was no direct funding of R&D in the private sector. R&D in the private sector was supported indirectly by (i) a scheme of recognition of in-house R&D units of companies that allowed simplified procedures for the import of capital goods and other inputs required for R&D and (ii) income tax concessions.

Today, however, the Government of India has a multitude of schemes to support research and development in the country. These include programmes to (i) support the absorption of imported technologies by industry, (ii) develop and demonstrate indigenous technologies, (iii) help individual innovators to become technology-based entrepreneurs, and (iv) commercialize indigenous technologies. There are also programmes to support collaboration between technical institutions (like national laboratories or institutions of higher technical education) and industrial enterprises. In addition to these "horizontal" support programmes, there are programmes targeted at specific sectors such as drug development and instrumentation. The large government scientific agencies in the atomic energy and space programmes also have programmes to involve industry in developing technologies and products for their programmes as well as commercializing spin-offs. A recent and more ambitious effort has been to launch an initiative (called the "New Millennium Indian Technology Leadership Initiative") to attain a global leadership position in selected niche areas by supporting scientific and technological innovation in these areas. More details of some of these schemes are given in Table 2 below.

Table 2 Major Government-supported Programmes to Promote R&D in Industry			
	Name of the Scheme/Programme	Key Features & Achievements	Nodal Agency
1.	Programme Aimed at Technological Self Reliance (PATSER)	Aimed at promoting industry's efforts in development and demonstration of indigenous technologies and absorption of imported technologies. Till November 2000, 113 projects of industrial units in both the private and public sectors had been supported with the total project cost of Rs. 1.5 billion of which the government's share was Rs. 450 million.	Department of Scientific & Industrial Research (DSIR), Govt. of India
2.	Home Grown Technologies Programme (HGT)	Aimed at promoting commercialization of indigenous technology. Attempts to catalyze R&D efforts by strengthening linkages between research institutions and industry with partial financial support. Launched in 1992. More than 50 projects funded already.	Technology Information Forecasting and Assess-ment Council (TIFAC), Govt. of India
3.	Technopreneur Promotion Programme (TePP)	Aimed at helping individual innovators to become technology-based entrepreneurs by providing financial support for the conversion of original ideas into working models and prototypes. Launched in 1998-99.	DSIR & Department of Science & Technology (DST)
4.	Technology Development Board (TDB)	The Technology Development Board (set up in 1996) uses money collected by the Government through a cess on import of technologies to invest (through equity or debt) in industrial concerns or other agencies to promote development and commercial applications of indigenous technology or adapt imported technology.	TDB
Source: *Research and Development in Industry: An Overview*. Department of Scientific & Industrial Research, Government of India, November 2000.			

Of the above schemes, some details of the projects funded under the Home Grown Technologies (HGT) Programme are given in Siddharthan and Rajan (2002). Of the 25 projects completed at the time of writing the book, 7 had been commercialized, 7 were in the process of being commercialized, 6 could not be commercialized due to unfavourable market conditions, and 5 were unlikely to be ever commercialized because the market had adopted other technologies. Sizes of the projects are not reported, nor is the success of the commercialized projects. The authors report difficulties in getting good project proposals for funding. It is too early to comment on the success of these schemes though awareness of the schemes, the scale on which they are implemented, and the quality of implementation are likely to be issues that need investigation in the years ahead.

Fiscal incentives for R&D include tax breaks for R&D expenditure and exemption from excise duty for products developed indigenously for which international patents have been obtained (DSIR, 2000). Specifically,

- Both revenue and capital expenditure on R&D are 100% deductible from taxable income under the Income Tax Act.
- A weighted tax deduction of 125% is allowed for sponsored research in approved national laboratories and institutions of higher technical education.
- A weighted tax deduction of 150% is allowed on R&D expenditure by companies in government-approved in-house R&D centres in selected industries.
- A company whose principal objective is research and development is exempt from income tax for ten years from its inception.
- Accelerated depreciation is allowed for investment in plant and machinery made on the basis of indigenous technology.
- Customs and excise duty exemptions for capital equipments and consumables required for R&D.
- Excise duty exemption for three years on goods designed and developed by a wholly owned Indian company and patented in any two countries out of: India, the United States, Japan and any country of the European Union.

In spite of these support measures, the national expenditure on R&D remains at around 0.8% of Gross National Product after dipping to 0.7% in the mid-1990s (see Table 3). However, private sector industry's share of national R&D expenditure has gone up from 13.8% in 1990-91 to 21.6% in 1998-99. While the government's investments in research and development have not kept pace with the growth of the economy, the private sector's investments have clearly been increasing at a much higher rate. However, the R&D intensity of Indian industry is only 0.52% in 1998-99, the latest year for which official figures are available (DST, 2002).

Table 3 : Research & Development Expenditure in India

	National R&D expenditure as % of GNP	% Share of private sector industry in national R&D expenditure
1990-91	0.79	13.8
1991-92	0.78	NR
1992-93	0.76	NR
1993-94	0.79	16.2
1994-95	0.73	19.9
1995-96	0.71	21.7
1996-97	0.72	26.1
1997-98	0.77	22.9
1998-99	0.81	21.6

Source: *Research & Development Statistics 2000-01*, Department of Science & Technology, Government of India, May 2002.
(NR=not reported)

Strategies of Manufacturing Firms during Liberalization

Manufacturing Competitiveness

As mentioned above, the Indian industrial sector grew at a little less than 7% in the 1990s. Some parts of Indian industry have become globally competitive. Many companies have downsized, and rationalized their manufacturing operations with the ostensible intention of becoming globally competitive. In scale-sensitive industries, companies have tried to increase their scale of operations to globally-competitive levels. Capital intensity has increased in the leading companies of such industries. Where such expansion has not been feasible, consolidations and sell-outs have taken place. Based on a survey of 110 large and medium-sized manufacturing firms, Ray (1998) found that in response to economic liberalization firms, in general, (a) aimed for higher growth and return compared to pre-liberalized era; (b) increased the scale of operation; (c) diversified into new products and business lines; (d) expanded the geographical base both in the domestic and international markets; (e) offered a wider range of products; (f) catered to diverse customer segments; and (g) laid increased emphasis on sharing of tangible and intangible resources across divisions and business units. Many large firms have used the advice of international consulting firms such as McKinsey and Company, Boston Consulting Group, Arthur D. Little or A.T. Kearney (all of whom set up offices in India in the 1990s) to facilitate restructuring and learning of international best practices.

Perhaps the best example of a company that has transformed itself into a globally competitive organization is the Tata Iron and Steel Company (Tata Steel). One of India's oldest companies, its future viability was in doubt at the onset of liberalization as it had outdated processes, a large workforce and an inward-looking mindset. However, by 2001, it had been ranked Number One in a survey of steelmakers conducted by World Steel Dynamics, a US-based research firm. While its main advantage in this survey came from historical and locational advantages such as ownership of low-cost iron ore and coking coal, it was number two in terms of operating costs. This transformation came about as a result of nearly ten years of concerted effort to "trim costs, improve operational efficiency, spend large sums to modernize the plant, develop a high margin downstream product mix and increase labour productivity." Introduction of a flatter structure (only three levels against the eleven existing previously) in new parts of the plant, in-house fabrication of specialized equipment, and a shift to an external focus on the customer were important managerial decisions. Raw material consumption efficiency improved from 4.81 tonnes per tonne of saleable steel in 1990-91 to 3.71 in 2000-01; labour productivity improved from 79 tonnes of saleable steel per man-year in 1995 to 189 in 2001 (Kanavi, 2001).

Other manufacturing companies have also demonstrated significant improvement in their internal processes. Sundaram Clayton and the TVS Motor Company, both part of the TVS group, won the prestigious Deming award for their quality systems. Sundram Fasteners has won the award for best supplier to General Motors over multiple years in succession. Reliance Industries has established itself as a globally competitive producer of petrochemicals and synthetic fibres and grown to become India's largest private sector company (2002-03 sales of Rs. 450 billion).

Product Development & Innovation

In addition to improving their production efficiencies and internal processes, some companies have also developed a strong product development capability. Prominent among these is Tata Motors (formely Tata Engineering & Locomotive Company). Better known as India's largest truck manufacturer, Tata Motors progressively diversified into the design and manufacture of passenger cars in the 1990s. Starting with products derived from their light commercial vehicles, the company launched a small passenger car, the *Indica*, to compete with small cars produced by Maruti Udyog (then a joint venture between the Indian government and the Suzuki Motor Company of Japan), Hyundai and Daewoo. The car has been reasonably successful in the market and has established Tata Motors as a significant player. The company has subsequently entered into an arrangement whereby the car will be sold under the Rover brandname in Europe. Another vehicle manufacturer, Mahindra & Mahindra has launched a new sports utility vehicle, the *Scorpio*, which is competing successfully with vehicles from Tata and Toyota.

Other prominent loci of product innovation have been the two-wheeler industry and the pharmaceutical industry. The Indian two-wheeler industry is one of the largest in the world and has grown at 35-40% in recent years, driven by a rising demand for affordable personal transportation. In this industry, product innovation and frequent product launches has become the key to competitive success (Krishnan and Prabhu, 1999). One of the most successful companies has been the TVS Motor Company, which was formerly a joint venture between the TVS group and the Suzuki Motor Company. Even before it broke the joint venture with Suzuki, the company had, on its own steam, developed a stream of successful mopeds and scooterettes (Krishnan, 2001); subsequently, it has launched the *Victor*, arguably India's most successful motorcycle that has sold more than 600,000 vehicles since its launch in 2001. Other two-wheeler companies like Bajaj Auto and Kinetic Motors have also launched products designed and developed in-house.

Companies like Tata Motors, Mahindra and Mahindra and TVS Motor have backed up their efforts in design and engineering by major investments in plant and machinery to produce their new products in large volumes with the latest manufacturing practices. They have all demonstrated a production capability, an investment capability and an innovation capability (Dahlman, Ross-Larson and Westphal, 1987). Their innovation capability centres on understanding user needs, conceptualizing distinctive products to meet these needs, system and industrial design, and system integration. They have outsourced technologies and designs for sub-assemblies (typically from vendors outside India), but managed the "integrity" of the design and the product.

The Indian pharmaceutical industry has been one of the high performance industries of the 1990s. About one-third of its 2002 production of $5.2 billion was exported to other countries. Among the ten entities based in India with the largest number of US patents during 1996-2001 are three Indian pharmaceutical companies (www.uspto.gov). These pharmaceutical companies are seeking to move from imitative research and reverse-engineering to the discovery of new molecules and drug delivery systems. The average R&D intensity of large Indian pharmaceutical firms is 2% (OPPI, 2002) but the R&D intensity of these innovative firms is substantially higher. Joint R&D initiatives with multinational drug companies, licensing of new discoveries to MNCs, sponsored research projects at national laboratories with government support, and the creation of international marketing networks in the hope of future exploitation of such networks to sell newly developed novel drugs are some of the developments in this area. One of the most successful pharmaceutical companies has been Dr. Reddy's Laboratories Ltd. (DRL). Starting a full-fledged R&D laboratory in 1992, DRL invested about Rs. 1.12 billion in R&D over an 8-year period. It filed 55 US patents of which 19 have been granted. It licensed three molecules to foreign drug firms (two to Novo Nordisk, and one to Novartis) for a total revenue of $8 million up to June 2001 (*Business Today*, 2001). In the current year, DRL has increased its R&D intensity from 5.5% to 8%. Ranbaxy, Cipla, Wockhardt and Sun Pharma are some other pharmaceutical companies with ambitious new drug discovery programmes.

Heterogeneity of Performance

While these success stories are noteworthy, the overall performance of the Indian industrial sector on the competitiveness front has been mixed. A study by Unni, Lalitha and Rani (2001) shows that total factor productivity in both the organized and unorganized sectors actually declined in the first half of the 1990s. Another study by the McKinsey Global Institute (see Krishnan, 2002a, for a critique) shows that the labour productivity of the modern sectors of the Indian economy is only 15% of the globally highest levels. This study also shows that while a good chunk of this may be due to the low wage levels in India that make the use of new technologies that can improve productivity unviable, a level of 43% of the globally highest levels can be attained through better work practices, investments in viable technologies and various organizational and managerial improvements. The higher level of investments in China, Thailand and Malaysia in the 1990s also suggests that investors do not perceive that India offers a comparative advantage in manufacturing.

What accounts for the fact that some industries and companies have made a successful transition to competitiveness, while others have been left behind? The evolution of innovation capabilities in the two-wheeler and pharmaceutical industries has been driven by regulatory changes, demand conditions, competitive forces and entrepreneurial initiative. While both have been high growth industries, regulatory changes have played an important role – in the two-wheeler industry, stringent new emission norms required upgradation of products, and since sourcing new designs from outside India would be too expensive, companies created their own designs; in the pharmaceutical industry, the impending changes in the patent laws following the government of India's acceptance of the WTO agreement put pressure on companies to move away from imitative research. Particularly in the two-wheeler market, the need to be able to differentiate products in a crowded marketplace has also influenced the creation of innovation capabilities.

Both the two wheeler and pharmaceutical industries have also had visionary entrepreneurs who were willing to make the investments and take the risks involved in creating and launching new products. These entrepreneurs became role models for the other companies in the industry. It is also interesting to note that many of the companies that have demonstrated innovative capabilities in the 1990s had a tradition of innovative behaviour even pre-liberalization. For example, Tata Motors (then Telco) successfully developed and launched a range of light commercial vehicles in the 1980s to combat the entry of Indo-Japanese joint ventures in the market. Telco's long-time CEO, Sumant Moolgaonkar, invested resources in the development of a strong engineering capability in Telco even at a time when due to regulatory constraints they were unable to leverage this in the market. Similarly, the TVS group's efforts at designing two-wheelers go back to the late 1970s when they launched a two-wheeler moped, the TVS 50. For these companies, liberalization allowed them to use their own technological capabilities, fill gaps through imports, and integrate these abilities with understanding of the market to launch successful products. In the pharmaceutical industry, government support and links with government research laboratories have also facilitated the process of innovation.

Many of India's large business houses are family-owned. Liberalization allowed these business families to use their entrepreneurial instincts to grow and build their businesses. However, these business houses are also managed in a highly hierarchical manner with very centralized authority. Technology is one area in which the owners often have limited expertise and interest. They have therefore been relatively unwilling to invest in technology development and preferred to source technologies from others. By contrast, in the companies and business houses that have been early movers in technology and product development, a technically qualified family member or very senior professional has played a pioneering role.

However, post-liberalization, access to the latest technologies has become more difficult as successful MNCs have access to the Indian market either through import of their products or local manufacture and have little interest in licensing their technologies to local companies. In response to this, some of the top business groups like India's largest group, Reliance, and another large group, the Aditya Birla group, have in the last few years taken the first steps towards technology development in their own areas of business.

Another weakness of large business houses is their failure to build a strong export orientation and their vulnerability due to their absence in competitors' key markets.

Approaches of Research Laboratories & Government Institutions of Higher Technical Education

While in the past the publicly-funded R&D infrastructure such as the laboratories of the Council of Scientific and Industrial Research tended to be isolated entities with poor links with industry, the last decade has seen many of these laboratories become much more commercially-oriented and direct their efforts towards international quality R&D. This is reflected in the increasing number of US patents and growing external earnings of these laboratories. CSIR laboratories filed 310 Indian patent applications in 1998-99 against

120 in 1987-88 and were awarded 133 Indian patents in 1998-99 against 76 in 1987-88. More impressive was the increase in patents filed abroad from 11 in 1987-88 to 112 in 1998-99. While no international patents were granted in 1987-88, the CSIR was awarded 38 international patents in 1998-99. External cash flows had reached Rs. 2040 million in 1998-99 with about Rs. 370 million (18.1%) coming from private industry and Rs. 150 million (7.3%) coming from foreign sources (CSIR, multiple years).

Some CSIR-specific policy changes facilitated this transition. Following a review in the mid-1980s, the CSIR adopted a target of achieving at least one third of its revenue from sources outside the government. This target was implemented with effect from 1989, but laboratories took the target more seriously after the onset of economic liberalization. The government also created a proxy for profitability by allowing laboratories to retain net earnings from externally sponsored projects in a separate laboratory reserve fund with the laboratories being given greater freedom to spend the proceeds from the laboratory reserve. Economic liberalization also created an environment in which laboratories could target customers outside India and also obtain contract research projects without being accused of violating their mandate (Krishnan, 2000).

The most prominent case of a laboratory that was able to reorient itself taking advantage of the policy changes was the National Chemical Laboratory (NCL) (Krishnan, 2002b). NCL succeeded in transforming itself into a global R&D platform, both licensing technologies and undertaking contract research for multinational corporations. The NCL leadership found that contract research allowed them to overcome the problem of having to provide complete production technologies, a requirement of Indian companies. This in turn avoided the need to set up pilot plants, scale-up technologies or provide performance guarantees. NCL became the trailblazer in obtaining US patents, accounting for more than 90% of the patents obtained by the CSIR and propelling the CSIR to the position of the largest holder of U.S. patents from India. To make this transformation, NCL's top management made a number of organizational changes including the creation of separate business planning and scientific information system divisions, medals for obtaining U.S. patents, awards for technology development and support functions, and a scheme to support "kite-flying ideas" from scientists. To fund the awards, a separate NCL Research Foundation was created using funding obtained from wellwishers of the laboratory.

Government funding cuts and expectations of greater interaction with industry have also influenced the leading government-sponsored institutions of higher learning to undertake more externally-sponsored research and consultancy work. The revenue from sponsored projects at the Indian Institute of Technology Kanpur, one of the top engineering schools, has increased tenfold while the consultancy income has gone up about sixteen times between 1993-94 and 2002-03 (Table 4). In another top engineering school, the Indian Institute of Technology Madras, revenue from sponsored projects increased 3.5 times and that of consultancy projects almost doubled over the same period, though from a larger base (Table 5).

Table 4: Revenue from Consultancy and Sponsored Research Projects at IIT Kanpur						
Year	Sponsored Projects		Consultancy Projects		Patents	
	No	Revenue Rs. Million	No	Revenue Rs. Million	Filed	Granted
2002-2003	115	302.5	136	57.4	8	1
2001-2002	59	176.7	153	71.8	7	3
2000-2001	99	161.7	130	22.4		
1999-2000	61	69.1	116	27.7		
1998-1999	83	82.9	107	14.4		
1997-1998	82	139.4	71	9.1		
1996-1997	94	61.5	74	9.0		
1995-1996	65	54.0	101	16.7		
1994-1995	72	46.3	100	5.2		
1993-1994	109	25.6	76	3.6		
Source: Dean (R&D), Indian Institute of Technology Kanpur						

Table 5: Revenue from Consultancy and Sponsored Research Projects at IIT Madras						
Year	Sponsored Projects		Consultancy Projects		Patents	
	No	Revenue Rs. Million	No	Revenue Rs. Million	Filed	Granted
2002-2003	91	180	636	66	42 patents filed since 1990	20 patents granted since 1990
2001-2002	89	181	737	71		
2000-2001	53	96	866	74		
1999-2000	42	45	833	68		
1998-1999	57	94	679	57		
1997-1998	58	67	732	49		
1996-1997	53	81	646	36		
1995-1996	55	49	668	34		
1994-1995	64	92	592	26		
1993-1994	52	50	596	37		
Source: Dean (IC&SR), Indian Institute of Technology Madras						

Under pressure from the government, the IITs have also doubled their intake over the last decade. However, the number of candidates in doctoral programmes has actually fallen over the same period.

The Growth of Services under Liberalization: The Case of the Software Industry

Evolution of the Indian Software Industry

The Indian software industry is perhaps the outstanding industrial success story of independent India. From a small beginning in 1970 when Tata Consultancy Services was founded, through a period of gradual growth in the 1980s, the industry came of age in the 1990s and by 2002 accounted for more than 2% of Gross Domestic Product and 15% of exports from the country. The post liberalization period has been a period of explosive growth of the software industry. Software exports were just Rs. 1.35 billion in 1990-91 but went up to Rs. 25.2 billion in 1995-96, Rs. 283.5 billion (US $ 6.2 billion) in 2000-01, and US $ 7.68 billion in 2001-02 (Nasscom, 2002). Subsidiaries of Multinational Corporations (MNCs) accounted for 27% of the software exports in 2001-02 and Indian companies for the remaining 73%.

Indian software companies entered the industry by providing low-cost, skilled manpower to clients in developed markets (principally the U.S.). To start with, this manpower provided labour at the customer's site, typically under the direction of an external consultant or the firm's own information systems department. Starting with low value-adding jobs like maintenance and testing, the software companies graduated to reengineering existing pieces of code to new operating systems and platforms. Demand for the latter was created by the shift of users from mainframes to client-server systems.

In the years immediately preceding 2000, Indian software companies obtained many projects to solve the "Y2K" problem (Arora et.al., 2001) The internet and e-commerce explosion helped companies graduate to large-scale coding assignments that actually developed new applications. Simultaneously, Indian software companies developed good project management and quality processes that enabled them to manage large projects whether at the customer's site or back in India ("offshore") at their own development centre.

The declining cost of telecommunication links and the wide diffusion of the "always on" internet combined with the good track record of the companies have led to a steady increase in the proportion of offshore revenues (Nasscom, 2002).

The success of the Indian software industry can be attributed to factors on both the demand and supply sides (Krishnan, Gupta and Matta, 2003). Globally, large corporations are under tremendous pressure to reduce their costs and yet exploit the potential benefits of advances in information technology. They have therefore moved towards operating models that allow them to concentrate on areas of their core competence and outsource other activities. This phenomenon has created the demand for software services. Indian software companies built on a strong human resource base to create organizational processes to quickly absorb new technologies and ramp-up internal delivery capabilities in a short time to meet customer requirements, and at the same time ensure on-time delivery at an acceptable level of quality. Using cost arbitrage as an entry strategy in an emerging business, they opportunistically expanded their business, at the same time building more sophisticated organizational capabilities within (Athreye, 2002). Their growth was facilitated by the fact that the software services model does not involve irreversible commitments on specialized resources, and that the basic skills required are fairly generic (Krishnan, Gupta and Matta, 2003). The persistent gap between demand and supply allowed for greater experimentation by firms to find the right business model and also prevented a downward spiral in rates (Athreye, 2002).

While the government can not claim the software industry as a "policy-driven success", it played an important facilitative role in the 1990s through the exemption of software industry export profits from income tax and the Software Technology Parks scheme that allowed companies to have the regulatory benefits of an export promotion zone irrespective of their location.

Software Industry and the Innovation System

To what extent has the evolution and growth of the software system benefited from the pre-existing innovation system? It is difficult to come by exact numbers, but it is evident that many of the early employees of the software industry came from scientific research organizations (such as the laboratories of the Defence Research & Development Organization) and some public sector enterprises that had good computer infrastructure such as Hindustan Aeronautics or Bharat Electronics. This was primarily due to the fact that these organizations were the ones that had an installed base of state-of-the-art computers and therefore also had people who were skilled at working on computers. Subsequently as the number of computers in the economy grew, and so did the number of formal education programmes training people in computer science or engineering, the need for people from the labs declined. Companies also created their own training programmes to convert raw engineers into programmers. As the industry matured, so did the people requirements of the industry.

It is also interesting to explore links in the opposite direction, i.e. to see what has been the impact of the software industry on the wider innovation system. Compared to manufacturing, software development has limited spillovers to the rest of the economy (Arora and Athreye, 2002). However, the growth of the Indian software industry has had a number of indirect yet positive benefits to the Indian economy. Software companies were among the first Indian companies to raise capital internationally and be listed on foreign stock exchanges such as Nasdaq and the New York Stock Exchange, thereby setting a trend towards raising capital internationally. In parallel, they set new standards for corporate governance, adopted US GAAP, and became benchmarks for disclosures. They also introduced US-style employee ownership plans (through the creation of stock options) to the Indian corporate environment. Compared to traditional Indian organizations, they are more egalitarian and less hierarchical.

Indian software companies also succeeded in converting the "Made in India" label from a liability to a source of competitive advantage, thus paving the way for the positioning of India as an Outsourcing Destination. This has enabled the creation of an "IT-enabled services" industry centered on business process outsourcing, call centers, and other remotely-provided services. This reputation also facilitated the movement of higher-end R&D services like chip design and engineering services to India; some MNCs have also started locating multi-disciplinary research and development centers in India. Prominent among the latter is the John F. Welch Technology Center set up by General Electric in Bangalore.

Indian software companies have also provided role models for entrepreneurship. Three out of the top five software companies – Infosys, Satyam and HCL - were started after 1980 by individuals who were not from Indian business families. They have therefore communicated a message that there is no need of a family business background to be successful in business. Their success and the status enjoyed by their founders have attracted many persons to start new ventures. The maximum impact of this could be seen during the dot-com boom.

The country's success in software has also had a wider rub-off. It has inspired a feeling of confidence in other sectors of the economy and even on the government. The southern states of India that have been at the forefront of the growth of the software industry have displayed entrepreneurial leadership in governance. They have also been pioneers in e-governance. The software industry has made more direct contributions to local governance – the CEO of one of the prominent software companies is leading the Bangalore Agenda Task Force, an industry-government joint initiative to renew the city's urban infrastructure; private foundations created by the founders of software companies are playing an increased role in the creation of civic facilities and in spreading primary education.

The software industry also attracted international venture capital to India and has been responsible for annual flows of ~$350 million to $1 billion. Many international investors came to India because of the software industry and it thus became the "conduit for flow of international capital to India". About 70% of the venture capital coming in to India is estimated to have gone to the software industry (Nigam, 2001). The software industry has used its influence to play a role in creating policy changes such as changing the norms for venture capital, international listing, and the acquisition of companies outside India,

The software services sector has attracted India's best talent and spurred a tremendous growth of technical education, much of it in the private sector. A sizeable computer and software training industry has also evolved in the shadow of the software industry. The software industry has created more than 500,000 jobs in addition to providing a stepping stone to hundreds of software professionals to emigrate to the United States.

The software industry, with its strong export orientation, has developed limited links with the local manufacturing industry. This is partly a result of the fact that export contracts are much more lucrative for the software industry. However, it is also a result of the limited sophistication of the Indian manufacturing sector's information technology infrastructure. The high cost of domestic telecommunications services (until the recent decline in the wake of telecom industry deregulation) and the low penetration of the internet have also prevented manufacturing companies from taking the benefit of networking their IT infrastructure.

Role of MNCs

Though not dominant in size, the subsidiaries of MNCs have had an important impact on the evolution of the Indian software industry. Early entrants such as Texas Instruments and Hewlett Packard helped build the brand of India as a software destination. They also inspired the model of offshore development centres that was subsequently adopted by the large Indian software companies (Arora and Athreye, 2002). They played an important role in the quality movement – Motorola's Indian software subsidiary was the first SEI CMM Level 5 certified facility in India. They have contributed to the development of manpower through training programmes and by supporting academic programmes in local universities. Some Indian MNC subsidiaries, notably those of Texas Instruments, Oracle and Adobe, have developed complete products (Patibandla and Petersen, 2002). MNCs that have subsidiaries in India have only subcontracted relatively insignificant projects to local software producers (Patibandla and Petersen, 2002). They have pushed up average salaries by offering substantially more than Indian software companies. Their job opportunities may have also contributed to the decline of Indians pursuing doctoral level qualifications in electronics and computer science though these same job opportunities have slowed down brain drain. The presence of local research and software development centres of MNCs has contributed to the exposure of some of their employees to sophisticated product and technology development and advanced managerial practices. Some of these people have migrated to Indian firms, and a smaller number have also become high technology entrepreneurs. However, in spite of some complementary capabilities, there is little evidence of the development of complete products jointly by the MNC subsidiaries and local high technology firms. The lack of such development is attributed to the absence of a strong local market and the way MNCs are managed in which the software subsidiaries are typically cost centres reporting to the R&D and business managers of the MNC in other countries. MNCs also have limited research links with local technical institutions (Krishnan, 2002c).

Innovation & Learning

Software is often referred to as a knowledge-intensive industry and sometimes even as a high technology industry (see, for example, Patibandla and Petersen, 2003), and India's success in this business is cited as evidence that latecomers can do well in high technology industries.

However, as per conventional definitions of "high technology industry" (such as R&D intensity), the Indian software industry would not qualify as a high technology industry, at least not using the figures disclosed by the companies themselves as their expenditure on R&D. One of the leaders of the Indian software industry, Infosys Technologies, reported an R&D to sales ratio of 0.38% in 2002-03 (Infosys, 2003) and other prominent Indian companies are not very different.

It is sometimes argued that because of the nature of the work undertaken by Indian software companies – customized services – R&D expenditures by Indian software companies tend to be understated. By this argument, every project is a new learning experience and involves fresh understanding of a problem, and sometimes even the application of new technology or approaches. However, the knowledge creation in the software industry has been more evident in the form of business-specific knowledge.

There are different types of knowledge that go into running a software business. At a generic level, there is the knowledge of different data structures and programming languages. Indian software companies have repeatedly proved to be adept at quickly learning new programming approaches and training a large number of software engineers within the company to use these approaches. Prominent examples of this capability are the quick ramp-up witnessed on solutions to solve the Y2K problem, internet and e-commerce technologies, and adoption of some of the new Microsoft technologies such as .NET. A second area in which the Indian software companies have displayed some learning abilities is in the realm of domain competencies. Over time, most of the large companies have created divisions focusing on different customer domains such as manufacturing, retailing, insurance or telecom and created teams of domain specialists who have enough understanding of these domains to enable the companies to provide software solutions that add value to the customer's business processes. However, there is still a gap between their domain competencies and those required to go into consulting or product development as explained in the following section. A third (and probably the most prominent) area in which Indian software companies have proved their learning ability is in the area of quality management systems. Starting with a simple ISO 9000 certification, Indian software companies are today at the vanguard of the quality movement and more than 30 of them have SEI CMM Level 5 certification, signifying the highest level of process maturity in the software engineering process. While some cynics question the incremental gains from further efforts to improve quality processes within the Indian software industry, there is little doubt that the industry or at least the larger companies have internalized a strong process orientation. Their ability to continually upgrade their processes has been recognized by their customers in terms of large contracts and a growing business. Obtaining certification has been a powerful signaling device.

How useful is this strong process orientation for innovation? Or are a process orientation and innovation mutually exclusive and contradictory? Discussions with managers in software companies suggest that the strong process orientation and an emphasis on efficiency and "getting it right the first time" do impede the flow of creative ideas, particularly in the context of new products and technologies. When performance is measured in terms of number of deviations from the quality process or in terms of number of errors per 100 lines of code, there is bound to be an impact on people's willingness to try out new things or experiment with new ideas. Research on product development by software service companies shows that there are basic cultural differences between software service and product companies, and that it is difficult to have both cultures in the same organization (Nambisan, 2001; Krishnan & Prabhu, 2002).

The Future of the Indian Software Industry

Indian software companies have had limited success in ascending the value curve into consulting and product development. The main barriers to growth in consulting have been lack of domain expertise, lack of a brand image, and the image of Indian software companies as efficient low-end service providers. The barriers to product development have been the high upfront investments involved, physical distance of the key global market for products from India (and the absence of challenging customers in India), lack of domain expertise, limited ability to conceptualize products and the easy revenues that can be generated from the services business thanks to the trend towards outsourcing by large multinational corporations (Krishnan and Prabhu, 2002). Other constraints to entry into higher value segments for Indian software companies include government restrictions on foreign acquisitions, and the increasing limits on the movement of professionals in the wake of the recession in major markets and the anti-terrorism drive.

It thus appears that while the software services sector has seen spectacular growth, its evolution has been based on a distinct role in the global production system that involves relatively low value-added work, "locked-in" to the global division of labour (D'Costa, 2002). While the software sector has both Indian and multinational firms, multinational firms appear to be doing more advanced software work; however, their links and spinoffs to the local innovation system have so far been limited. The growth of the software sector appears to have done little to enhance productivity in other sectors of the Indian economy though it has provided alternate organizational paradigms and management models that have influenced companies in other industries. Capabilities developed by the software industry may, however, find application in the newly emerging IT-enabled services industries and enable India to build a strong base in these industries.

Other Dimensions of the Innovation System

Engineering Education: Quantity without Quality

In 1990, there were 339 institutions offering formal degree-level education in engineering and admitting about 87,000 students every year. Today, there are 1,208 engineering colleges offering more than 360,000 places for admission. Most of these are self-financed colleges, set up in the 1990s, to cater to the burgeoning demand for engineering education. Five states - Tamil Nadu, Karnataka, Andhra Pradesh, Kerala and Maharashtra - account for 806 engineering colleges (The Hindu, 2003). The rapid growth in engineering education helped meet the increasing needs of the software industry, but it is apparent that there are now too many colleges with too many seats. Of greater concern, is the quality of the new engineering colleges that have been opened. The Comptroller and Auditor General of India audited 171 new institutions set up after accreditation by the All India Council of Technical Education (AICTE) and found that each of these institutions failed on at least one of the pre-requisites (classrooms, basic facilities, library, laboratory equipment, and faculty) of the AICTE (Goswami, 2003).

Entrepreneurship

Though reliable data on the formation of new ventures is not available, anecdotal evidence suggests that there was a surge of entrepreneurship during 1999-2001, related to the dot-com and internet boom. Inspired by the success of India's software entrepreneurs, and believing that the internet represented a paradigm shift in the way business is done, hundreds of people from established companies and universities founded new companies. This marked the high point of entrepreneurship and capped a decade in which businessmen became more respected people in Indian society. Further, there is now a belief that the new environment allows ventures to succeed or fail based on their own merits rather than the owners' ability to influence the political process. While the dot-com boom did not sustain, the change in societal attitude towards entrepreneurship, if widespread, should be of benefit in the years ahead. Doubts arise because a recent survey of India's adult population found that small entrepreneurs and failure are not respected, and that wealth distribution is more important than wealth creation (Reynolds, et. al. 2000). However, this study also found that there is growing respect for first-generation entrepreneurs, driven largely by the growth in the information technology sector.

Geographical Clustering

Prior to economic liberalization, the Indian government offered distinct incentives such as subsidies and industrial licenses to companies setting up their undertakings in "backward areas" as a means of achieving balanced economic development. The deregulation post-liberalization has seen a distinct clustering of enterprises around large metropolitan cities - e.g. Bangalore has become a hub for the software industry, and Chennai for the automobile industry. While companies see clear benefits of locating in the vicinity of large cities (such as better infrastructure, access to a pool of skilled manpower, good transportation and logistics links), this agglomeration is putting tremendous pressure on the urban infrastructure. Traffic congestion, pollution, water shortage and rise in the cost of housing are all outcomes of this concentration. However, some characteristics of high tech clusters such as specialization and alliances between companies with complementary skills are beginning to emerge, albeit slowly.

Labour Movement

Indian trade unions were suspicious of many attempts to upgrade technology and restructure industries in the 1980s. In the banking industry, for many years, they opposed the introduction of computerization. However, post-liberalization, in most cases, unions have been willing to go along with productivity-linked incentive schemes and there are few known cases of unions thwarting the introduction of new technology over extended periods of time. Though the unions have opposed privatization, they have been able to slow it down but not prevent it, as in the case of allowing foreign insurance companies into the Indian insurance industry. Indian industry has been seeking greater flexibility in employment rules to be able to deal with the changes in the external environment. While "hire and fire" has not yet become a norm in Indian industry, many unions have gone along with "voluntary retirement" schemes that allow companies to reduce their workforce based on generous severance payments. The companies also desire to hire more people on a "casual" basis and many are doing this through the award of labour contracts. Overall, the bargaining power of unions appears to have declined over the period of liberalization. For a good review of the impact of liberalization on the Indian trade unions after liberalization, see Bhattacherjee (1999).

Summing Up

Has economic liberalization facilitated the translation of India's technological capabilities into goods and services leading to enhanced economic growth and competitiveness? Has the innovation system become more dynamic and strong, or has greater integration with the world economy weakened the innovative capabilities of the Indian economy?

In trying to answer these questions, a number of features of the Indian innovation system become evident. In manufacturing-related industries, economic liberalization has provided an opportunity for companies, research organizations and institutions of higher learning that had already developed a base of innovative capabilities, to build further on these and target their output to markets – external or internal – that value this output. Some sectors – pharmaceuticals and two wheelers are two – have seen a strengthening of innovation (technological + technology-linked market) capabilities within the industrial sector thanks to deliberate efforts by trend-setting companies. On the average, particularly in large industry, the importance of quality has increased, and quality practices have been integrated into the business processes of these organizations. More companies have moved up on the continuum to competitiveness - learn to produce; learn to produce efficiently; learn to improve production; learn to improve products; and, finally, learn to design new products (Forbes and Wield, 2002).

The services sector that has grown faster than the industrial sector has leveraged a strong resource base to exploit a major market opportunity, and in the process created a number of organizational capabilities that can be used in other service businesses. However, the nature of the capabilities built seems applicable to a range of services in the lower and middle ranges of the value ladder. It seems likely that the software companies will remain locked into these services though there will be opportunities to transfer the capabilities to other service industries of a similar nature.

A notable gap is the lack of synergies between the services and the manufacturing sectors – in spite of the considerable success of the software services industry and the strengthening of competitiveness of some parts of the manufacturing industry, there have been few efforts to use Indian software capabilities to make the Indian manufacturing sector more efficient.

Overall, Indian manufacturing and service organizations appear better positioned to succeed in global markets than they did before economic liberalization. However, if India is to move on to the next level of competitiveness, many issues remain as discussed in the following sections.

The Future of the Indian Innovation System

What are the future challenges faced by India in strengthening its potential for innovation? What are its prospects in emerging industries/technologies? Can it hope to transform itself into a knowledge society?

The challenges for India as the global economy becomes more knowledge intensive are manifold. Though India has impressive achievements on the innovation dimension, it remains a poor country with the second largest population in the world. As a democracy, decision-making has to take into account the concerns of diverse interest groups. Politicians who have to face the electorate once in five years (or sooner if the government falls prematurely) have few stakes in long-term plans that take more than five years to show results. Yet, lasting changes in the innovation system have longer gestation periods. For the people of the country, employment and having enough money to buy their next meal are more important than whether India is a technological superpower or not. If liberalization has to be sustained and built on, the fruits of liberalization have to go beyond the middle class in urban India. These concerns are important as we explore how India can build on the base it has created and build its industrial and services base.

Some of the challenges faced by India are to (i) sustain growth in employment intensive (though not necessarily high value-added) service businesses; (ii) maintain the competitiveness of existing manufacturing and service businesses by constant upgradation of capabilities; (iii) recover competitiveness in sectors where India has some traditional advantages (e.g. textiles); and (iv) enter and succeed in select emerging high technology industries.

Of these four challenges, the first three are more operational in nature in the sense that many countries (and companies) have shown how this can be done and the key to success is good implementation and execution. The fourth challenge is the most tricky because this is where risks are high, role models are few, and forecasting trajectories is difficult. Succeeding in this challenge will require the ability to develop and absorb new technologies. Building this ability will require greater care in resource allocation, improving the quality of education, greater flexibility in organizational structures and processes, promoting technological entrepreneurship and shaping societal attitudes and values towards knowledge.

Resource Allocation: For a country with scarce resources and high levels of poverty, careful allocation of resources is crucial. Recent research by Chandrashekar and Basavarajappa (2001) and by Parthasarathi (2002) shows that resources for science and technology in India have not been targeted at obvious national priorities. To build critical capabilities in new areas, major investments have to be directed towards such areas. Lack of critical mass can result in disproportionate under-performance. For instance the NMTLI which seeks to build new capabilities in frontier areas had an initial budget of Rs. 500 million (about $11 million). Contrast this with the Korean Highly Advanced National R&D Project that has a budget of $5.7 billion (Kim, 2000:347).

Improving the Quality of Education: The explosion of higher technical education may have fulfilled the aspiration of many individuals to get an engineering degree, but may do little to enhance technological capabilities. To move up to the next level, India needs high quality education. The government has shown some recognition of this fact by upgrading an important technological university into an IIT, repositioning and restructuring the RECs as National Institutes of Technology (NITs), and announcing that a select group of

5 NITs will be upgraded into IITs. However, the crux is not in renaming institutions but in attracting and motivating qualified faculty to come and teach in them. Academic salaries are pegged to civil service scales of pay, and promotions even in the top institutions linked to seniority. Unless this is changed, it will be difficult to attract the top minds to Indian academia.

Greater flexibility in organizational structures and processes: C-DOT was once considered India's most successful research laboratory, but is today on the verge of closure. One reason, apart from political reasons, is that the government did not allow CDOT to evolve naturally into a more integrated telecom organization. Because CDOT remained a standalone R&D organization and gave licences for its technology to practically anyone who asked for it, it took on too many licensees; the capacity created was underutilized; and many of the licensees lacked the capability to make any improvements or upgrades of their own and were totally dependent on CDOT for product enhancements. CDOT was isolated as an R&D organization and was dependent on the then government monopoly service provider for trials or user feedback. This situation did not improve substantially even when CDOT was formally brought under the umbrella of the Department of Telecommunications. The pace of development fell, and CDOT was unable to maintain its technological edge. Contrast this with Chinese companies like Datang or Legend which evolved from the Chinese S&T institutional infrastructure. The Chinese have alleviated the problem of transferring technology from laboratory to enterprise by encouraging the transformation of laboratories or parts of labs into commercial organizations (Lu, 2000). Ownership may rest legally with the Chinese government, but enough flexibility is given to the S&T enterprises to find their own commercial feet. Another important dimension of organizational flexibility is the need to merge and restructure different national laboratories so as to attain a critical mass of people in different domains. The government should also use its own procurement and projects as a means of developing capabilities in industry as happens in many developed countries.

Promoting technological entrepreneurship: Setting existing family-owned firms on the path of growth and technological upgradation may be a difficult task because becoming more technology-focused also means the entrepreneur giving up a degree of control unless he has a background, interest and competence in technology-related issues. Greater technological sophistication is thus closely linked to greater professionalisation of the enterprise and this is likely to be a slow process. It therefore appears that a technological renaissance in India can not happen without a new generation of technology and business-savvy entrepreneurs. To facilitate this process, the country needs to provide a conducive climate for the creation of new firms whose owner-technologists are already part of technological (if not business) networks. This is the approach pursued successfully by Taiwan through efforts to attract their technologically-qualified citizens residing overseas to invest in creating high technology ventures in Taiwan. The primary vehicle for this has been the creation of science parks through which new enterprises set up by overseas Taiwanese get access to world-class infrastructural facilities (including residential and schooling arrangements) and seed funding to cover start-up expenses. By virtue of the links of their founders, these enterprises are automatically part of an international network from day 1 and become part of the Taiwanese manufacturing cluster over time. This idea has been subsequently adopted by China as well. Just as successful venture capitalists try to put ideas and people together to create new ventures when the need arises, a more proactive approach to technology-based venture formation will be needed if we are to build on existing networks rather than trying to create new ones. Another important way of creating technology enterprises is by being more flexible about the transformation of research laboratories as explained above.

Shaping societal attitudes and values towards knowledge: This is the most difficult but also the most important of the issues confronting India. Though developing a scientific temper has for long been a fundamental duty of Indian citizens under the constitution of India, many important values needed for a knowledge society are not embedded in India. Those values absent include a questioning attitude, openness to debate, verification and validation, recognition of the value of failure in knowledge creation, the importance of specialized skills, and the value of "learning by doing." Unless Indian society can cultivate these values, it is unlikely that it can evolve into a true knowledge society.

Issues for Innovation System Research

What are the implications of the trends described above for the future evolution of the innovation system of other developing countries? One Indian achievement that has caught the eye of many other countries is the success of the software industry and a steady stream of heads of state and government from other developing countries visit Bangalore hoping to learn the secret of India's success. Though the government of India never planned or developed specific institutions for the growth of the software industry, the broad-based technological infrastructure created in the country has facilitated its growth. Should all developing countries try to develop a similar infrastructure and then just hope that they will be able to catch the next wave?

Innovations in business models, organizational design, and functional strategies can be critical for success in emerging industries. In the software industry, these have been more important than technological innovation. The focus of the innovation systems literature has largely been on technological capability building. The perspective needs to be broadened to include a wider variety of innovative capabilities.

Like the resource-based view of the firm that looks at strategy primarily from an inside-out perspective, the innovation system approach also looks more at a country's resources and the connections and consistency between them rather than at markets and how to build on absolute or comparative advantages in competitive markets. Strengthening the links of this research with markets and how value can be appropriated by firms is a key area for future research. Much of this would have to be at the firm level but with a clear systems perspective.

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