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Internationalisation of R&D and Global Nature of Innovation: Emerging Trends in India

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Till the end of 1980s, offshoring of R&D (Research and Development) by TNCs (Trans National Corporations) were mainly confined to industrially advanced countries, particularly among the 'Triad' (US, Europe and Japan). Even if TNCs moved to the developing countries, during the early to mid-1990s, their R&D activities were mainly restricted to 'one way technology transfer' or oriented towards 'adaptive R&D' rather than 'creative R&D'. This study finds that during the last two decades, this paradigm has changed significantly. India has emerged as an important destination for about 471 TNCs with about 649 R&D units. Indian R&D and innovation threshold has moved up quite dramatically in the last decade to transform from 'one way' to two-way knowledge transfer. Now many foreign R&D units are developing products from India for their global product mandate. The exploration of TNCs and their impact in the Indian context advances the view that India is emerging as an important partner in the globalization of innovation. Another important trend of globalization and the global nature of innovation emerging is the rise of the Indian firms that expand business and link up with the global production networks.

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Introduction

THE LAST DECADE witnessed two rapidly increasing trends in the pattern of global science and technology system, namely, internationalisation of R&D and globalisation of innovation. The former signifies Foreign Direct Investment (FDI), foreign R&D affiliates of Trans National Corporations (TNCs) and other companies and international collaborations and so on. Business- and knowledge-process outsourcing, R&D and technical services outsourcing and moving other institutional and organisational operations to foreign locations also fall in this category (Turpin and Krishna, 2007). The latter is a recent trend signifying innovation networks of companies stretching beyond in-house or home country locations into foreign locations. Innovation networks do not require co-location of R&D with either the consumer or the manufacturing facility. Global products can be created by driving greater integration of R&D across different locations, thus efficiently combining multiple talents/capabilities of different economies.[1] There are a number of innovation network operations conducted or contracted to foreign locations that create new business opportunities. The corporate model of R&D pursued within home country locations within physical boundaries of the corporate firm is fast eroding (*The Economist* 3 March 2007). The internet and telecommunication revolutions have dismantled geographical barriers, creating a new innovation potential at different levels of the value chain. This was mainly restricted to industrially advanced countries until about early 1980s, but during the last decade and a half, this trend has spread into the developing countries (Pearce, 2005; Reddy, 2005).

The Asia and Pacific region has occupied a significant space in these trends. From the region, Japan, Australia, South Korea and Taiwan have already made a mark. India and China have recently emerged as important players and destinations for internationalisation of R&D and globalisation of innovation during the last decade. As the World Investment Report (WIR) notes:

> …the rise of developing Asia and Oceania has been the most dramatic development in the global landscape of R&D. Some economies in the region have been able to capture a broad range of R&D functions from TNCs, including innovative R&D and basic research. World Investment Report (2005:139)

Further, as the data by WIR (2005) reveals, of the 885 R&D-oriented Greenfield Foreign Direct Investment (FDI) projects announced in 2002–2004, 75 per cent (723 projects) were cornered by India and China. These countries are host to some 800 leading global TNCs that are operating R&D units or R&D-based firms mainly in ICT (Information and Communications Technologies), biotechnology, pharmaceuticals, telecommunications and automobiles. During the last decade, Bangalore—India's Silicon Valley—Hyderabad's high technology city, Beijing's Zhongguancun Science Park at Haidan District and Shanghai's Pudong New District are host to some 500 global companies that have opened up R&D units. These cities have emerged as global R&D and innovation hubs or networks with

horizontal and vertical integration to globally dispersed TNCs. UNCTAD's (United Nations Conference on Trade and Development) survey of the largest R&D spenders confirmed the growing importance of Asian economies as the most favoured R&D destination of foreign locations. China (third position), Japan (fifth position), India (sixth position) and Singapore (ninth position) figured among the top 10 countries in this survey (WIR, 2005:133). In the latest survey by UNCTAD (World Investment Prospect, 2007–2009), India emerged as the second most preferred destination after China for the location of FDI. In R&D activities, 47 per cent (of the 191 companies that were part of this survey) were eager to internationalise as compared with only 42 per cent in 2006.

The objective of the paper is to explore three main issues in the Indian context. The *first* objective is to briefly review and trace developments in the Research and Development (R&D)-related FDI in developing countries. *Second*, it will explore the structure of internationalisation of R&D in India. This section will trace the growth of foreign R&D units, spatial distribution, sectors and fields of operation and their activity structure, among other factors. The *third section* will attempt to bring out the main implications of these trends from the perspective of globalisation of innovation in the last few years in the broad perspective of internationalisation of R&D. For example, the section will explore the questions such as: What is the impact of R&D related FDI? What is the direct and in-direct impact? What is happening to Indian firms and how are they partnering with foreign R&D units and firms? To what extent are Indian firms globalising?

In doing so, the paper will explore the context of innovation to see whether these trends signify a 'new international division of labour' between North and South or whether there is evidence to suggest a transformation towards globalisation of innovation.

R&D-Related FDI in Developing Countries (DCs)—A Framework

Internationalisation of R&D as understood in terms of firms operating with their affiliates and collaborations in foreign locations is indeed a very old trend. This trend can be traced back to the colonial period in the DCs such as India. Influential writings from Reddy (1997, 2000, 2005, 2011) and others draw attention to internationalisation of R&D, which has progressed in two waves or phases during 1960s and 1970s, respectively. Culminating in the third and fourth waves in the 1980s and 1990s, respectively, these are termed as globalisation of R&D.[2] While the firms performing R&D abroad in the 1960s were said to be relatively small and much of the R&D undertaken abroad was characterised as technology transfer units linked to local adaptation, the decade of the 1970s witnessed the trend of going beyond technology transfer of earlier phases to performing R&D abroad by firms in a significant way. Even indigenous firms and institutions in DCs enhanced their local and national technological capabilities to absorb foreign technology to new products and processes. In India, policies of self-reliance and import-substitution led to the strengthening of local and national S&T (science and technology) capabilities.

Government has taken a number of policy measures; like the Indian Patent Act of 1970, India's first S&T Plan of 1974 and the Technology Policy Statement (1983).

The third phase witnessed the extension from internationalisation of R&D to the globalisation of R&D, wherein, 'higher-order R&D, such as regional technology units, global technology units and corporate technology units, had been located abroad in what can be regarded as the third wave of globalisation of R&D' (Reddy 2005, p. 95). Furthermore, the main forces that are driving this phenomenon are identified as:

- Global basis of competition coupled with convergence of consumer tastes and preferences worldwide that are creating a need for learning.
- Increasing science-base of new technologies, which demand multi-sourcing.
- Rationalisation of TNC operations which assigned a specific role to their affiliates.

The rise of Information and Communication Technologies (ICT) and the new structure of science-based technologies were seen to foster the de-linking of R&D and manufacturing activities in the decade beginning in the 1980s. The decade since the 1990s is seen to have paved the way for the fourth wave. In India, this phase witnessed the introduction of new economic reforms that promoted liberalisation and FDI for both financial and R&D-related components. The global scenario has also changed substantially, for example, there is increasing demand for skills in industrially advanced countries coupled with mismatch between production and demand. The firm's research network has widened to tap into geographically dispersed knowledge hubs. There is rising wages in the North and availability of highly skilled human resources in India and other DCs. Many developing countries have considerably enhanced their science and technology (S&T) capacities. All these factors culminated with the wave of globalisation and liberalisation policies in the Indian context. [3] In this phase, the sector of Business Process Outsourcing (BPO) and Knowledge Processing Outsourcing (KPO) activities found firm roots in India. Coupled with the ICT revolution, these activities accelerated the earlier trend of de-linking manufacturing and R&D to pave the way for R&D networking, on the one hand, and opened up a vast 'window of opportunity' for Indian software firms to partner with global firms, on the other.

While the frameworks put forward by Reddy and others are quite useful to explore the growth and structure of R&D-related FDI in terms of the four phases and waves reviewed above, they do not however explicitly bring in the changing context of innovation and link up with the trends in internationalisation of R&D. In other words, strictly speaking, 'globalisation of R&D' is not the same as 'globalisation of innovation' even though it is closely associated with it. As the context of global innovation is changing rapidly, it is more meaningful to talk about dispersed or networked innovation in which firms and R&D institutions in DCs are assuming the role of partnerships in both knowledge production and its use. It is the objective of

this paper to go beyond the rich perspectives and literature on internationalisation of R&D and globalisation of R&D to explore emerging trends in the globalisation of innovation from an Indian perspective. What Pearce (2005:29–30) says in this regard seems quite relevant:

> …single most important element in the changing ….TNCs… has been the perception of a breakdown in such an immutable home-country orientation of creative activity and moves towards globalised programmes of innovation and R&D. … to see TNCs organisational structures as predominantly hierarchical has been replaced by attempts to analyse them in terms of heterarchy or as differentiated networks.

Even though R&D is an important component of innovation, it is appropriate to distinguish between the two. The notion of innovation draws attention to technological changes both radical and incremental, inventions and other R&D-related activities undertaken at the laboratory level, which find relevance in the industry or market of commercial or non-commercial types. In this sense, the globalisation of innovation relates to various components of knowledge production and consumption chains that are not hierarchical but are horizontally connected networks and are geographically dispersed across various actors, agencies and regulated by institutions at different levels and locations. As Ernst (2005:73) observes, even big firms like IBM are in no position to 'mobilize all the diverse resources, capabilities and bodies of knowledge internally'. Firms need to tap knowledge inputs from trans-border locations. Furthermore, scholars such as Chesbrough (2003) have termed these types knowledge-scouting process as the 'model' of 'open' innovation system.

Contemporary development of horizontally networked, geographically dispersed and partnered innovation process—which is shifting away from industrially advanced countries (US and Western Europe) to India, China and other DCs—is closely associated with the rise of science, technology and innovation capacities of these latter countries. The nature of R&D and knowledge-related links, partnerships, working relationships between Indian firms, knowledge institutions (both private and public research systems) with Indian-based foreign TNCs, their subsidiary R&D units and laboratories assumes considerable significance to explore the development of globalisation of innovation from the Indian experience. Further, Reddy (2005) and others draw attention to the fact that that there is a whole range of impact-related factors of TNC operations in developing countries that point towards spin-offs, spillovers among others, which seem very relevant.[4]

The other important development in India during the last decade since the late 1990s has been the rise of what may be termed as Indian TNCs or enterprises and firms (both public and private) that operate and carry out business in more than two to three countries and are involved in knowledge production and linked to knowledge consumption for a variety of sectors from engineering, medical, ICT related to legal and social services and manufacturing on a global scale—for example, Tata Consultancy Services, Infosys, Wipro, Ranbaxy, Reddy Laboratories. Each of them operates in over a dozen foreign locations or countries. Further, leading Indian

Table 1
Taxonomy of Internationalisation of R&D to Globalisation of Innovation

Reddy (1997 and 2005)	*Archibugi and Michie (1995)*	*Proposed framework for the Indian situation*
First wave 1960s— Internationalisation of R&D: Focus on Technology Transfer	*International exploitation of nationally produced innovations*: focus on exports and foreign production of goods	1960s and 1970s: phase of international technology transfer
Second wave 1970s— Internationalisation of corporate R&D in host countries	*Global generation of innovations*: R&D and innovation in home and host countries	1980s: Emergence of Internationalisation of R&D
Third wave 1980s— Globalisation of R&D: global role to TNC affiliates in host countries	*Global techno-scientific collaborations*: focus on joint research projects and science exchanges	1990s: Globalisation of R&D with TNCs and local institutions participating in R&D
Fourth wave 1990s— Globalisation of R&D: shortages of skills and widening research networks to tap geographically dispersed talent	Continuation: focus on joint ventures for specific innovative projects	2000 and beyond: Globally dispersed networked innovation and internationalisation of Indian firms (mergers and acquisitions abroad)

Source: Reddy (1997, 2005), Archibugi and Michie (1995), Author's own compilation

software firms provide high technology knowledge-based services to at least 400 of the FORTUNE 500 firms. As Bowonder (2001) implies in the case of WIPRO, Indian software firms since the 1990s begun to acquire global status in three ways, namely, *(a)* global contract research in information services, *(b)* moving up the research value chain, and *(c)* expanding with research units in India and foreign locations (mainly the US in the case of WIPRO). Kash et al. (2004) study of two Indian companies (TCS and Infosys) shows that a growing portion of the services they are providing is at the upper end of the value chain, and these services are taking on the characteristics of complexity. The same can be said about the leading Indian software firms by adding a fourth factor of research partnerships with global TNCs. This indeed is emerging as the other main feature of globalisation of innovation from an Indian perspective. Taxonomy of internationalisation of R&D to globalisation of innovation as given in the literature may be summarised as in Table 1.

Mapping Internationalisation of R&D in India Since 1990s

The period since the late 1990s witnessed proliferation of foreign TNCs in parallel to the rise of Indian TNCs. FDI surveys by agencies such as McKinsey and Indian Federation of Chambers and Commerce (FICCI) were undertaken at different spans of time and throw ample light on the extent of R&D-related FDI in India since the 1990s. While the information in these surveys tilt more towards financial and other aspects than on R&D-related FDI. Indian government-funded Technology,

Information, Forecasting and Assessment Council (TIFAC) of the Department of Science and Technology (DST) carried out a survey, *FDI in the R&D Sector—Study for the Pattern in 1998—2003,* in 2004 and published the report in 2006 (hereafter, TIFAC Survey 2006). That survey gave out results of the structure of FDI-related R&D in India for about 100 foreign TNCs.

Looking into the objective and the theoretical proposition outline data above on the foreign firms, R&D activities are collected from various source. The available empirical evidence on the internationalization of R&D consists of three types of data, namely, patenting activity of foreign affiliates, the geographical distribution of the R&D expenditures of MNEs (Multinational Enterprises), and survey-based evidence on the question of R&D location (Dunning and Lundan, 2009). To achieve the objectives for this study, a rigorous searching from all major newspaper reports has been conducted for the period from 1990 to 2011. The information on the foreign R&D units was collected and a relational database is prepared. All information collected from newspaper report, press release, annual report of companies are collected and stored in Micro CDS/ISIS database management software. It is an advanced non-numerical information storage and retrieval software developed by UNESCO (United Nations Educational, Scientific and Cultural Organisation). The information was further refined and stored in a separate database using Microsoft Access as a backhand tool. The database developed using MS access is a relational database, which contains separate data files. All individual record of firms are stored under different fields, such as the name of the firms, address in India, year of entry, major products, manpower employed in R&D, R&D investment, different types of linkages (arm length, joint development or joint R&D). So far, information on 471 foreign firms that have green field investment in R&D in India has been collected. The firms are classified using the GISC classification.[5]

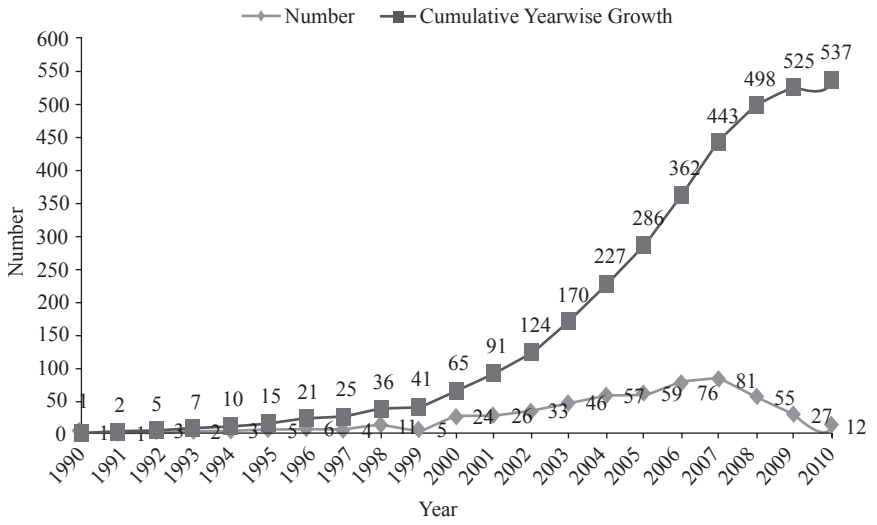
Growth, Location and R&D Areas of Foreign R&D Units

Texas Instruments was the first foreign firm to set up an R&D unit in India in 1985. However, the actual momentum of foreign firms started only after the late 1990s. The growth trend has been shown in Figure 1. Figure 1 shows that there is an increase in the number of R&D units being established by foreign firms in India. In 2007, the maximum number of units had started. The type of firms that were being established from 1999 onwards also changed significantly in structure and composition with ICT being the dominant sector in which foreign R&D units were getting established.

Further, the sector-wise distribution foreign firms and their R&D units are shown in Table 2. It is evident form Table 2 that there are about 261 firms in IT sector, followed by 72 firms in healthcare sector. The 261 IT firms have a total of 405 R&D units that constitute 62.40 per cent of the total R&D units. In the healthcare sector, 67 firms have 72 (11.09 per cent) R&D units. It is evident from the following table that India is a favoured destination for high-technology sector firms.

Among the 471 firms in the sample 293 firms (62.20 per cent) are from the US, followed by Germany 25 (5.30 per cent) and UK 24 (5.09 per cent). The number of

Figure 1
Growth of Foreign R&D Units in India



Source: Author's own compilation from USPTO data

Table 2
Sector-wise Distribution of Foreign R&D Units in India

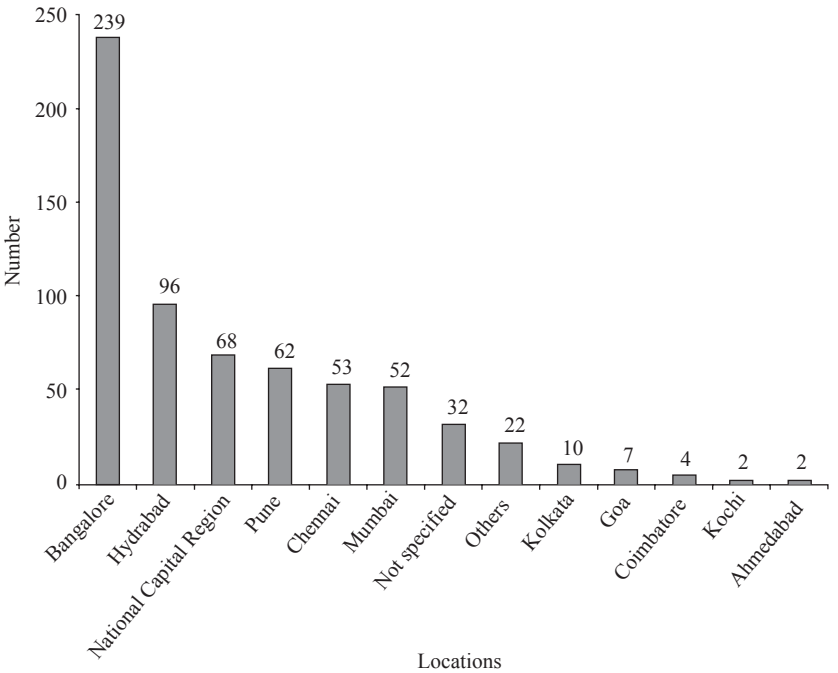
Sector	*Number of firms*	*Percentage*	*Number of R&D units*	*Percentage*
Information technology	261	55.41	405	62.40
Healthcare	67	14.22	72	11.09
Industrials	51	10.82	65	10.01
Consumer discretionary	38	8.06	45	6.93
Materials	25	5.30	32	4.93
Consumer staples	18	3.82	23	3.54
Telecommunication services	6	1.27	2	0.30
Energy	3	0.63	3	0.46
Financials	2	0.42	2	0.30
Total	471		649	

Source: Author's own compilation

firms originating from countries are follows Japan (19), France (19), Sweden (10), The Netherlands (7), China (6), Korea (6), Canada (5), Denmark (5), Belgium (4), Italy (4), Taiwan (4), Finland (3) and Israel (3). Rest of the other firms originating are from other different countries.

In terms of location of these units, more than 90 per cent of the units are established in mainly five major city regions in India, namely, Bangalore, Hyderabad, Chennai, National Capital Region (Delhi), and Pune–Mumbai as shown in the Figure 2. As expected, Bangalore is the most preferred destination for foreign

FIGURE 2
Location of Foreign R&D Units in India



Source: Author's own compilation

R&D units. Among the total of 649 firms, about 239 (37 per cent) firms have their R&D units in Bangalore. Hyderabad is in second position, and accounts for 14.79 per cent of the firms, followed by Delhi, National Capital Region, with 10.47 per cent of the total units.

Bangalore, Chennai, Pune–Mumbai and National Capital Regions (NCR) are the major knowledge-intensive city clusters in India. The following table shows the number of universities and government research institutions that are located in and around these cities. Presence of a number of world-class educational and research institutes, promotes various forms of University Industry Linkages (UILs) in these cities (Basant and Chandra, 2007). Availability of certain capabilities in the institution may lead to the building of some of these linkages in the city cluster and exploitation of available opportunities. Specific needs of the city cluster can also result in the building of required capabilities at the institution level. The co-existence of 'external' and 'internal' linkages may create spillover benefits for the city cluster (Krishna, 2012). The Table 3 shows Indian major cities and their educational institutes.

During the last few years, unprecedented inflow surge of FDI-related R&D happened. According to a source, total of US$ 8.6 billion investment is pledged by TNCs such as Microsoft (1.7), Intel (1.0), Cisco Systems (1.1) and IBM (6.0).[6]

Table 3
India's Emerging Knowledge Innovation Clusters

Cities / State	*Univ.+ Colleges (state)*	*Engg.+ Medical Institutes*	*Paper 10Ys (State)**	*Tertiary Enrol. (State)*
Bangalore (Karnataka)	16+1970	180+420	35,000 (11.6%)	708,195
Chennai (Tamil Nadu)	17+1,244	270+200	48,000 (16%)	841,755
Pune /Mumbai(Maharashtra)	20+2487	185+330	46000 (15.3%)	1,506,702
Delhi/Noida/Gurgaon(NCR)	5+285	85+25	45000 (15%)	636,093
Hyderabad (Andhra Pradesh)	16+2131	275+225	21,000 (7%)	911,709
Calcutta (West Bengal)	16+565	60+75	22,000 (7.3%)	721,762

Source: Krishna, 2012.

Analysis of various newspaper reports show that many of the established R&D units are significantly scaling up their investments. For example, Maruti Suzuki India Ltd. has announced an investment of US$1.8 billion for its R&D facility. Microsoft announced an investment of US$1.7 billion (₹ 7,858 crores) in 2005 to expand its R&D activities.

Among the firms that are opening up their R&D units, for many, it is their first R&D unit outside their home country. Among them are ₹ 1 trillion US-based science-and-technology company E.I. du Pont (this unit will be involved in high-end R&D in different sectors), Axiom Design (embedded design applications), Vanu Inc. (complex switching systems).

Having mapped the foreign R&D units during the last decade, it will be pertinent here to explore the types of activity carried out by these TNC units in India.

Types of R&D Activity of Foreign R&D Units in India

Pearce and Singh (1992) and Pearce (2005) categorised TNC's R&D units in foreign location into three types. The first is the *support laboratories* which facilitate 'effective transfer and application of group's already successful technologies embodied in the current product range' (Pearce, 2005:35). Comparative advantages of lower costs to carry out R&D, foreign country's innovation capacities, its market and adaptation of technology processes, among other factors, characterise these support laboratories.

The second type—*locally integrated laboratories*—indicate technology-transfer processes from parent firms in one form or other. For example, the US software giant, Oracle, has three R&D units in Bangalore and Hyderabad, employing 4,000 professionals who create products for Oracle's global business and customers. However, Oracle also has six offices spread across India which work in banking and insurance, telecommunications, manufacturing and airports, among other sectors such as police departments in three states. The *locally integrated laboratories* go beyond the first type to develop links with the local firms and innovation systems.

These types of laboratories are also involved in the production and consumption of R&D for local/national and global markets, links with manufacturing and marketing. These types of laboratories are also seen to have all the signs to contribute positively to the host economies.

The third type of laboratories are what are termed as *internationally independent laboratories*—linked to international interdependencies between independent TNC labs which are more focused on the autonomous path of more basic and pure sciences.

In the light of the brief discussion above, three types of R&D activities can be identified in the Indian context. For this study, the R&D units have been categorised according to the type of R&D carried out in their local units, that is, whether they are responsible for adapting technology developed at home base, or developing new products for local market needs, or undertaking pure basic research and so on. This study has used geographic scope of the unit, and uses three simple categorises *local, regional and global R&D units*, according to the products developed by the foreign R&D units. India is a huge market of increasing middle-class population. India is also a centre for the regional product mandate. Also some of the foreign R&D units use the high-skilled, low-cost manpower to develop products for their global product mandate. This classification is not a very strict categorisation; it can further be extended with a combination of these three types into another three types *global–local*, *global–regional*, *local–regional* or *local–regional–global* types of units, which develop products for all three markets.

From the in-house developed database, for this study, a sample of 98 ICT firms and their types have been analysed based on their products developed for the market segment. It is observed that Global Units are the most predominant types of R&D unit in India. The Table 4 shows that a majority of the firms are doing their R&D in India, for the firm's global product mandate. Although it has been discussed above that this classification may not be followed strictly for that particular market and many units have their product mandate spanning more than one market segment, still it can be said that foreign firms in India have functions beyond the product mandate for the local market condition. R&D units are not a mere one-way technology transfer developed in a firm's home base, rather it is a two-way technology transfer and with a close relationship between parent and subsidiary.

TABLE 4
Types of foreign R&D Units in India

Pearce (1989, 2005) R&D Type	*New Typology suggested for this study*	*Number /percentage n=98 firms*
Support Laboratories	Local units	27 (27.55%)
Locally Integrated Laboratories	Regional units	14 (14.28%)
Internationally interdependent Laboratory	Global units	86 (87.75%)

Source: Author's own compilation

Emerging Structure with Local Firms and Institutions

The role of TNCs and their operations in host developing countries has been the subject of discourse and considerable research interest for quite some time now. At one extreme, one can find the positive view of R&D-related FDI being beneficial in varying forms and at the other extreme, there are counter views. This issue will be addressed in the concluding discussion after the initial exploration of the impact of TNC's R&D units and their links with the local firms and institutions. The impact of TNC's R&D units has three types of effects on the host country. They are *direct effects, spin-off effects* and *spillover effects* (Reddy, 2005).[7] While these three features reflect the impact on the host country's situation, the fourth feature which has emerged and is evolving is the *transnational innovation networks*. However, here, this study will explore: *a)* two-way knowledge transfer, *b)* collaborative R&D innovation, *c)* globally dispersed networked innovation, and *d)* rise of Indian firms and institutions at a global level.

Two-way Knowledge Transfer between Home and Host Country TNCs

TNCs as one of the main sources of international technology transfer to developing countries are a very old subject but the type and nature of the technology transferred is still an issue of discourse. Much of the earlier writings deal with firms and are not necessarily R&D related. However, here the issue is the links between parent and offshore R&D units of TNCs. It has been observed that there is a wide range of technology development, knowledge generation and transfer between different types of TNC's R&D units as depicted in Table 5. For instance, big TNCs such as IBM, Oracle, General Electric, Intel, Texas Instruments, Bell Labs, Philips International, among others, operate in all types of R&D as shown in Table 5 and are involved in technology and knowledge transfer. What is rather 'new' is that the development of technology, knowledge production and its transfer is not one sided but operates in both ways in an interactive fashion that is often linked with the local host country knowledge institutions. The section follows deals with some examples of TNC R&D units and the nature of work carried out by these labs in India.

IBM is an appropriate example. For instance, out of eight IBM R&D units in the world, two are maintained in India, where more than 3,000 scientists and engineers work along with 73,000 workers (of the 250,000 workforce globally). IBM is projected to have 100,000 workers in India by 2010—a quarter of its global workforce.[8] India Research Laboratory (IRL) of IBM was established in the Indian Institute of Technology, Delhi, campus initially in 1998 and moved to its own premises in New Delhi. In 2006, it opened its second R&D unit in Bangalore. IRL is working on a number of conventional areas of adaptive research such as information and knowledge management, interaction and collaboration technologies, systems management, software engineering, analytics and optimisations, services innovation, telecommunications research and industrial research among many others. In almost all these areas, the knowledge transfer is both ways between

Indian and home country R&D units. However, what is also notable is that IRL in India is in a large measure involved with cutting edge research of distributed and high-performance computing, which is linked to IBM's BlueGene/L supercomputer installed at the Lawrence Livermore National Laboratory, US. This is the fastest supercomputer in the world. In addition, four of the top five most powerful computers in the world are from IBM in 2007. Two key research papers published by the Indian lab in 2006 won two international awards that are closely linked to BlueGene/L computing. The IRL team has been working in close collaboration with IIT, Delhi and IISc (Indian Institute of Science), Banaglore on cutting-edge computing research and other management institutions such as ISB, Hyderabad, in evolving the first of its kind management course on 'service science management engineering'.[9] Another instance of how cutting edge human–computer interaction research linked to local adaptation is the work going on new generation speech-, grammar-, pronunciation-recognition computers in local languages and translation devices for user-friendly mediums.[10]

IBM India has been cited as the only unit in the world working on 'solution accelerators' and has developed over 120 solution accelerators for 17 verticals that help cut short overall development of technology and business solutions (*Business Line*, 19 December, 2007). These solutions draw upon IBM's domain knowledge of consultations provided to clients worldwide.

The second good example is that of Intel Corporation of the US, based in Oregon, which has a Development Centre in Bangalore where 2,900 R&D professionals work. It is reported that a significant proportion of researchers in Intel's Indian Development Centre work on logic, circuit and physical design of Intel's recently announced development of a 'Teraflop Research Chip', which crams 80 core chips (100 million transistors in one core chip) on a finger nail-sized device.[11] Significant parts of the Intel's first low-powered chip with sub-1 watt to 2 watts power for mobile internet devices and phones was developed at Intel India. This chip has achieved a major technological challenge for Intel, as it meets low-power requirements of hand-held devices and opens a new product segment for Intel.[12] The unit's rate of innovation compares favorably with Intel's mature development centres in the United States. Intel has formed R&D and technology alliances with three IITs in Delhi, Chennai and Mumbai, IISc, Bangalore and with the National Centre for Software Technology, Mumbai. Companies such as Cisco Systems, IBM, Intel and Texas Instruments and others (GE and Motorola) who are the major global patentees have established R&D units in semiconductors, mainly undertaking the work of advance chip designing. As the Managing Director of Texas Instruments India recently observed, the 'semiconductor ecosystem in India has reached a stage of maturity where design engineers are playing a key role in designing for world and India market'.[13,14]

Another good example is that of Adobe India Ltd. Indian operations, spread across two units located in Noida and Bangalore, currently employing about 900 people out of Adobe's 6,000 employees worldwide. Adobe has developed a number of products fully engineered from India. Contribute 4.0, Captivate 2, Premier

Elements 3.0, Page Maker 7.0, Frame Maker, RoboHelp, PostScript, Acrobat Reader on handheld devices, Acrobat Reader on Linux, Photoshop Album Starter Edition and Premiere Elements.

CISCO's R&D operation in India is also an interesting case. Cisco Systems Inc., the worldwide leader in networking for the internet, first established operations in India in 1995 and today employs over 1,400 people in the country in its global R&D unit in Bangalore and offices in New Delhi, Mumbai, Bangalore, Chennai, Kolkata, Pune and Hyderabad. CISCO plans to invest US$ 1.1 billion for R&D in India for a three-year period. Cisco Systems India Private Limited (CSIPL) is the largest research and development (R&D) unit established by Cisco outside of the US.[15] Small Network Management Solution (SNMS) was conceived and developed entirely in India. This is a web-based network management solution that provides monitoring, configuration, and management tools to simplify the administration of small to medium business networks and work groups. It can be used in networks that feature both Cisco and non-Cisco devices. Another product coming out of India is the Cisco Emergency Responder (CER)—part of IP telephony solutions.[16]

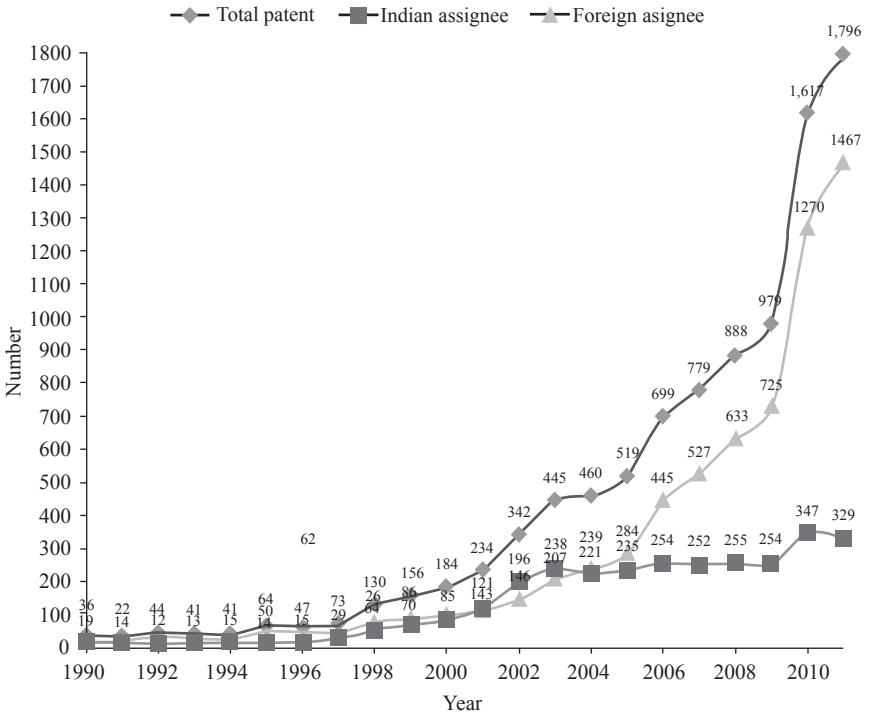
Examples of IBM, together with big firms such as Texas Instruments, GE, Intel, Adobe, Cisco and other big TNCs, signify a 'new threshold' of TNC operations in India at the cutting edge of R&D and innovation[17] linked to global production. There is, however, considerable evidence to suggest there is knowledge transfer between the home and host country TNC R&D units in new equipment and instrumentation, engineering knowhow, research methodologies and knowledge management mechanisms, among other elements.

Knowledge Production by TNCs

Two-way knowledge transfers between Indian and home country TNCs is closely connected with the feature of knowledge production which in fact precedes knowledge transfer. Foreign firms in India obtaining US patents is one of the good indicators for knowledge production by TNCs. Figure 3 shows a significant increase in pace during the last few years.[18]

A total of 9,622 patents are granted to the innovators with Indian addresses, from 1990–2011. It is assumed here that if a patent contains at least one of the innovator's address in India, then that particular patent is originated from India. The United States Patents and Trademark Office (USPTO) database searched with Indian innovator's address. The downloaded records were isolated according to the Indian assignee and on Indian assignee. The non-Indian assignee is assumed as the foreign patents. Among the 9,622 patents granted to Indian innovators till 2011, about 6,580 patents (about 70 per cent) were granted to foreign entities by the USPTO from their R&D work undertaken in India during the period from 1990–2011. The patents cover a wide range of technological areas. The period from 2000–2011 reveals a technological shift in the types of firms involved and the types of patents that were granted.[19] Pharmaceutical, chemical and consumer

FIGURE 3
USPTO Granted Patents to Different Entities from Their R&D Work in India



Source: Author's own compilation from USPTO data

goods firms were predominantly involved in patenting activity before 1995, whereas from 1995 onwards, ICT firms were more involved in this process. This has strong correlation with the R&D units that are opening in India over the period. It may be noted that patenting in software is only a recent trend. Much of the R&D work carried out in India in software, though of high quality, is of contractual nature, feeding into parent companies. The established practice of the software firms was to obtain 'protection' through copyrights.

Table 6 shows firms that accounted for maximum number of patents in the USPTO of their research work undertaken in India. Examination of patents of these organizations reveals important insights of the technological complexities. Patents being granted in the cutting-edge high technological areas by the US patent office provide a strong indication of the advanced-level research work being undertaken by them in India. One can also observe that the Indian entities of these foreign firms are building up 'portfolio' of key patents covering a specific technology. ICT was the main domain in which patents have been granted. The examination of the patents show that the patents cover present high-end applications (for mobile phones, routers, digital signal processors, RF sensors) as well as future technologies

Table 5
Year-wise Growth of Patents Granted to Indian and Foreign Assignee with Indian Innovator's Address

		Patents granted to	
Year	*Total patents*	*Indian assignee*	*Foreign assignee*
1990	36	19	17
1991	33	14	19
1992	44	12	32
1993	41	13	28
1994	41	15	26
1995	64	14	50
1996	62	15	47
1997	73	29	44
1998	130	54	76
1999	156	70	86
2000	184	85	99
2001	234	121	113
2002	342	196	146
2003	445	238	207
2004	460	221	239
2005	519	235	284
2006	699	254	445
2007	779	252	527
2008	888	255	633
2009	979	254	725
2010	1,617	347	1270
2011	1,796	329	1467
Total	9,622	3,042	6,580

Source: Author's own compilation from USPTO data

(cover inter-operability/scalability of devices and applications through building 'adaptive' wireless solutions—driven by software rather than confined by hardware specifications). These patents are emerging from R&D units of IBM, GE, Texas Instruments, CISCO ('world technology leaders in ICT'). GE Medical has obtained patents covering the healthcare domain targeting medical instruments. A number of patents have been obtained in 'X-ray systems' covering improved diagnostic precision, lower radiation dosage, high image quality. STMicroelectronics, Intel, Lucent have obtained patents in VLSI, micro-processor controlled applications, and so on.

Table 7 exhibits the firms actively filing patent applications during 2002–2011. It is interesting to note the differences with the firms that were granted patents (refer Table 6). However, further introspection by taking account of the datedness of the granted data[20] reveals a much closer correspondence. Except for Honeywell (involved in Aerospace R&D) and Unilever (consumer goods), the other firms are ICT based entities, this mirrors the firms granted patents during the period 2001–2011.

Table 6
Foreign Firms with Significant Patents from India in USPTO

	Before 2000	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*	*2010*	*2011*	*Total*
General Electric Company	11	11	11	17	12	24	42	59	69	61	61	95	147	620
International Business Machines Corporation	5	5	12	13	20	35	32	31	47	52	81	120	161	614
Texas Instruments Incorporated	40	14	15	12	29	27	29	48	48	53	47	68	51	481
Cisco Technology					2	5	9	14	19	28	30	58	46	211
STMicroelectronics Ltd.			1	2	8	3	16	20	37	31	28	29	24	199
Honywell International Co.				1		2	10	6	14	18	29	48	53	181
Intel Corporation	1	2		3	4	6	5	16	14	28	26	47	14	166
Hewlett Packard	3		1	2	9	8	6	9	12	9	13	31	51	154
Broadcom Corporation					2	1	7	10	19	16	19	19	28	121
Cypress Semiconductor Corp.	5	1	3	4	10	3	3	1	5	10	4	10	7	66
Adobe Systems Inc.			1	1		2	4		1	4	6	20	24	63
Freescale Semiconductor, Inc.						1	3	8	5	10	4	12	17	60
Hoechst Aktiengesellschaft	54	3												57
Sun Microsystems, Inc.					2		4	7	8	19	12	4		56
Yahoo Inc								1		2	12	18	22	55
GE Medical System Global				2	3	10	1	10	7	7	3	1	1	45
Novell, Inc.			2	1	1	1	2	4	6	4	1	10	13	45
Cadence Design						4	1	4	2	4	3	7	18	43
Veritas Operating Corporation						2	7	15	14	1	3			42
Motorola, Inc.	3	1	2		1	1	3	6	3	4	5	1	7	37
Analog Devices	2			1	1	1	4	2	3	4		8	4	30
Unilever Home & Personal Care		1	5	3	2	7	5	1	1	1			1	27
Cirrus Logic, Inc.			1	1	4		1	4	2			1		14

Source: Author's own compilation from USPTO data

Table 7
Patent Applications Trends of Selected Foreign Firms from India

	2002	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*	*2010*	*2011*	*Total*
Analog Devices		1	2	2	6	3		3	3	4	24
Broadcom		6	3	14	9	18	5	5	3	6	69
Cisco Technology			1	13	24	35	23	16	17	26	155
Freescale Semiconductor, Inc.						10	11	4	11	27	63
General Electric		4	29	43	50	93	131	137	163	216	866
Hewlett-Packard			1	7	13	15	42	17	10	2	107
Honeywell	2	15	4	14	26	77	44	77	90	70	419
Intel	1	1	3	16	6	10	4	5	1	1	48
International Business Machines	20	26	16	37	37	61	99	153	157	261	867
Koninklijke Philips Electronics		1			3	12	5	21	12	13	67
Microsoft		1	3	11	30	36	107	83	69	51	391
Motorola, Inc.	3	1		1	1	4	28	16	23	13	90
Nokia Corporation			1		2	3	4	3	11	22	46
Oracle		2	6	8	26	27	31	61	80	90	331
Qualcomm, Inc.						1	3	28	28	16	76
Samsung Electronics		3		4	8	16	28	20	42	32	153
SAP Aktiengesellschaft				2	1	21	14	4	11	12	65
STMicroelectronics	9	18	20	37	42	29	34	10	35	47	281
Sun Microsystems		6	11	12	1	5	7	2	3	1	48
Texas Instruments	0	19	29	36	46	59	48	58	65	75	435
Unilever Home & Personal Care	8	11	3	5	10	2	4	8	2	3	56
Yahoo! Inc.				2	4	3	14	39	41	39	142

Source: Author's own compilation from USPTO data

Collaborative R&D and Innovation

There are different forms of collaborative R&D (sponsor research, research alliances subcontracting, consultancy and through exchange of human resources, and so on), wherein host country institutions and firms and TNCs participate in the knowledge production and transfer to its user. Closer scrutiny reveals that most of these contracts concern pharma, software, agri-biotechnology, and so on. Most of the contract research in the pharmaceutical industry is now gaining momentum in the domain of clinical research, drug screening and testing-related activities, which is estimated at over US$ 2 billion currently. The recent trends in collaborative ventures between TNC R&D units and Indian institutions are now part and parcel of the global research and innovation system. For instance, GE Healthcare, which is operating in India since the mid-1990s has opened up an Integrated Development Centre at Manipal Hospital in Bangalore, which will participate in the global multi-country clinical studies in the US, European Union and other countries. Local hospital and patients may be benefitted from state-of-the-art techniques and technology with access to global advances in diagnostic imaging and medical needs in oncology, neurology and cardiology.

At a more sophisticated and high-technology end, public research laboratories are leveraged by TNCs for basic oriented research and commercialisation, which are more R&D-intensive and focus on oriented or directed basic research (Table 8). A good example of this new development is the collaborations between National Chemical Laboratory (NCL), Pune, and more than 20 TNCs such as Du Pont, Ciba Geigy, Dow Chemicals, Eastman Chemicals, General Electric, Parke Davis, Pfizer Research Center, Polaroid, Nestle, Rhone Poulenc from France, Specs and Biospecs from Netherlands, Unilever, and so on, in polymers, process chemistry, anti-HIV drugs, designed organic synthesis, titanium technologies, several drug molecules and development of synthetic methodologies.

NCL was able to obtain highly complex patents on its work in the area on polycarbonates in the early 1990s. This work attracted the attention of GE, global R&D leader in this domain, and led to an alliance of NCL with GE in 1993. This alliance has been beneficial to both partners. GE got assignment rights to a number of patents created by NCL. It has been estimated that US$ 8.5 million has been given by GE to NCL. One of the important outcomes of this alliance was the development of proprietary process for THPE [1,1′,1″-Tris(4′-hydroxyphenyl) ethane], a branching agent used in the synthesis of high-grade polycarbonates with properties of high transparency, good mechanical and high parison strength. Patent applications were filed in India and abroad. This broke the monopoly of a single supplier, Hoechst Celanesa, US. THPE, valued at around Rs 30 crores over a three-year period, was exported from 2001 to 2003. NCL has received US$ 50,000 as license fee and a royalty payment of around US$ 1, 00,000. Similarly, large Indian drug firms such as Biocon, Dr Reddy's Labs and Ranbaxy have entered into R&D collaborations for drug development and innovation processes as shown in Table 8.

Table 8
Collaborations of Select Indian Firms and Other Institutions

Ranbaxy Labs	• Ciprofloxacin (Cipr OD) technology licensed to Bayer for about US$ 40 million—blockbuster antibiotic • Static molecule licensed to world's top contract research organisation in the US—PPD for developing, marketing worldwide. • Benign prostrate hyperplasia (BPH)—asthma molecule licensing, drug development and marketing negotiations with three major firms.[21]
Dr Reddy's Labs	• Clintec International for co-development of anti-cancer drug • Merc to produce generic version of Proscar and Zocor for the treatment of benign prostatic hyperplasia • Rheoscience, the Netherlands, for the diabetes drug • Roche acquisition and development of 18 products, including steroids
Biocon	• Center of Molecular Immunology, Cuba, to develop first anti-cancer drug • Vaccinex Inc., to discover and co-develop antibodies for cancer • Karolinska Inst, Sweden—product development • Deakin University Australia in bio-processing • Bentley Pharma in insulins • Syngene and Innate Pharma, Sweden for viulence blockers in diarrhoeal disease • Syngene and Bristol Meyers Sqiubb in R&D services and drug development
Indian Institute of Science, Bangalore	• Intel Techology lab • Texas Instruments runs a digital Signal Processing labs • Hindustan Lever • IBM labs • Hewlett-Packard (HP)
Indian Institutes of Technology	• IIT, Kharagpur: Motorloa, Compaq, Oracle and GE Caps • IIT, Chennai: HP joint laboratory, • IIT, Bombay: Intel, Lever • IIT, Delhi: IBM, Intel, Samsung
National Chemical Laboratory, Pune	• 20 TNCs collaborate on R&D with this lab. They include: Du Pont, Ciba Geigy, Dow Chemicals, Eastman Chemicals, General Electric, Parke Davis, Pfizer Research Center, Polaroid, Nestle, Rhone Poulenc from France, Specs and Biospecs from the Netherlands

Source: Author's own compilation

Knowledge links are getting further institutionalised with collaborative agreements being signed for joint research. Among the big names is the recent agreement among Boeing and IISc, Wipro Technologies and HCL Technologies to develop wireless and other network technologies for aerospace-related applications (*Business Line*, 30 January 2008). The agreement forms the Aerospace Network

Research Consortium (ANRC); a statement issued by Boeing states that this is the country's first public-private aerospace research consortium.

Collaborative Patents between Indian and Foreign Entities

Many Indian firms had varied types of linkages with international firms. Collaborative patents were defined as patents that were assigned to more than one entity. Thus, 'monopoly' rights to the patented invention are jointly owned by the collaborative partners. Some of these linkages had translated into development of novel products/processes. Patents are a strong assertion of the 'novel' technology being created. Joint assignment thus indicates that co-assignee firms had strong R&D partnership. However, co-assignment that shows collaboration in technology development is only a partial indicator of collaboration in R&D. For example, major Indian software firms such as Infosys, Wipro and TCS are under contractual obligations to transfer the ownership of intellectual property created to the host organisation. In general, TNCs use collaboration at a later stage to avoid possible infringements. These collaborations are in terms of cross-licensing, patent pooling (pooling patents in a given field and license them as package) and so on (*The Economist*, 2001). Thus, in spite of these caveats, patents that are co-assigned with foreign entities is a good indicator of high-level technology partnership. Table 9 shows the Indian firms and organisations that were involved in technology development with foreign partners, leading to the patent(s) granted by the USPTO.

TABLE 9
Joint Patents between Indian and Foreign Assignee

Indian organisation	*Foreign partners*	*No. of patents*
Council of Scientific & Industrial Research	General Electric Company	3
Council of Scientific & Industrial Research	University of California	1
Council of Scientific & Industrial Research	Laboratoire des Materiaux Organiques a Proprietes Speciques	1
Council of Scientific & Industrial Research	Bar-Ilan University	1
Council of Scientific and Industrial Research	Unichem Laboratories Ltd.	1
Council of Scientific and Industrial Research	Ecole Superieur de Physique et Chimie Industrielles de la Ville de Paris (ESPCI) (Paris, FR)	1
Defence Research & Development Organisation	Societe Nationale d'Etude et de Construction de Moteurs d'Aviation and Association pour la Recherche et le Development des Methods et	1

Table 9 (Continued)

Table 9 (Continued)

Indian organisation	*Foreign partners*	*No. of patents*
Department of Biotechnology	University of Maryland, Baltimore	1
Dr Reddy's Research Foundation	Novo-Nordisk A/S	10
Exide Industries Ltd.	Shin-Kobe Electric Machinery Co. Ltd	2
Indian Herbs Research & Supply Company Ltd.	Natreon Inc	8
Indian Institute of Technology	Intel Corporation	2
Indian Petrochemicals Corporation Limited	Korea Institute of Energy Research	2
Indian Statistical Institute	Intel Corporation	1
National Institute of Immunology	International Centre for Genetic Engineering and Biotechnology	1
Purna Global Infotech, Ltd	QSSolutions, Inc	1
Ranbaxy Laboratories	Toyonoma Chemical Co. Ltd	1
Sami Chemicals & Extracts	Sabinsa Corporation	1
Sami Labs LTD	Sabinsa Corporation	1
Satyam Enterprise Solutions Limited	In Touch Technologies Limited	1
Tata Institute of Fundamental Research	NEC Research Institute, Inc. and TPPED Technical Physics and Protype Engineering Division	1
The University of Hyderabad	The Board of Regents for Oklahoma State University (Stillwater, OK, US)	1
Vittal Mallya Scientific Research Foundation	The University of Leicester	1
Vittal Mallya Scientific Research Foundation	Renaissance Herbs, Inc.	1

Source: Author's own compilation from USPTO data

Patenting Activity of Indian Firms and Institutions

Concurrently with the rise of Indian firms and growing influence of knowledge production of TNC R&D units in India, the last decade witnessed an increase in pace of Indian firms and institutions obtaining US patents as shown in Table 10. Patenting by Indian firms has significantly increased in domestic as well as foreign patent systems. Pharmaceuticals and chemicals have been the two broad areas where Indian patenting activity is primarily concentrated. Biotechnology and telecommunications are among the emerging areas were patenting is significantly increasing (Bhattacharya et al., 2007). These firms are developing 'portfolios' in 'novel drug discovery' covering various pharmaceutical product groups, herbal formulations, industrial catalysts, high-tensile fibres, and so on. Obtaining patents in the US provides them with 'monopoly' rights to exploit their invention in the US market. Patenting by Indian firms such as Ranbaxy, Reddy Labs, CSIR and pharma-based firms is closely associated with network partnerships for drug development and marketing at the global level.

Table 10
Patent of Selected Indian Firms in the USPTO

Indian firms	*Before 2000*	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*	*2010*	*2011*	*Total*
Ranbaxy Laboratories Limited	21	4	8	7	9	12	8	12	4	6	9	5	11	116
Dr. Reddy's Laboratories Limited	10	8	8	11	8	7	5	10	11	7	9	9	16	119
Dabur Research Foundation	1	3	5	6	9	1	6	3	4	1	1	4		44
Orchid Chemicals & Pharmaceuticals	0			2	5	6	5	1	3	6		6	1	35
Lupin Laboratories Limited	9	1	1			1	2	2	1	5	6	8	1	37
Panacea Biotech Limited	6	2	3	2	1			1	1	1			1	18
Infosys									2		1	12	15	30
Satyam Computer Services Ltd.			1			1			1	2	5	4	5	19
Wockhard Limited	1		1		5	2	2	3	2	3	4	2	3	28
Aurobindo Pharma				2		3	1	2	1		4		3	16
Bicon India Limited			1		4	1	2	1	10	8	9	5	8	49
Piramal Life Sciences Limited						1		1	2	1	2	5	11	23
Wipro Limited	1									2	2	8	10	23
Suven Life Sciences Limited									1	3	1	2	7	14
CIPLA Limited							1	2	1	8	15	6	15	48
Tata Consultancy						2	1	3		4	1	4	3	18

Source: Author's own compilation from USPTO data.

Globally Dispersed Networked Innovation

Beyond cost and size of market in countries such as India and China, what is driving internationalisation of R&D via TNCs are the speed of innovation and quantity of innovation (Doz et al., 2006).[22] Coupled with this, the emergence of science and technology capacities in new technologies and its potential for innovation is dispersed across the globe (Chesbrough, 2003; Ernst, 2005). A good example can be drawn from the new development that while India commands certain expertise in the software, China does the same in hardware and manufacturing. Rather, software and embedded software and its design has become generic in varying forms and mediums and an important component of innovation in high-technology fields as much as in non-technology markets, financial and global operating systems. The other important aspect is the convergence of technologies, fields of research with non-science and technology factors in the domain of finance, banking, social and cultural, among other factors. All crucial components or factors of innovation are becoming impossible to locate in one place or locate in the corporate home country R&D sites in North America and Western Europe. Innovation is more and more coming to be seen in the footprint of networks whose actors are rather dispersed. As INSEAD Survey 2006 implies, 'optimising the configuration and integration of R&D networks' (p. 7) is becoming crucial for improving the speed of innovation for global TNCs. While the demands of speed and quantity of innovation for global competition is driving TNCs to enter new form of strategic partnerships and collaborations, countries such as India and China, have come to occupy a significant position in the globally dispersed networked innovation. The basis of this development is not merely the low-cost skill base which was the case initially in the 1980s and early 1990s, but the development of increasing national innovation capacities and endowment of highly trained human resources and R&D institutional base as evident from the results of INSEAD Survey 2006 as shown in Table 11. This survey covered 186 global companies in 19 countries (which spent US$ 76 billion in R&D in 2004) operating in 17 sectors. The survey asked companies to respond as to what is driving their future R&D sites.

The INSEAD Survey 2006 revealed that global firms would like to strengthen their 'optimally configured' R&D network over the next five years by opening up new R&D sites in China (22 per cent), India (19 per cent), the US (19 per cent) and Western Europe (13 per cent). These developments are also closely related to plan growth pattern of R&D human resources. By the end of 2007, the survey

Table 11
Drivers of Future R&D Sites (figures in % in response from 186 global firms)

	China	*India*	*Brazil*	*US*
Qualified workers	12	25	21	17
Technology cluster and Academic institutions	13	13	14	27
Low-cost skill base	24	30	11	3
Proximity to production facilities	17	11	18	12
Others (business/markets)	34	21	36	41

Source: (INSEAD & Booz report 2006, p. 5)

indicated that India (contributing 23 per cent) and China (contributing 16 per cent) will account for a total 39 per cent of global R&D staff, up from 19 per cent (India 14 per cent and China 5 per cent) in 2004.[23] Another important finding from the survey relates to the insight that 45 per cent of foreign R&D sites are seen to be important (by 186 global TNCs) due to core technology research and full development capabilities; and 55 per cent of R&D foreign sites due to specific development capabilities coupled with customisation for local markets.

Innovation networks are increasingly being used in ICT for client-tailored innovation services—to design custom chips and supply chain software algorithms. Indian firms are trying to exploit the opportunities of innovation networks by focusing on 'product engineering services' such as innovation of ASIC chips.[24] Except the final fabrication, the full R&D work related to the functionality of the chip is being undertaken by Indian firms.

This development of networked innovation is very much in alignment with the features of *two-way technology transfer* (particularly the case of IBM in India) and *collaborative R&D and innovation* briefly discussed above. Multiple-technology partnerships are also evolving (see, for example, the case study that follows of WIPRO's PES innovation network). This is due to the fact that knowledge-supply chain and consumption in these processes are directly or indirectly linked to global operations of TNCs involved in the specific cases. For example, IBM's research and knowledge inputs from India, feeds into global business operations of the firm. In the light of this, the next section looks into some concrete examples of Indian firms for specific globally dispersed networked innovation.

Case 1: Infosys with its 75,000 professionals worldwide (13,000 professionals in 30 units outside India) has developed a global delivery model—a framework for globally dispersed project management and multi-location execution of R&D and services for innovation. It provides 'end-to-end business solutions that leverage technology… provide solutions for a dynamic environment where business and technology strategies converge…..work with large global corporations and new generation technology companies—to build new products or services …in today's dynamic digital environment'.[25] A good example where an Indian firm is a crucial player in the globally dispersed networked innovation is Infosys's participation in Automotive Open Systems Architecture—Autosar. It is a network of major global automobile manufacturers involved in R&D and standardisation of software for auto electronics innovation. Firms such as Toyota, Bosch, BMW, Volkswagen, Siemens, Ford, DaimlerChrysler and Continental Teves are partners in this global network.[26] Further, Infosys formed a 'product lifecycle and engineering solutions' (PLES) group to focus on developing embedded solutions, product design and product lifecycle management (PLM) solutions for the automotive sector. It works in close collaboration with Autosar to develop the protocols and standards for the next generation automotive electronics.[27]

Case 2: The second example of an Indian firm that plays a crucial role in the networked innovation is Tata Consultancy Services (TCS)—with 89,000 IT professionals operating in 47 countries with revenues around US$ 4.3 billion in 2007. It

Table 12
Areas of Operation and Select Global Clients of Two Indian Firms

Infosys	*Tata consultancy services*
Aerospace and defence, automotive, banking and capital markets, communication services, consumer discrete manufacturing, education, energy , healthcare , high technology , hospitality and leisure, insurance and life sciences and media and entertainment	Aerospace, automotive, chemicals, pharmaceuticals, industrial machinery, high technology, minerals and metals, oil and gas, power water, medical devices, finance and insurance, and so on
Network partner firms—Select examples	**Network partner firms—Select examples**
Aerospace and defense: Boeing (787), Airbus 380 Freighter, National Oceanography Centre, UK	**Telecom:** Hutchison 3G Austria, Motorola, Sonofon
High technology: Cisco, Apple, Oracle, Telecom Australia; Toshiba; and Siebel CRM solutions	**Manufacturing:** Philips semiconductors
Life sciences and Healthcare: Global contract research organisations/firms	**Banking and Insurance:** Aviva, ABN Amro, American Express
	Information Technology: ABN Amro in Brazil, UK, France, Germany, Hong Kong, Switzerland and the Netherlands

develops software solutions for American Express, Microsoft and General Motors among others. TCS initiated what is known as 'global co-innovation network' with firms, research and academic institutions around the world to partner for developing advanced software systems and solutions for global customers. A case in point is its collaboration with the University of Massachusetts, Amherst's laboratory for advanced software engineering research (LASER). Different sectors in which the above two companies operate and partner in the globally dispersed networked innovation is given in Table 12.

Kash et al. (2004) has earlier undertaken a case study of these two firms. Their paper shows how these two firms have progressed over the years. Learning and incremental innovations have helped these firms transition to complex technologies. Evidences from Table 12 show the next stage of their evolution—becoming partners in global innovation networks.

Case 3: Another firm that is increasingly participating in 'electronics innovation network' is Wipro Technologies, the global IT services business of Wipro. It is partnering with major firms and providing them 'product engineering services' (PES). PES generated 28 per cent of Wipro Technologies' US$ 1.35 billion revenues last year. Wipro has also partnered with Semiconductor Manufacturing International Corporation (SMIC), Taiwan Semiconductor Manufacturing Company (TSMC), and United Microelectronics Corporation (UMC), which would help it bring in-house designed chip in the market.

Rise of Indian Firms

The last decade witnessed a new trend of Indian firms expanding their business and getting integrated into the global production networks (GPNs) beginning with

the Lakshmi Mittal group based in UK which acquired the European steel giant, Arcelor. The pace of Mergers and Acquisitions (M&A) route to expand business in foreign locations and take part in the GPNs has increased in the last four years. However, going beyond business operations, several Indian software firms have begun to use their human resource base in knowledge, software, R&D and engineering services to expand their operations at the global level. In fact, there is a two-way process of knowledge transfer and technological capability building that can be observed in this new development. While hard-core engineering firms in steel and automotive (Mittal Steel, Tata Steel, Bharat Forge and Tata Motors, for instance) stand to benefit with new technological innovations and manufacturing processes through M&As, software- and knowledge-based service oriented firms are likely to provide their highly skilled software knowledge services and design capabilities across a large number of sectors varying from banking and finance to power and aerospace industries. While the actual quantity and type of knowledge transferred and the way in which it gets into production and consumption at the global level is open to empirical investigation via case studies, the present trend of local firms' participation in GPNs signals a new indicator of global nature of innovation from an Indian perspective. Table 12 indicates the emerging structure of top Indian Firms in M&As during the last few years.

Range of underlying factors has driven the outward FDI (Nayar 2008; Jha 2006). Increasing competitiveness, market access for exports, capturing international brand names, access to technology, sourcing raw materials, distribution networks, skills were some of the strategic considerations that has driven Indian enterprises to expand abroad. Acquisitions were mainly in the manufacturing (40 per cent) and IT sector (30 per cent); 80 per cent of the acquisitions were in the industrialised

TABLE 13
Major Overseas Acquisitions by Indian Firms (2000–2007)[1]

Indian Firm	*Target Firm*	*Country*	*Year*	*Deal value (US$ million)*	*Sector*
ONGC Videsh Ltd	Petrobras	Brazil	2006	1,400	Petroleum
	Greater Plutonic Project	Angola	2004	600	Petroleum
	Greater Nile Oil Project	Sudan	2002	760	Petroleum
	Sakhalin-I PSA Project	Russia	2000	323	Petroleum
Dr Reddy's Laboratories	Betapharm Arzneimittel	Germany	2006	572	Pharmaceutical
Suzlon Energy Ltd	Hansen Transmissions International	Belgium	2006	565	Energy

Table 13 (Continued)

Table 13 (Continued)

Indian Firm	*Target Firm*	*Country*	*Year*	*Deal value (US$ million)*	*Sector*
Ranbaxy Laboratories Ltd	Therapia S.A.	Romainia	2006	324	Pharmaceutical
Opto Circuits India	Eurocor GmbH	Germany	2005	600	Medical equipments
Kraft Foods	United Biscuits	UK	2006	520	Food & beverages
Tata Tea	Tetley	UK	2000	407	Food & beverages
Tata Motors	Daewoo Commercial	South Korea	2004	465	Automotive
Tata Chemicals	Brunner Mod	UK	2005	798	Chemicals
Tata Coffee	Eight O' Clock	US	2006	220	Food & beverages
Tata Steel	Corus Steel	UK	2007	12100	Steel
	PT Bumi Resources Tbk	Indonesia	2007	1100	Power
	Millenium Steel	Thailand	2006	404	Steel
	Natsteel	Singapore	2005	285	Steel
VSNL	Teleglobe	Canada	2005	239	Telecom
Hindalco	Novelis	Canada	2007	5892	Aluminum
Videocon	Daewoo Electronics	Korea		729	Electronics
Videocon	Thomson SA	France	2005	290	Electronics
Ispat Industries	Finmetal Holdings	Bulgaria	2005	300	Steel
Bharat Forge	Swedish Imatra Kilstra AB	Sweden		1300	Automotive
Reliance Ind.	Flag Telecom	Bermuda	2003	212	Telecom
HPCL	Kenya Petroleum	Kenya		500	Oil and Gas
Matrix Laboratories	Docpharma NV	Belgium	2005	235	Pharmaceutical
Ballarpur Industries	Sabah Forest Industries	Malaysia	2006	209	Pulp and paper
Sasken Communications	Bornia Hightec	Finland	2006	210	Information Technology
Essar Steel	Algoma	Canada	2007	1600	Steel

Source: Various websites: http://track.in/Tags/Business/category/mergers/; Wall Street Journal; http://ibef.org; Prowess database (CMIE), Nayar (2008), Mitra (2007), Jha (2006), various newspaper reports.

Note: [1] Deal value at least US$ 200 million.

countries, 15 firms mainly responsible for nearly one-third of the total acquisitions (Nayar, 2008).

Discussion and Concluding Remarks

The theme of internationalisation of R&D and global nature of innovation in emerging economies such as India provide a new context for exploration. More than anything else, this new context directs research attention to the ways in which

economies are getting integrated not by just economic and financial means but through knowledge-based institutions and innovation systems that are now geographically dispersed. The domination of a centralised corporate R&D and innovation by TNCs mainly based in home countries is fast breaking down. Disintegration of the production of knowledge and innovation into discrete networks has been further exacerbated by the impact of the ICT revolution coupled with the generic nature of software technology. It is becoming more meaningful to talk about globally dispersed networked innovation. The changing locus of R&D and innovation structures of TNCs and the growing importance of foreign locations for knowledge and R&D are at the 'centre of gravity' of this emerging globalisation of R&D and horizontal nature of innovation.

Influential writings from Archibugi and Michie (1995, 1997) and Reddy (2000 and 2005) have shown, in varying ways, the progress of internationalisation and globalisation of R&D by global TNCs being mainly confined to industrially advanced countries in Western Europe and North America with the possible exceptions of Japan and South Korea in Asia. These scholarly works argued that even if TNCs moved to developing countries in the era of early to mid 1990s, their operations were confined to 'one way technology transfer' or oriented towards 'adaptive R&D' rather than 'creative R&D'. In the specific case of India, an influential study by Kumar and Aggarwal (2000, p. 22) reflect a similar view when they observe, 'MNE affiliates focus on a customization of their parents' technology for the local market or on exploiting the advantages of India as an R&D platform for their parents [now referred to as home-base augmenting R&D]'.[28]

Studies based on patenting behaviour of TNCs provide further insights of the changing trends. Pavitt and Patel (1999) do not contest the internationalisation of R&D but question whether globalisation of technology has taken place. By analysing US patenting activities of 569 firms (based on 13 countries and in 17 product groups) they show that firms primarily undertake patenting in their home locations. Carlsson (2006) while reviewing the literature of innovation systems (citing the works of Meyer-Krahmer 1999; Cantwell and Santangelo 2000; Le Bas and Sierra 2002 among others) have found the changing patenting behaviour of TNCs from 1990 onwards. The reason for this change is attributed by them to speeding of the rate of technological change that made it extremely difficult for large firms to diversify their home technology base at a sufficient pace and thus compelled them to exploit the competence of foreign locations. However, all these patent-based studies again show that these activities are confined among the 'triad' (the United States, Europe and Japan).

This study reveals that during the last decade, this situation has changed significantly. India emerged as an important destination for 650 global TNC R&D units (see Table 3). A closer scrutiny of about 98 ICT firm's R&D units reveals that over 87 per cent of these units are 'Internationally Independent laboratory' and work for the global product mandate (see Table 5). The way in which knowledge is tapped and drawn from their Indian affiliates closely feeds into their parent, home country TNCs and is often integrated with global production networks. The

nature of the R&D undertaken by Microsoft, Intel and IBM labs, among others, in India are typical examples of this kind. The point of research relevance to local and global (to home country units) is due to the fact that such big TNCs in India have R&D units oriented to different needs and demands with links between research personnel and projects in these units. Patent statistics also showed the changing trends (see for reference, Figure 3 and Tables 4, 5 and 6). Foreign TNC R&D units located in India were granted 6,580 US patents from 1990–2011. This reflects significant and positive trends. Information presented in Tables 8 and 9, on the other hand, show the emergence of partnerships. What is of significance here is the new development of collaborative R&D and innovation between TNCs and Indian firms and institutions, particularly in biopharmaceuticals and ICT.[29]

There is enough evidence to suggest that the R&D undertaken by TNCs in India and its collaboration with Indian firms and institutions cannot be described solely in terms of either 'home base augmenting R&D' or 'home based exploiting site', reflective of the situation in the1990s, even though they still find relevance.[30] Indian R&D and innovation threshold has quite dramatically moved up in the last decade to transform from 'one way' to two-way knowledge transfer as argued in this paper. Research carried out at IBM's Indian labs in advance computing; and collaborations between Indian firms (such as Biocon, Dr Reddy's Labs and Ranbaxy) and the TNCs in drug discovery and its commercialisation are examples of the nature of research in computing and biopharmaceutical fields. Together with the patent data presented, the paper reveals the emerging trend of TNC R&D units towards 'creative R&D' linked to global competition.

ICT is a major driver of the world economy. One can discern from the foreign R&D units establishing in India, a large number of firms in ICT-based applications are primarily involved in chip design. Indian firms such as TCS, WIPRO are also trying to address various functionalities associated with chip design. The missing link, that is, fabrication (chip manufacturing) is being addressed by the innovation network involving other manufacturing locations such as China or Taiwan for fabrication. The empirical findings support Rajdou's observation that India is getting recognition as a base for semiconductor chip design. India will become a major hub in the global electronics Innovation Networks—a fluid market structure that matches global innovation demand with worldwide supply of talent and capabilities.

A parallel development is taking place to complete the full product cycle within India with big investments in fabrication (for example, US$ 3 billiom SemIndia project, US$ 4 billion fabrication project of Hindustan Semiconductor Manufacturing Company, a consortium of NRIs or Non-Resident Indians). These are new initiatives after the setback of Intel withdrawing their proposed chip-manufacturing facility in India. The new fabrication units will have to confront established fabrication units. Whether these units can integrate successfully with chip design that is undertaken in India is a question that remains to be answered.

The exploration of TNCs and their impact in the Indian context advances the view that India is emerging as an important partner in the globalisation of innovation. For instance, big Indian software firms have become important actors in the globally dispersed networked innovation processes in a number of high-technology areas such as aerospace, automotive, telecommunications, banking and finance, and so on. In varying ways, Indian developments reveal the changing structure of TNCs in the context of 'new approach' which 'moves towards globalized programmes for innovation and R&D' or 'dynamic differentiated networks' (Pearce, 2005; 29:30). As Ernst (2005:61) says, TNCs are 'increasing their overseas investment in R&D, while seeking to integrate geographically dispersed innovation clusters into global networks of production, engineering, development and research'. This paper advances the view of Ernst and Pearce to some extent. Further, the INSEAD Survey 2006, based on the responses from 186 global firms, also lends support to this view of India assuming some importance in the globally dispersed networked innovation. As this survey clearly reveals, even though India continues to enjoy the comparative advantage of low wage and highly skilled human resources, India has emerged as an important destination for TNCs with the growing threshold of its R&D and innovation base. The patent data of select Indian firms and institutions presented in Table 9 supports this view. In the case of ICT software, in parallel to software services to over 400 global firms from India, big firms such as TCS, Infosys and Wipro are now closely linked to globally dispersed innovation networks. The situation has changed during the last seven years compared to 1980s and 1990s of the 'body shopping era'.

Another important trend of globalisation and the global nature of innovation emerging is the rise of Indian firms that expand business and link up with the global production networks as depicted in Table 13. Much of this development is closely associated with economic and market growth of Indian firms over the years which are now entering a phase of M&As. This appears to be another important route for technology acquisition at global level for firms such as Tatas and Bharat Forge in engineering and manufacturing; production, commercialisation and marketing of new molecules and generic drugs for pharmaceutical firms; and partnering in the globally dispersed innovation networks for software firms.

All these insights advanced in this section, however, deserve further research to validate the initial findings.

NOTES

1. Radjou (Forrester Research, 2006) envisages Innovation Networks as the next big wave of outsourcing. In this new scenario, he posits that US firms will 'source not simply low-cost talent, but "invention services" [R&D services] in India and "transformation services" [manufacturing services] in China to build products for a global economy.
2. According to Reddy (2005), these periods or phases are not a water-tight compartment but to be seen as an indications. This study, transpose these phases to Indian context and assumed that the phases stretch much beyond the decade identified. Much of the framework for these four phases is drawn from Reddy (Ibid.).

3. Reddy's (2005) period of different waves or phases since the 1960s can be extended a decade further in the Indian context.
4. Reddy (2005) has given a number of good examples of spin-offs and spillovers in the Indian context. This paper goes beyond the globalisation of R&D to explore the emerging trends in globalisation of innovation.
5. The Global Industry Classification Standard (GICS) is an industrial classification system jointly developed and maintained by Morgan Stanley Capital International (MSCI), and Standard & Poor's (S&P) since 1999. The system is accepted worldwide among different groups of people with different interests. It has categorized all major public companies. Different news magazines, for example, Bloomsburg, BusinessWeek are also following this classification scheme. The system is similar to ICB (Industry Classification Benchmark), a classification structure maintained by Dow Jones Indexes and FTSE Group. GICS consists of 10 sectors, 24 industry groups, 67 industries and 147 sub-industries.
6. Raja M. Mitra (2007), *India's Emerging as a Global R&D Center,* Working Paper, Swedish Institute for Growth Policy Studies, R2007:012, Ostersund, Sweden.
7. As noted above the study will focus more on the globalisation of innovation.
8. This issue was raised by the US Committee on Science and Technology (See OECD discussion paper on 'OECD Global Forum on Trade, Innovation and Growth', OECD, Paris, presented at a meeting during 15–16 October 2007)
9. **IBM Research India** retrieved from http://www-07.ibm.com/in/research/smartes_systems_research.html, accessed on 21 April 2012.
10. Ibid.
11. Intel Research Advances 'Era Of Tera' Intel India Development Center Contributes in the Development of the World's First Programmable 80 – Core Processor to Deliver Teraflops Performance Bangalore, February 22, 2007. Retrieved from http://www.intel.com/cd/in/corporate-pressroom/apac/eng/archives/2007/340167.htm, accessed on 15 April 2012.
12. Anthony, Regina. Feb 4 2008. "India at the heart of Intel's mobiles push." in *Livemint.com*. New Delhi. Retrieved from http://www.livemint.com/2008/02/04235832/India-at-the-heart-of-Intel8.html, accessed on 21 April 2012
13. Texas Instruments To Showcase Technologies For Emerging Electronics Industries At Developer Conference (TIDC), Bangalore, November 27, 2006. Retrieved from http://www.ti.com/ww/in/news_detail/2008_2005/news_detail_tidccurtain.html, accessed on 30 April 2012.
14. Ibid.
15. Six individual technology groups operate in India: Routing Technology, Voice Technology, Optical Networking, Internet Switching Technology, IOS Technology Division and Network Management. On-going development of the 7,500 router platform primarily takes place in India.
16. Enhancing the existing E911 functionality of Cisco Call manager, CER enables emergency agencies to identify the location of 911-emergency callers. This product provides customers around the world with caller location and on-site alerting to security operations, even when public infrastructures do not support these services.
17. For example, Texas Instruments India has just released the 'world's first floating point digital signal controller'—a chip completely designed and developed by India-based engineers. The product has applications in solar and other un-interruptible power supplies.
18. Patents granted to a foreign firm in which at least one of the inventor had an Indian address is considered as the patent originates from Indian R&D Centre.
19. Examining the data from 1971 to 1989 further underscores the significant shift that has taken place in comparison to patents granted to foreign MNCs after 1995. Two pharmaceutical MNC, Ciba-Giegy (23 patents) and Hoechst (13 patents), were actively involved during this period, that is, 1971 to 1989. The other firms that were granted patents were mainly consumer goods firms.
20. Granted data is dated to the extent of three to four years, that is, the average time it takes for a patent to be granted after filing.

21. Krishnan, A. (2002). "Ranbaxy negotiating with three overseas cos for BPH molecule." in *Business Line*, Chennai, June 3,2002. Retrieved from http://www.thehindubusinessline.in/2002/06/03/stories/2002060301900300.htm, accessed on 15 March 2012.
22. Hereafter will be referred to as INSEAD Survey 2006.
23. It is rather interesting to note that China increased its R&D staff by three times compared to India during 2004 and 2007.
24. ASIC chips (application specific integrated circuits) can be programmed for a specific application (for example, a device for a sound card/video card), without having the chip manufactured in large quantities.
25. Infosys View Point retrieved from http://www.infosys.com/IT-services/infrastructure-management-services/service-offerings/Documents/Infosys-Services-Management.pdf, accessed on 31 March 2012
26. Infosys is first Indian premium member of Autosar consortium (28 March 2005). Retrieved from http://www.domain-b.com/companies/companies_i/infosys/20050328_consortium.html, accessed on 1 May 2012.
27. Ibid.
28. Kumar, N. and Aggarwal, A. (2000). *Liberalization, outward orientation and in-house R&D activity of multinational and local firms: A quantitative exploration for Indian manufacturing*. (Research and Information System for Developing Countries, Discussion paper No #7, New Delhi) Retrieved form http://depot.gdnet.org/gdnshare/pdf/827_Agarwal_rev.pdf , accessed on 31 March 2012.
29. As such, 17 per cent of 115 TNCs are characterised as falling in the category of collaborative R&D by the TIFAC Survey 2005. Collaborations in ICT is discussed in other sections of this concluding discussion.
30. For instance, India will take advantage of its high-skilled and low wages human resources in various sectors, but at the same time, the nature of R&D threshold is moving up in pharma, ICT software, chip designing, auto and so on.

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