# Global Innovation in Emerging Economies

Prasada Reddy

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# Global Innovation in Emerging Economies

In recent decades, there have been significant changes in the way corporate innovation is performed. They include changes in the innovation process, flexibility to outsource innovation activities, and most importantly, the location of innovation. There are mainly two new trends: First, location of globally strategic R&D by the multinational corporations (MNCs) in some developing countries; second, more recently, some companies from the emerging economies have also started performing R&D to develop products and services for global markets. These trends are occurring in a dynamic business environment that consists of mutually reinforcing economic and technological changes. These trends have managerial implications for companies and policy implications for the emerging economies where such R&D is performed, as well as for the industrialized home countries of the companies. Further, innovative products and services resulting from R&D activities in emerging economies seem to better address the needs of consumers at the bottom-of-the-pyramid in other developing countries.

*Global Innovation in Emerging Economies* examines the dynamics of the globalization processes and the emergence of new locations for innovation and its implications. Exploring twenty in-depth case studies of MNCs, local companies, and research institutes/universities based in Brazil, China, India, and South Africa (the so-called BRICS Group), Prasada Reddy develops a conceptual framework of the evolution of globalization of corporate R&D. This unique books addresses many issues including the context for location of global R&D in emerging economies by MNCs and the driving forces behind this trend, performance of global R&D by companies from emerging economies, and national and corporate implications of these new trends for innovation systems.

**Prasada Reddy** is a faculty member at the Research Policy Institute, Lund University, Sweden. He also worked at the Centre for Entrepreneurship, University of Oslo, Norway. He has been a consultant to several multilateral organizations. His broad areas of work include: foreign direct investments, industrialization, innovation, and intellectual property rights.

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**In Memory of My Parents**
**Akepati Chengal Reddy and Akepati Kamalamma**

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# Abbreviations

| | |
|---|---|
| API | Active Pharmaceutical Ingredient |
| ARCI | Astra Research Center India |
| ASEAN | Association of South East Asian Nations |
| BITs | Bilateral Investment Treaties |
| BRICs Countries | Brazil, Russia, India & China |
| CAD | Computer Aided Design |
| CAE | Computer Aided Engineering |
| CAM | Computer Aided Manufacturing |
| CAS | Chinese Academy of Sciences |
| CDMA | Code Division Multiple Access |
| CITI | Cape IT Initiative |
| CMM | Capability Maturity Model |
| CoE | Center of Excellence |
| CRO | Contract Research Organization |
| CSIR | Council for Scientific and Industrial Research |
| CTU | Corporate Technology Unit |
| DST | Department of Science and Technology |
| EIU | Economist Intelligence Unit |
| EU | European Union |
| FDI | Foreign Direct Investment |
| FTA | Free Trade Agreement |
| G6 Countries | US, Japan, UK, Germany, France & Italy |
| GATS | General Agreement on Trade in Services |
| GATT | General Agreement on Tariffs and Trade |
| GcP | Good Clinical Practice |

| | |
|---|---|
| GDP | Gross Domestic Product |
| GMP | Good Manufacturing Practice |
| GNP | Gross National Product |
| GPD | Global Product Development |
| GSM | General System for Mobile Communication |
| GTU | Global Technology Unit |
| HCR&D | Hitachi (China) Research & Development Corporation |
| HEI | Higher Education Institution |
| HP | Hewlett-Packard |
| IC | Integrated Circuit |
| ICRC | Intel China Research Center |
| ICT | Information and Communication Technologies |
| IDRC | International Development Research Centre |
| IICT | Indian Institute of Chemical Technologies |
| IIL | Internationally Interdependent Laboratory |
| IISc | Indian Institute of Science |
| IIT | Indian Institute of Technology |
| IND | Investigational New Drug |
| IP | Intellectual Property |
| IPRs | Intellectual Property Rights |
| IT | Information Technology |
| ITU | Indigenous Technology Unit |
| LIL | Locally Integrated Laboratory |
| M&A | Merger & Acquisition |
| MIDC | Microsoft India Development Center |
| MNC | Multinational Corporation |
| MOST | Ministry of Science and Technology |
| MSR Asia | Microsoft Research Asia |
| NACI | National Advisory Council on Innovation |
| NAFTA | North American Free Trade Agreement |
| NASSCOM | National Association of Software and Services Companies |
| NCE | New Chemical Entity |
| NCL | National Chemical Laboratories |

| | |
|---|---|
| NIEs | Newly Industrializing Economies |
| NRCSTD | National Research Center for Science & Technology Development |
| NRDC | National Research and Development Corporation |
| NSB | National Science Board |
| NSF | National Science Foundation |
| NSFC | Natural Science Foundation of China |
| NSI | National Systems of Innovation |
| OBM | Original Brand Manufacturing |
| ODM | Original Design Manufacturing |
| OECD | Organization for Economic Cooperation and Development |
| OEM | Original Equipment Manufacturing |
| PC | Personal Computer |
| PCT | Patent Cooperation Treaty |
| PRI | Public Research Institute |
| R&D | Research and Development |
| RTU | Regional Technology Unit |
| S&E | Science and Engineering |
| S&T | Science and Technology |
| SCI | Science Citation Index |
| SEI | Software Engineering Institute |
| SI | Systems of Innovation |
| SID | Society for Innovation and Discovery |
| SL | Support Laboratory |
| SMEs | Small and Medium Enterprises |
| STI | Science, Technology and Innovation |
| TCS | Tata Consultancy Services |
| The USA | United States of America |
| TI | Texas Instruments Inc. |
| TIH | The Innovation Hub |
| TRIPS | Trade-Related Intellectual Property Rights |
| TTU | Technology Transfer Unit |
| UK | United Kingdom |

| | |
|---|---|
| UNCTAD | United Nations Conference on Trade and Development |
| UNESCO | United Nations Educational, Social and Cultural Organization |
| USA | United States of America |
| USFDA | United States Food and Drug Agency |
| USPTO | United States Patent and Trademark Office |
| VR | Virtual Reality |
| WTO | World Trade Organization |

# Foreword

In the 1960s, the long-run outlook for economic development in even the most precocious de-colonized countries was grim, as observed through the prism of 'dependency theory,' which maintained that poor countries would always remain economically behind because of their inability to develop original technology. By the 1990s, the outlook had brightened somewhat, as technological capabilities in pockets of the developing world began to be examined through the lens of the 'national innovation system,' which acknowledged the steps being taken to develop local technological skills. Now, with Reddy's book in the forefront, leading Third World countries are examined from the viewpoint of providing a new and fast-growing locale for R&D, the ultimate in economic development, for national investors as well as for multinational firms, whether in the form of R&D subsidiaries, joint ventures or subcontracting services.

One of the many virtues of Reddy's book is its scholarly energy and the material it provides to ponder what the world is beginning to look like as this far-out stage in development is being reached.

What I infer from Reddy's scholarship is that the world is not necessarily becoming 'universalist,' with the multinational form of doing business spreading from North to South in a seamless web of collaboration and orderly competition in the R&D field. Universalism is more or less the picture painted by the most eminent scholars of the 1950s-era MNCs to whom Reddy refers, notably Chris Bartlett and Sumantra Ghoshal. Yet during the catch-up period of "emerging multinationals from emerging economies" (as Ravi Ramamurti and Jitendra Singh term it), the de-colonized generation, owing to being latecomers, may spawn a new global business structure, and their narrowing of the gap is likely to be long and hard. Reddy reminds us that despite all the glamor, at least two-thirds of all R&D is still undertaken in the developed world, and only a small fraction of the top 500 or 1,000 business enterprises are from the South, mostly national oil companies and banks. Instead of MNCs from the South joining hands in R&D with those from the North with little organizational difference between them, the old 1950s(+) MNC model may not become universal in practice. The MNCs that originate from the North, with vast global networks and less centrifugal force to optimize their home base, may have to compete in the markets of a growing number of countries that have their own first-rate national firms. Country after country is likely to exhibit a very formidable set of national enterprises against which the MNC must compete, as first seen in South Korea, then China, India, Brazil, Vietnam, South Africa. . . . These national privately owned enterprises (POEs) are smaller overall than the largest MNCs, but their corporate headquarters are formidable and fine-tuned. POEs globalize (witness Samsung and Tata), but their international networks are likely to be less far-flung than those of the MNC, and to enjoy more regional coherence, especially in Asia (Reddy provides an interesting chapter on the South-South dimension of innovation). The strong country model may constitute a challenge in the aggregate to the diffuse multinational model, at least during the decades-long (?) phase of catch-up.

As Reddy observes, the advantages of the MNC are enormous, including sheer size, first-mover advantage and rich stocks of innovative skills. But if need be POEs can also keep their R&D costs down by outsourcing to lower-wage countries, but their costs of doing business are likely to stabilize at a lower wage level for some time to come (presently, Reddy notes, the need to reduce labor costs accounts for more than 90 percent of outsourced R&D investment, which, in turn, is responsible for a large share of the total). The wage gap between the emerged and emerging economy may remain much wider, and the skill gap may become much narrower, than what the American multinational has encountered in Europe or even Japan. At present, Third World multinationals can also leapfrog, and acquire new capabilities overnight, if they can manage them well, by outward foreign direct investment, acquiring the plum assets of multinationals in financial distress (such as the acquisition in 2009 by Saudi Arabia's state-owned petrochemical company, SABIC, of GE's chemical company in China, equipped with R&D facilities). Yet Reddy provides data that strongly suggest that the attention paid by POEs to their domestic base may remain intense, if only because their managers and engineers perceive the persistence in the North of a black and yellow 'glass ceiling.' Increasingly, the best people may return from wherever they studied to work at home.

The MNCs are locating R&D overseas, but Reddy aptly asks, is it ever at the world frontier? Isn't Raymond Vernon's product-cycle theory still correct in suggesting that a firm always retains its most developmental, non-standardized operations at home? The tugging at the apron strings to break away nationally and decentralize R&D functions for cost reasons may be expected to be greater among MNCs than POEs, given different cost conditions. Which model, in our generation, is better no one yet knows, but it is something worth thinking about.

Reddy gives us food for thought by providing us with a rich set of case studies of R&D in the 'BICS' (Brazil, India, China and South Africa). India is the MNCs' favorite location, whereas the largest 'foreign' investor in China is Taiwan (the company conducting the most advanced R&D is Nokia).

It is fun to read Reddy's book because the information he generously provides is fresh. We must thank him for revealing to us the foundations of a new phenomenon.

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April 2010

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# Preface

In the early 1990s I started working at the Research Policy Institute, where research work on internationalization of R&D was being led by Prof. Jon Sigurdson. At about the same time, research on the topic started picking up momentum worldwide. I was soon bitten by the bug, and a review of the scenario showed that almost all the research was focused on the industrialized world. Having worked in India in the 1980s, I witnessed some multinational corporations (MNCs) locating their strategic R&D units in India in the mid-1980s. This made me curious as to whether the location of such units in a developing country was an evolutionary trend in the process of globalization of R&D. Questions that aroused my interest included: What were the driving forces? What types of technologies were being developed? What were the implications for the host country? A survey of the then existing literature did not help much as there were few studies dealing specifically with these issues.

My research started with case studies of the MNCs' R&D units in India, and, based on the results, a questionnaire survey was carried out in 1997. The results showed that MNCs that located strategic R&D in India were mainly in the new science-based technologies, and they were doing so mainly to gain access to research personnel.

To validate my hypothesis that globalization of corporate R&D was evolving further to encompass more geographical areas outside the industrialized world, it was necessary for me to develop a database of MNCs' R&D activities in developing Asia and transition economies. Based on the research work over the years, I have developed an evolutionary framework of the globalization of corporate R&D dating back roughly to the 1960s, in terms of waves and the driving forces in each of these waves, the type of R&D located abroad in each wave and the potential implications for the host country.

The results of all this research, apart from partially appearing as articles in international academic journals, culminated in an integrated publication of a book titled *Globalization of Corporate R & D: Implications for Innovation Systems in Host Countries,* by Routledge in 2000. Since this publication, based on research in the 1990s, many developments of revolutionary nature have taken place in terms of location innovation. For instance, the emergence of China in the global economy and then the prediction of Goldman Sachs about the growth potential of Brazil, Russia, India and China (BRICs).

Because my research applies equally to both industrialized and developing worlds, I have received a number of invitations to address both of them (of course from different perspectives—one wanting to prevent R&D from moving away and the other wanting more R&D-related investments).

Since 2005, there has been a constant encouragement and pressure from my well-wishers to document and analyze the development that has taken place since my previous work in the late 1990s. Fortunately, the International Development Research Centre (IDRC), Canada, came forward to support my research, which culminates in the form of this book.

The book may well be deemed an extensive study of the process of globalization of innovation, as it also integrates the evolving phenomenon that encompasses hitherto-unknown countries for such high-end activities and the potential implications of this phenomenon.

I hope readers will find the book useful and interesting.

# Acknowledgements

My research has benefited immensely from the help of several individuals and organizations over the years. Acknowledging all individually would be impractical. Needless to say, I am highly indebted to all the organizations in the present study that have allowed me to carry out the case studies of their entities by sparing their valuable time.

As usual a study of this nature across several countries could not be undertaken without major help from the local academic and other professional staff. A large number of such people helped me by discussing the analytical details as well as arranging meetings with other actors in the innovation systems. I am particularly grateful to Simone Vasconcelos R. Galina and Sergio Robles Reis de Queiroz in Brazil; and Rasigan Maharajh and Raven Naidoo in South Africa.

This research work began at the end of 2006 when I was still affiliated to Lund University, Sweden, but much of the work was carried out when I was working at the Center for Entrepreneurship (SFE), University of Oslo (UiO), Norway. A number of friends and colleagues at the UiO supported me not only through comments and suggestions, but also by facilitating my research. I am grateful to all of them, particularly to my former colleagues at SFE, Nils Damm Christophersen, Tomas Hellström, Kim Larsen, Espen Solhaug, Mari S. Svalastog and Silvia Tofte. I have also often consulted Merle Jacob of TIK Center at the UiO. I am also grateful to my friends Bjørn Kraabol and Ivy Kraabol for their encouragement and help in arranging meetings in China.

Coming to the home front at the Research Policy Institute, Lund University, Sweden, a number of people have supported me in various ways. I am particularly indebted to the following people with whom I have had the privilege of continuously interacting: Mats Benner, Claes Brundenius, Anders Granberg, Bo Göransson, and Rikard Stankiewicz. I am also grateful to Christer Gunnarsson and Jon Sigurdson, who have constantly supported me over the years.

I also owe much to my uncle Pola Venkata Reddy and aunt Sakuntalamma, brother Akepati Rajanikantha Reddy and sister-in-law Sandhya.

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Needless to say, all the disclaimers apply.

# 1 Introduction

In recent decades, there have been significant changes in the way corporate innovation activities are performed. They include changes in the innovation process, flexibility to outsource certain innovation activities and, by far the most important one, wider choice in the location of innovation. What caught the most attention of policymakers, academics and corporate management is the trend toward globalization of research and development (R&D) and thereby performance of innovation activities away from the home countries.

The main concerns relate to the two new trends: first, the new trend of multinational corporations (MNCs) locating strategic innovation activities in some countries outside the industrialized world, which can be referred to as 'emerging economies'; and second, since 2000, some companies from the emerging economies have started entering the global markets with innovative products and services, developed through their own R&D. Both these new developments have managerial implications for companies and policy implications for the host countries (where such R&D is performed), as well as for the home countries of the companies.

## 1.1 GLOBALIZATION OF INNOVATION

Internationalization of innovation activities is not as recent a phenomenon as it is viewed to be. Since the 1960s, companies have been performing some sort of R&D outside their home countries for one reason or the other. In a study, Cantwell (1998) found that even as early as the 1930s, the largest European and American companies performed about seven percent of their total R&D outside their home countries. But the magnitude, nature and scope of such overseas R&D in the past were limited. It was mainly undertaken either to facilitate technology transfer by adapting the parent's technology to local operating conditions or to gain greater share of the local markets by developing products that meet the preferences of local customers better.

MNCs started internationalizing their R&D on a larger scale in the 1980s, and this became significant in the 1990s. Foreign R&D expenditures of US MNCs increased every year since 1994 and reached a record US$21 billion in 2002, accounting for 13.3 percent of those MNCs' total R&D expenditure, an increase from 11.5 percent in 1994 (Morris 2005). In terms of employment, in 1999, 16 percent of the people employed in R&D by these MNCs were in foreign subsidiaries, up from 14 percent in 1994 (UNCTAD 2005, p. 122).

However, there are wide differences in the degree of globalization of R&D between different industry groups. For instance, in the case of Japanese MNCs, most of their overseas R&D units are in the electronic equipment, pharmaceutical and automotive industries (Odagiri and Yasuda 1996). In general, it is observed that technology-intensive industries, such as electronics, biotechnology, chemicals and pharmaceuticals, tend to internationalize their strategic R&D to a greater degree than other industries (Niosi 1999).

In the 1990s, the performance of R&D abroad by MNCs had not only increased substantially in quantitative terms, but the nature of such R&D had also undergone significant qualitative change. The scope of work in overseas R&D units of MNCs has gone beyond adaptation tasks to encompass innovation activities of strategic nature such as developing products for the global markets or even undertaking basic research to develop generic technologies (Reddy 1997).

The significant increase in the overseas R&D activities of MNCs can be mainly attributed to the changes in MNCs' strategies to attain global competitiveness. According to Pearce (1999, 157), the new strategic approach involves recasting of the roles of individual subsidiaries and their intragroup interdependencies. The growing importance of overseas R&D units in MNCs' strategies reflects: "(i) an increasing involvement in product development rather than adaptation, (ii) an interdependent rather than dependent position in group technology programs, (iii) increased relevance of supply-side influences (host country technology competencies, capacities and heritage), (iv) decline of centralizing forces on R&D (e.g., economies of scale, communication and co-ordination problems, concerns of knowledge security)."

Over the years, various methods of exploiting internationally dispersed innovation activities have been evolving. Bartlett and Ghoshal (1991) suggested four different types of management structures: (i) center-for-global—developing new products and processes in the home country for the global markets; (ii) local-for-local—developing products and processes independently in each of the R&D units abroad for use in the local market of the subsidiary; (iii) locally linked—developing novel products and processes in each location for global exploitation; and (iv) globally linked—developing novelty through the collaboration of R&D units located in different countries for exploitation in the global markets. Each type has specific advantages and disadvantages, but all the four types could be adopted at the same time for different projects within the same MNC.

Similarly, Håkanson (1990) suggests that the organizational structure of MNCs for international R&D has undergone three evolutionary stages: the centralized hub, the decentralized federation and the integrated network. Now, an emerging evolutionary framework considers the 'organizational learning' by MNCs as the core explanation for globalization of R&D. This is reflected in the MNCs locating their R&D units abroad closer to major centers of innovation, where reputed universities and R&D units of competitors exist. Learning takes place through closer interaction with major customers, suppliers and knowledge producers, such as universities (Niosi 1999).

Kuemmerle (1997, pp. 62–63) classifies new overseas R&D sites on the basis of their primary objective, usually one of the two missions: (1) the 'home-base-augmenting site,' which is established in order to access knowledge from the local scientific community, creating new knowledge, and transferring it back to the company's headquarters; (2) the 'home-base-exploiting site,' which is established to support manufacturing facilities in foreign locations or to adapt standard products to the demand there. The main objective is to commercialize knowledge by transferring it from the company's home base to the R&D unit abroad and from there to local manufacturing and marketing.

Zanfei (2000, p. 516) suggests that with regard to innovation activities, MNCs are in the process of adopting a new organization mode that is defined as a 'double network.'.First, MNCs are increasingly characterized by the interconnection of a large number of internal units that are engaged in the company's use and generation of knowledge. This is referred to as MNC's 'internal network.' The traditional organizational model of transfer of knowledge from center to periphery is giving way to a new model in which the units are not just absorbing knowledge generated elsewhere, but are also generating and circulating new knowledge and are linked to one another through cultural (values and languages) rather than hierarchical linkages. Second, units in the internal network tend to build 'external networks' with other firms and institutions outside the MNC's network to increase the potential for use and generation of knowledge. Such cooperative linkages are developed not only by the central units of MNCs but also by the decentralized units, which use such local external networks to gain access to local sources of information and application abilities.

According to Alcácer and Chung (2007, p. 761), often firms strategically choose to locate R&D activities in a given geographical area in order to benefit from localized knowledge spillovers. Firms that locate operations in such areas while receiving knowledge would also become a source of spillovers through leakage of their own knowledge. So such firms are exposed to two competing constraints: (i) maximizing benefits from a location's knowledge activities; and (ii) minimizing spillovers to competitors. There are three potential knowledge sources in a given geographical area—industry, academia, and government. Foreign firms entering the host country for the first time, on an average, are not interested in areas that have large government and industry technical activity. Less technologically advanced firms tend to locate in geographical areas with any level of academic activity and high levels of industrial innovative activities. On the other hand, firms that are technologically more advanced tend to favor locations with high level of academic activity and avoid geographical areas with any level of industrial activity. The academic and government sources produce more basic and less appropriable knowledge, which is less attractive to technologically less advanced firms. Technologically more advanced firms have greater knowledge base and are better able to benefit from spillovers from all sources.

The scope and level of technological activities carried out abroad by MNCs are determined by the national capabilities of both home and host countries. Cantwell and Janne (1999) propose that when MNCs based in countries with more advanced technological capabilities in a given industry relocate to less advanced countries in the same industry, they tend to 'differentiate their technological activities.' On the other hand, when MNCs based in less advanced countries relocate R&D abroad, they tend to 'specialize within the same areas of the parent company' at home. They also suggest that the MNCs located in leading centers in a particular industry tend to build up specialization on the basis of the local technological capabilities in host countries. At the same time, MNCs located in less advanced centers tend to draw more on their home-based capabilities, by replicating their home specialization abroad.

## 1.2 GLOBALIZATION OF R&D AND EMERGING ECONOMIES

Until the mid-1980s, the globalization of corporate R&D had been mainly limited to location of R&D units within the industrialized countries, where much of the R&D is still concentrated. Developing countries seldom figured as locations for innovation activities. According to Amsden et al. (2001, pp. 1–3), latecomer nations to industrialization differ among themselves in two key aspects: (1) the ownership of their leading manufacturing companies; and (2) the depth and breadth of their R&D. In countries where the dominant companies are nationally owned, as in China, India, Korea and Taiwan, the aggregate investments in R&D tend to be high. Conversely, in countries with high incidence of foreign ownership of companies, as in Argentina, Brazil and Mexico, the aggregate investments in R&D tend to be low. Certain industries such as electrical and nonelectrical machinery, transportation equipment and chemicals are likely to be subject to 'first mover' advantage. Therefore, if an MNC becomes the first mover in such an industry in an emerging economy, it may succeed in 'crowding out' the entry of national firms. Because MNCs conduct very little R&D in developing countries, local R&D in these dynamic industries is unlikely to occur. These countries will be dependent on the MNC for transfer of new technologies. Consequently, in these dynamic industries, emerging economies will not be able to earn 'monopoly,' 'technological' or 'entrepreneurial' rents due to their failure to acquire the skill base that is a prerequisite for earning such rents. According to Fagerberg (1994), technological innovations do not flow easily across economic actors or distances as the generation and application of innovations are closely tied to specific firms, networks and economic institutions.

Globalization of corporate R&D, however, continues to evolve as a phenomenon, by encompassing more industrial sectors, as well as more geographical areas. Hitherto uncommon locations are attracting R&D-related foreign direct investments (FDI) by MNCs. Beginning in the mid-1980s, MNCs started locating strategic R&D units, perhaps on an experimental basis, in some developing countries, such as India. This strategic move by MNCs has been facilitated by the availability of large pools of scientifically and technically trained human resources, at substantially lower wages compared to their counterparts in industrialized countries, and an adequate infrastructure (Reddy 1993; Reddy and Sigurdson 1994).

This does not imply that a major proportion of corporate R&D is being relocated to emerging economies. More than two-thirds of the world's industrial R&D is still being carried out in traditional locations within the industrialized world. However, the trend of locating innovation activities in emerging economies is likely to be strengthened as well as extended to more sectors.

With the collapse of the Soviet Union in the early 1990s, a large pool of scientists and engineers with specialist knowledge from Russia and East European countries entered the global market for talent. Around the same time, some developing countries, particularly Brazil, China, India and South Africa, started liberalizing their economies for trade and investments. These countries started attracting the attention of foreign investors and MNCs not only for their large and rapidly growing economies, but also because of their technological capabilities. These countries were seen as potential location for some innovation activities.

Furman and Hayes (2004) through an analysis of the US patent data show that the innovative productivity among the 'follower' countries is growing at a faster pace than is that of the industrialized countries. Over the last few decades, the difference in the relative innovative productivity of the most innovative countries (e.g., the US, Switzerland and Japan) and other innovative countries (e.g., Israel, Singapore, South Korea, Taiwan) has declined, in terms of innovative output per capita. Although there is still a gap in absolute terms between the former and the latter, the gap is relatively narrower now than it was about a couple of decades ago. Based on historical patterns in their innovative capacity levels, Furman and Hayes categorize countries into four groups: (1) leading innovator countries; (2) middle-tier innovator countries; (3) third-tier innovator countries; and (4) emerging innovator countries. The average innovative capacity in the 'emerging innovator' countries grew significantly during 1978–1999 from slightly higher than those of the third category of countries to levels that exceed those of the second category of countries. Although not on a par with the most innovative countries, emerging innovator countries as a group have surpassed a number of countries who historically had greater wealth and technology than them. This the authors attribute mainly to the "ever deepening investments in the drivers of national innovative capacity, both by committing to innovation-enhancing policies and investing in physical and human capital" (p. 1331).

An Economist Intelligence Unit (EIU) global survey in September 2004 (EIU 2004) showed that companies are redistributing their innovation activities across the globe. About 70 percent of the companies surveyed had R&D activities abroad. Around 52 percent of the respondents reported that increasing their overseas R&D was a priority. Among the likely locations for R&D-related FDI, 30 percent of the respondents cited China, 29 percent the US, followed by India at 28 percent. India is viewed to be a large recipient of global strategic R&D investments in the future. The EIU considers India a potential global 'R&D hotspot.' According to another survey by A. T. Kearney in 2007, India emerged as the second most likely destination for R&D-related FDI, behind China and just ahead of the US. More than 300 MNCs have already set up R&D centers in India, including over 125 *Fortune* 500 companies (Yoshida 2008, p. 3).

In 2005, INSEAD and Booz Allen Hamilton surveyed R&D managers in 186 companies from 17 industrial sectors across 19 countries. The survey respondents together accounted for about 20 percent of the global corporate R&D expenditures (US$76 billion). Between 1975 and 2005, among the respondents, the share of R&D sites located outside the markets of their corporate headquarters has risen from 45 to 66 percent (Goldbrunner et al. 2006, pp. 1–2). The survey showed that the relative share of China and India among R&D sites has been increasing; the two countries together accounted for 3.4 percent of foreign sites of the respondents in 1990, and this increased to 13.9 percent by 2004. Over the same period, the proportion of foreign R&D in the US fell from 19.6 percent to 15.9 percent, while in Western Europe it fell from 30.0 percent to 28.1 percent. In order to build an 'optimally configured' R&D network, the respondents plan to open new or scale up existing R&D sites over the next five years, with 22 percent of all new R&D sites going to China and 19 percent to India. This trend was common across all subsets within the sample (subsets: home country; highly dispersed versus less dispersed; users of complex versus noncomplex knowledge; and technology innovators versus the rest). The US also retained its attraction as an R&D location with 19 percent of the new sites, but mainly in just three sectors, defense, chemicals and pharmaceuticals. Only 13 percent of the new sites would be in Western Europe, closely followed by Eastern Europe with 12 percent. South America attracted a five percent share of the new sites (Doz et al. 2006, pp. 4–5).

The survey also showed that the driving forces for location of innovation activities are differentiated by region, suggesting that R&D location decisions seek to create a network of unique skills and capabilities across the globe. Future location of R&D units in the industrialized world will be based mainly on criteria relating to: 'access to technology or research clusters,' 'access to markets or customers' and 'access to qualified workforce.' The growth of foreign R&D units in the developing countries showed quite a different set of drivers: In all developing regions, access to 'low cost skills base' and 'access to markets and customers' are important factors for establishing new R&D sites. However, in India and Eastern Europe, companies are also attracted by the availability of highly qualified human resources. "In China, the low cost skills base is paired with a need for market and customer access, which implies companies are focusing lower on the innovation value chain in China than in India or Eastern Europe" (Doz et al. 2006, pp. 5–6).

In terms of jobs created globally by inward FDI (including R&D-related FDI), a study by IBM's PLI-Global Location Strategies service showed that in 2006 the top 15 locations for inward FDI accounted for 73 percent of jobs, a decrease from 85 percent in 2005, suggesting that MNCs are widening their search for investment opportunities for manufacturing, services and R&D. In 2006, inward FDI created a total of 900,000 manufacturing jobs worldwide, followed by 330,000 service jobs and 100,000 R&D jobs. India and China continue to lead in the total number of new manufacturing jobs created through inward FDI; however, Vietnam is rising rapidly. India attained the first place in terms of manufacturing jobs created (126,000), displacing China. Vietnam doubled its total over the previous and tied with China at 100,000 jobs. Mexico and Eastern European countries have also benefited in terms of manufacturing jobs created. India attracted manufacturing particularly in the ICT and transportation equipment industries, whereas China and Vietnam were more successful in electronics. Mexico and Eastern Europe achieved higher than average on transportation equipment jobs. With respect to jobs created by inward FDI in the services sector, India and the Philippines cornered the global shared services activity with 32 percent and 16 percent of such jobs, respectively. Brazil has also emerged as a strong regional shared services location. India and China dominate the global ranking in terms of R&D jobs created through inward FDI, with 54 percent and 12 percent, respectively. Other emerging economies such as Romania and Vietnam, however, are increasingly being seen as attractive locations for R&D-related FDI (IBM 2006).

Similarly, in a transition economy, according to data collected by CzechInvest, an agency of the Ministry of Industry & Trade of the Czech Republic, in 2006, over 60 percent of the FDI in the Czech Republic announced by US companies are R&D-related in high-tech industries. Out of 16 investments projects of US companies in the Czech Republic, 12 are R&D and high-value-added services projects. They include Sun Microsystems' development and technology center, Microsoft's center for mobile applications and Ingersoll-Rand's research and training center. About 30 percent of the new projects and inquiries have been from small- and medium-sized enterprises (SMEs) based in Silicon Valley, seeking affordable engineering R&D talent and design services (Clarke, *Electronics Supply & Manufacturing*, 12/27/2006).[1]

Another sector, which is growing in terms of globalization of innovation activities, is the 'engineering & technical services.' A recent study by Booz Allen Hamilton and India's National Association of Software and Service Companies (NASSCOM)—the first study to assess the evolving global market for engineering and technical services—found that global sourcing of innovation is growing rapidly in locations, such as India, China, Thailand and Brazil. According to the study, current global expenditure on outsourced (offshore) engineering is US$15 billion. By 2020, the figure is expected to be in the range of US$150 billion to US$225 billion, with growth occurring in emerging economies such as India, China and Russia. Presently, the need to reduce labor costs accounts for more than 90 percent of offshored (outsourced) innovation activity in emerging economies, but during the next 10 years this will be due to more strategic priorities: market access, resource quality, increased productivity and expanded capacity (Dehoff and Sehgal 2007, p. 3).

Such R&D outsourcing to service providers abroad often involves joint work by one or more emerging economies as well as by industrialized countries. For instance, beginning in 1991, Boeing started subcontracting (outsourcing) R&D work to Russian scientists to take advantage of their knowledge and expertise in aerodynamic issues and new aviation alloys. Following its success, in 1998 Boeing opened an aeronautical engineering design center in Moscow. The center employs 800 Russian engineers and scientists, and the number is expected to go up to 1,500 over time. Boeing has contracts with major Russian aircraft manufacturers such as Ilyushin, Tupolev and Sukhoi, who, in turn, provide the engineers and scientists for Boeing's different projects. By using French-made airplane design software, the Russian engineers collaborate with Boeing company's engineers in Seattle and Wichita in the US. For Boeing such outsourcing of R&D has become a necessity mainly due the substantial shortage of aeronautical engineers in the US. As a sign of growing linkages among the emerging economies, the Russian teams have further outsourced some elements of their work for Boeing to Hindustan Aeronautical Limited (HAL) in Bangalore, India, which specializes in digitizing airplane designs to make them easier to manufacture. Boeing has also outsourced design and manufacture of wings for its new 7E7 (since then changed to 787) aircraft to Mitsubishi in Japan. Mitsubishi, in turn, outsources some of its work to Russian engineers whom Boeing is using for other parts of the plane. Such business potential in providing R&D services is encouraging entrepreneurship among Russian engineers and scientists, who are leaving the large companies to set up their own design companies. Boeing is planning to buy shares in some of these start-ups (Friedman 2006, pp. 227–228).

As a further development, the aerospace giants Airbus and Boeing, who until recently were outsourcing only simple work like digitizing old hardcopy drawings, began to outsource more complex innovation activities to their Indian partners. These Indian partners now employ their own aerospace engineers, many of whom accumulated several years of experience in the Indian state-owned aviation sector. For instance, Airbus contracted Infosys, an Indian IT company based in Bangalore, to design part of the wing of its double-decker plane A380. Airbus is also teamed up with another Indian IT company, Tata Consultancy Services, to build software for next-generation cockpits, which aims at replacing switches by touch screens. Airbus subcontracted a third Indian firm to design and build doors for its jet planes. In Boeing's forthcoming 787 Dreamliner, two mission-critical systems—one to avert airborne collisions and another allowing landing in zero visibility—are being developed and built largely by HCL Technologies, another Indian firm (Giridharadas 2007).

Following its successful experiments with outsourcing activities in India, in 2007, Airbus established its own R&D center, the Indian Airbus Engineering Center in Bangalore. According to Airbus, Indian engineers at this high-tech center are involved in developing advanced modeling and simulation, covering critical factors in the design and production of aircraft such as A380. The center started with 25 engineers, and within a year it expanded to 300. Together with employees of the suppliers of Airbus, the center now houses over 1,000 engineers and is expected to grow further in the future (Dikshit 2008).

This phenomenon is not confined to large MNCs alone; even the start-ups in the US have caught onto the idea of locating some innovation activities in emerging economies. For instance, US venture capitalists estimate that anywhere from one-third to three-quarters of the software, chip and e-commerce start-ups that they invest in have Indian R&D teams from the start. In fact, the economics are so compelling that some venture capitalists demand that start-ups include Indian R&D in business plans from the beginning (*Business Week* 2003, pp. 42–45; Ernst 2006, pp. 10–11). This has led to new business models of innovation offshoring, involving foreign-born engineers from Taiwan, China and India, who are based in the US, to emerge as increasingly important "offshoring brokers" (or outsourcing consultants). They provide important support for start-ups based in Silicon Valley. As an example, an Indian design engineer with a distinguished track record in leading US semiconductor firms founded a company, based both in California, and Ahmedabad, India. The company was founded to work as an offshoring broker to the US semiconductor industry. It began by testing designs, but now has expanded to provide everything from concept design to the development of silicon intellectual properties (SIPs) (Ernst 2006, pp. 10–11).

Globally distributed research teams across different cultural settings are able to exchange complex knowledge because the knowledge workers who share specialized skills (e.g., mixed signal chip design) tend to follow common rules and codes of exchanging knowledge. Members of such global research communities "will share more jargon and trust among each other than with any outsider within their present local communities. And even when meetings are required, their frequency will not necessarily be as high as to impose co-localization as a necessary requirement for belonging to the epistemic community" (Breschi and Lissoni 2001, p. 991).

### Forms of Globalization of Corporate R&D in Emerging Economies

Globalization of corporate R&D is occurring in various forms. These include:

- Establishment of wholly owned R&D subsidiaries;
- Establishment of joint venture R&D units with local or MNC partners;
- Technology alliances with local or MNC partners in emerging economies;
- Outsourcing of basic research components to local universities/research institutes abroad;
- Outsourcing of parts of the innovation to local service providers;
- Outsourcing of complete innovation to service providers.

## 1.3 GLOBAL INNOVATION BY COMPANIES BASED IN EMERGING ECONOMIES

The patterns of MNCs locating their global innovation activities in emerging economies and the local companies in host countries becoming service providers are being accompanied by another new trend. The companies based in emerging economies traditionally competed in their own local markets by manufacturing products based on either adapted or locally improved technologies imported from abroad. In the cases where they exported such products, they mainly went to markets in other developing countries. Their customer base was also different from those of MNCs and other companies from the industrialized world. But since the beginning of 2000, some these emerging-economy companies started developing products and services for the global markets through their own R&D efforts. These innovative products tend to compete for the same customer base of companies from industrialized countries across the globe: (i) either directly competing in the existing markets (e.g., markets for generic drugs); and/or (ii) entering the potential future markets for MNCs (e.g., in the third countries). This new phenomenon has not been studied much as yet.

For instance, a consumer using a scanner or a digital camera anywhere in the world today to convert documents into computer-readable and editable texts is most likely to use software developed by Russian engineers. These devices made by leading manufacturers such as Xerox, Panasonic and Fujitsu contain 'FineReader,' an Optical Character Recognition technology developed by Russia's ABBYY company (Radyuhin 2008, p. OP-ED 11).

According to Mathews (2006, pp. 6–7), some firms from the peripheral (developing) countries, particularly from the Asia Pacific region, have emerged as challengers to traditional MNCs. He calls them 'dragon multinationals.' These are firms that started late and have overcome their disadvantages, such as low resource-base, skills, knowledge, lack of proximity to major markets and social capital that is to be found in regions like Silicon Valley, to emerge as industry leaders. They have succeeded mainly by leveraging their way into global markets through partnerships and joint ventures. The globalization process also includes a countervailing pressure by the periphery on the center, as organizations in the periphery are ready to exploit the new opportunities generated by the creation of global markets. This is easier for them than the firms from the industrialized world that are burdened by existing attitudes that make them treat the world market as their own home market. Firms from emerging economies are also in a relatively better position to exploit certain home-based advantages, such as reserves of engineering talents available at substantially lower cost and low-cost manufacturing infrastructure (Wong and Mathews 2004, p. 2).

Mathews (2006, 7–9) analyzes the entry of developing country firms into the global markets in terms of two waves: (1) the 'first wave' of MNCs from developing countries, studied by researchers such as Kumar and McLeod (1981), Wells (1983) and Lall (1983), successfully competed in the international markets despite the obstacles and the difficulties encountered in their home countries (such as market restrictions and export difficulties). They were 'pre-globalization' success cases, when FDI flows were still small. (2) The 'second wave' of MNCs from developing countries represents a different phenomenon. The causes for the emergence of these MNCs can be found in pull factors that draw firms into global connections, rather than push factors that drove firms as stand-alone players in the first wave. According to Yeung (2000, p. 12), the rise of second wave MNCs from developing countries "is less driven by cost per se, but more by a search for markets and technological innovations to compete successfully in the global economy." These firms are influencing the shape of global market by creating new economic space using their own organizational and strategic innovations (Mathews 2006).

Standard & Poor and *Business Week* developed an index that is made up of 25 of the most innovative listed companies around the globe, and the 'Most Innovative Companies' ranking is an annual survey prepared by *Business Week* in partnership with Boston Consulting Group. In its survey results for 2008, two Indian companies were ranked as being among the 25 Most Innovative Companies around the globe: Tata Group (rank six) for its product innovations and Reliance Industries (rank 19) for its business models. This is the first time any company from the emerging economies made the list (*Business Week* 2008).[2]

Apart from developing the world's cheapest car, Tata Nano (by Tata Motors), which is considered highly innovative, the Tata Group is proving its innovativeness through its other Group companies as well. For instance, the Tata Consultancy Services (TCS), another of the Group's companies, developed a software package, BioSuit, to facilitate drug discovery research that has become a success in the global market, particularly among the start-up biotech companies. Some of the Indian pharmaceutical companies such as Ranbaxy, Dr. Reddy's Laboratories and Arabindo have started developing new chemical entities (NCEs), protected with international (including the US) patents, for diseases ranging from cancer, diabetes and obesity, which usually afflict well-to-do patients. Until a few years ago, these companies were only known for their notorious ability to produce generic drugs through reverse engineering of patented knowledge held by the pharma MNCs.

Brazilian firms such as Embraer and Petrobras are well-known for their global innovations. By turning local engineering excellence into innovation on a global scale, Embraer has become the third-largest aircraft company, focusing on regional jets. Embraer has overtaken Canada's Bombardier to become the world's leading maker of regional jets through its innovations that became superior substitutes to replace traditional, noisy turboprop aircraft with sleeker, faster small jets. By 2006, over 95 percent of its US$3.8 billion sales were outside Brazil. It is one of Brazil's biggest exporters that achieved its success by combining low-cost manufacturing with advanced R&D (*The Economist* 2008). Apart from such giants, even Brazilian start-up companies are involved in global innovation. For instance, in 1999, FK Biotec became the first Brazilian biotechnology company to receive venture capital for the development of its innovative technologies. FK Biotec, which develops, manufactures and markets immunodiagnostic kits, is presently involved with developing vaccines for cancer. The company is developing an experimental vaccine composed of cancer cells that work as medical treatment as they are capable of stimulating the immunological system to fight against cancer (WIPO case study).[3]

Similarly, China's Huawei Technologies, a telecom network systems and solutions provider for both mobile and landline operators, and Lenovo, which bought IBM's PC business and the Haier and Hisense Groups in domestic appliances and consumer electronics are rapidly increasing their share of the global markets through innovative products combined with low-cost manufacturing. Huawei's network products are now used by 35 of the world's top 50 operators, with one billion users. In addition to several R&D centers in China, it has global R&D centers in Bangalore in India, Moscow in Russia, Stockholm in Sweden and Silicon Valley and Dallas in the US. By the end of 2007, Huawei has filed 26,880 patent applications, of which 4,256 were already granted (www.huawei.com). One of the strategies of the Chinese firms has been to leverage brands from local to global. For instance, Hisense, a US$3.3 billion consumer-electronics group, has turned its attention to the wider world with a product range that includes air conditioners, PCs and telecom equipment. It has production facilities in Algeria, Hungary, Iran, Pakistan and South Africa. It sells over 10 million TVs and three million air conditioners a year in more than 40 countries. The home country provides Hisense with a large market as well as a low-cost manufacturing base, to which it adds other competitive advantages such as stylish design and an internationally comparable R&D center. Another emerging economy company, Johnson Electric, based in Hong Kong, now manufactures mainly in China and designs and manufactures tiny electric motors for products such as cameras or cars. As an example, a BMW five series has over 100 tiny motors (of less than one horsepower) to move the wing mirrors, adjust the seats and open the sunroof. Johnson manufactures three million of these motors a day, most of them for export. It now has manufacturing plants in America and Western Europe and R&D centers in Israel, Italy, Japan and America (*The Economist* 2008).

These are not the only global innovators among the companies from emerging economies. There are so many others. For instance, the Czech Republic's Skoda Automobiles (now owned by Volkswagen of Germany) and Tatra Trucks, whose products were once sold among the communist countries, now are making strong inroads into the global markets, with stylish and reliable product, based on in-house R&D. Similarly, South African companies such as SAPPI, a paper and pulp manufacturer, and Sasol, an oil company, are known as innovative companies. For instance, Sasol's technology to convert coal into gas and then gas into fuel is in great demand worldwide. Several countries, including India and even the Gulf countries like Qatar, are entering into partnerships with Sasol for these technologies.

Globalization process has certainly integrated some developing countries into the global innovation networks. However, this is also raising a concern among industrialized countries about losing competitiveness (including jobs) in knowledge-intensive industries. Recent studies in the field of international trade suggest some shifting of relative comparative advantages among trading partners. The study by Gomroy and Baumol (2000) suggests that in a multicountry, multiproduct setting where the trade is based mostly on created comparative advantages and economies of scale, the terms of trade tend to shift among partners. The productivity improvements that arise due to trade among some trading partners may be such that the conventional argument that free trade benefits all countries involved is not necessarily valid. On similar lines, Samuelson (2004), in his study, argued that productivity growth in trading partners (exporting countries) may sometimes 'permanently harm' the trading (importing) country.

Such fears are also reflected in the debate about the emergence of Asian competitors. According to Ernst (2006, p. 5), some scholars underestimate China's rise in the global economy by pointing out that China's share of global GDP in 2005 was only 4.9 percent, and its exports accounted for only 7.3 percent of total global exports. However, whereas the aggregate data shows such a picture, the data on specific sectors such as the electronics industry reveal a totally different scenario. Five Asian countries (China, South Korea, Taiwan, Singapore and Malaysia) together account for more than one-fourth of world electronics manufacturing output, with leading positions in global markets for digital consumer electronics, computers, mobile devices and high-precision components, such as semiconductors and displays. For example, in the semiconductor industry about 70 percent of output is now based in Asia. Furthermore, India has become a global export production base for software. Since 2004, China has displaced the US as the world's largest exporter of electronic products, from its 10th position in 2000. Its export product mix has also changed from commodity-type appliances to digital consumer electronics and mobile telecom equipment.

According to Athreye and Cantwell (2007, p. 210), these concerns about the productivity growth in trading partners are also closely related to the technological catch-up of developing countries. Growth in productivity in developing country trading partners usually starts with transfer of technology from abroad and then proceeds through investments by developing country firms in capability building in distinctive niche areas that reflect the competitive advantages of those countries. The relationship between technological catch-up and their global integration varies with the developmental levels of the countries: (i) in the initial stages of capability building, small firms tend to perform a more prominent independent entrepreneurial role. This initial technological catch-up relies more on indigenous learning activities and less on international links; and (ii) for countries with some basic capabilities, the recent rise in technology trade and the outsourcing of innovation-related activities that has followed the disintegration of value chains have opened up new opportunities. These countries are now able to create new niches for themselves in global technology development without relying on the existing trade and FDI regimes. However, their perspective still does not recognize that some emerging economies have gone beyond confining themselves to the 'niche' areas and are catching up with the MNCs in the mainstream areas of business.

Technologically more advanced countries seem to have greater concerns regarding the knowledge outflows through globalization of R&D.

To address these issues, J. Singh (2007, pp. 765–766) analyzed the US patent data focusing on the 30 technologically advanced countries that together represent 99.5 percent of all patents filed with the USPTO. His findings suggest that knowledge actually flows in both directions, from foreign MNCs to host country organizations as well as from host country organizations to foreign MNCs. On an average, MNCs seem to gain more in terms of knowledge flows from the host country organizations than what flows out from MNCs to the host country. This asymmetry in knowledge flows is reflected not only in the aggregate picture, but also in the case of the large majority of the individual countries. In some countries such as the UK and Belgium, however, the two-way knowledge flows between MNC subsidiaries and host country organizations are almost symmetric. In the case of some other countries, such as Taiwan, South Korea, Sweden, Israel, Finland, Austria, Spain and Hong Kong, knowledge flows from foreign MNCs to host country organizations exceed knowledge inflows to MNCs. The cross-sector differences within countries show that knowledge outflows are greater in sectors where the host country has relatively stronger technological capabilities. Analyzing the data on career histories of patent inventors, Singh indicated that in countries with where MNCs have hired substantially more number of personnel from domestic organizations than they lost to them led to greater knowledge.

## 1.4 OBJECTIVE OF THE STUDY

The objective of this study is to better understand the dynamics of the globalization processes and the emergence of new locations for innovation and its implications. The study develops a conceptual framework of the evolution of globalization of corporate R&D (in terms of waves) and then addresses the following issues: (i) location of innovation activities in emerging economies by MNCs; (ii) the driving forces behind this new trend and the type of R&D being performed; (iii) performance of R&D by companies from emerging economies to develop products for the global markets; and (iv) implications of these new trends for the companies, host countries and home countries of the companies. Whereas the study is carried out in a broader framework of globalization of R&D in general, the focus is on the emerging economies as locations for strategic innovation. For in-depth analysis of the factors underlying the phenomenon, the study focused on the following emerging economies: Brazil, China, India and South Africa.

Ever since Goldman Sachs, the global investment company, coined the term BRICs in 2003 to refer to development prospects of Brazil, Russia, India and China and their potential impact on the global economy, there has been a wide interest among researchers and policymakers worldwide on the happenings in these countries. There is a concern in industrialized countries regarding the potential competition from these countries, while there is interest in the developing world about learning from the experiences of BRIC countries. This study was initially planned as a study of global innovation activities in BRIC countries plus South Africa. But due to constraints of time, case studies of global innovation activities in Russia could not be included in this study.

While the term corporate research and development (R&D) encompasses everything from testing, adaptation, product development for local or regional or global markets to basic research, this study focuses only on innovation activities relating to product development for regional and global markets and corporate basic research. Adaptation and product development for the local market types of innovation activities are excluded from the study.

## 1.5 ORGANIZATION OF THE BOOK

This book is organized into 11 chapters. Chapter 2 discusses the global business environment and the conditions under which the new trends in globalization of corporate R&D are emerging, i.e., the context in which globalization of R&D has come to extend its scope to emerging economies, as well as the opportunities for companies from emerging economies to develop global products and services.

Chapter 3 seeks theoretical explanations for the developments described in Chapters 1 and 2. In the first part of the chapter, the theories of internationalization of production are reviewed to better understand the globalization phenomenon in a broader perspective. In the second part, studies relating to internationalization of R&D are discussed in a historical perspective to bring out the changes in the driving forces over a period of time. In the third part, studies relating to systems of innovation are discussed in the context of globalization. The review also includes the analysis relating to the emergence of a new techno-economic paradigm and catching-up opportunities for latecomers, because the majority of the companies carrying out global R&D seem to be those dealing with new technologies. Furthermore, a conceptual framework has been developed for better understanding of the evolutionary process of globalization of corporate R&D and is set out in the last part of the chapter.

Chapter 4 provides an analysis of the innovation environment in emerging economies. The first section presents an overview of the innovation environment in emerging economies in general. The second section offers a detailed analysis of the national systems of innovation in the case study countries (India, China, Brazil and South Africa). The objective of this chapter is to highlight the aspects of the innovation environment in emerging economies that have the potential to support global innovation activities.

Chapter 5 presents the global innovation activities in India through detailed case studies. These cases include the MNCs, the Indian companies involved in global innovation (including R&D service providers) and Indian research institutes.

Chapter 6 presents the global innovation activities in China through detailed case studies. These cases include the MNCs and the Chinese companies involved in global innovation.

Chapter 7 presents the global innovation activities in Brazil through detailed case studies. These cases include the MNCs as well as the local research institutes involved in global innovation.

Chapter 8 presents the global innovation activities in South Africa through detailed case studies. These cases include the MNCs as well as the local research institutes and companies involved in global innovation.

Chapter 9 draws implications of location of global innovation in emerging economies for the innovation systems of the corporations, the host and the home countries of the companies. The chapter also draws policy implications for host and home countries.

Chapter 10 draws implications of global R&D capabilities in emerging economies for other developing countries and the potential for South-South cooperation in innovation.

Chapter 11 presents summary and conclusions with implications for the theories of international economics/business.

# 2 Global Business Environment

The globalization of corporate R&D by MNCs and the performance of global innovation by companies belonging to emerging economies are taking place in a rapidly changing business environment. Some of these changes are external to the companies but directly affect their internal operations, which in turn add to the volatility of the business environment. This dynamic background is analyzed under four subheadings: (1) global economic changes; (2) science and technology dynamics; (3) implications for corporate operations; and (4) corporate strategic responses to the business environment, which, in turn, influence the business environment.

## 2.1 GLOBAL ECONOMIC CHANGES

Internationalization of business activities is a natural growth process for dynamic companies. The tendency for companies had traditionally been to initially enter into the neighboring markets within the region and then gradually expand to wider markets. Geographical proximity was considered a major determining factor in international trade. By the 1980s, international trade and investment policies were liberalized substantially mainly among industrialized countries and a few Asian newly industrializing economies (NIEs). The economic success achieved by the NIEs, through liberal trade and export-oriented development policies, enhanced the enthusiasm of other developing countries to adopt liberal economic policies. The collapse of the Soviet Union further accelerated this process. These efforts culminated in the formation of the World Trade Organization (WTO) in January 1995. In a sense, with this development, a real global market for business has come to be established, with transparent and standardized regulations. This development, coupled with improved communication and transport infrastructures, has reduced the importance of 'geographical proximity' as a determining factor for international trade and investments. Furthermore, the free trade agreements (FTAs) between regional blocks and countries, as well as the bilateral investment treaties (BITs), have strengthened the regulatory frameworks governing the international trade and investment flows among the signatory countries.

In addition to the liberalization of macro policies on trade and investments, countries worldwide have also adopted better micro policies that directly affect the operations and value creation by companies in specific sectors. Some of the sector-specific policy changes that have a bearing on high-tech sectors include:

- *Enhanced intellectual property (IP) protection:* with minimum global standards; a dispute settlement mechanism; extension of intellectual property rights (IPRs) to a greater variety of products, processes and services;
- *More liberal rules on FDI:* permission for foreign investments across almost all sectors of the economy, including in private health care insurance; mergers and acquisitions (M&As), which are important for ICT, biomedical and financial services companies;
- *Reform of regulations relating to health care products:* standardization of regulations to make them more transparent; permission for early phase clinical trials by foreign companies; adoption of global standards such as good manufacturing practice (GMP) and good clinical practice (GCP);
- *Similarity of health care needs:* growing affluence in emerging economies demands superior medical products; shift from hygiene-related profile toward chronic and lifestyle-related diseases; with growing transport links and movement of people across regions local diseases are becoming global diseases requiring collective response from health authorities worldwide (e.g., emergence and spread of severe acute respiratory syndrome (SARS), avian flu, swine flu, tuberculosis);
- *Growing demand for sophisticated products in emerging economies:* growing income in emerging economies is promoting demand for sophisticated products and services, with advanced features, high quality, safety and reliability as prominent features. However, these consumers demand that all these features be delivered at lower prices than in the developed world. This requires not just adaptation of products from developed markets, but designing and developing totally new products for the emerging markets. The new business model calls for developing 'Emerging Products for Emerging Markets.'

## 2.2 SCIENCE AND TECHNOLOGY DYNAMICS

Since the early 1980s, a number of far-reaching changes have occurred in macro technological systems, which, in turn, are influencing the location of innovation. One such change has been the emergence of new pervasive technologies, in particular, microelectronics, ICT, biotechnology and advanced materials, which are diffusing rapidly through the creation of new products, processes and services leading to productivity improvements and new work practices.[1] Innovation in these technologies requires inputs from a diverse range of scientific and technological disciplines.

According to Chesnais (1988a, pp. 509–510), there are two series of major driving forces explaining why present trends of international sourcing of technology will not be easily reversed: The first series of factors relates to the 'global competition'. In all R&D-intensive industries, and in industries where scale economies are critical, competition now takes place: (a) between a relatively small number of large firms (e.g., oligopolistic); (b) in a geographical area that includes the respective home and host markets of rival MNCs, as well as third markets, within and outside OECD; and (c) through a wide range of means by which firms can gain access to technology and markets, using a "variety of combinations between competition and cooperation" (p. 509). The second series of factors relates to contemporary developments in science and technology (S&T), where the general trend has been that: (a) basic scientific knowledge is playing an increasingly crucial role in major technological advance; (b) many recent major innovations have occurred through cross-fertilization of different scientific disciplines; (c) technology has acquired stronger systemic features. These ongoing paradigmatic changes compel firms to increase in-house R&D, both at home and abroad, and also to acquire knowledge from other organizations, such as universities or firms.

In conjunction with the changes in macro techno-economic conditions, the conditions in the labor market for talented personnel have also been changing, with cost, quality and accessibility implications. The key driving force for globalization of R&D in recent years has been the increasing demand and competition for skilled scientists. The demand for scientists and engineers, and national disparities in the incentives offered to them, has led to reported shortages in several OECD countries as early as in the late 1980s (OECD 1988). The shortages of research personnel are compelling companies to widen their research networks in order to tap more geographically dispersed scientific talent (Doz 1987), such as Israel, Brazil and India.

A more recent study by OECD (2006) indicated that over the last decade the proportion of young people studying science and technology has been decreasing in many European countries. The figures relating to average annual change in the share of S&T students as a percentage of the total number of students during the 1993–2003 period show that in terms of percentage of S&T entrants, the decline ranges from about 0.5 percent per annum in Denmark to about 1.5 percent in The Netherlands and France to nearly two percent in Portugal and Norway. The figures in terms of percentage of S&T graduates shows a decline of about one percent per annum in Portugal to about 2.5 percent in Germany and The Netherlands to over 5 percent in Denmark to about 7 percent in Poland.

Although this problem seems to be more acute in the case of European countries, almost all countries seem to face similar problems to one degree or the other. For instance, with the emergence of ICT industry and its demand for personnel, young people in countries such as India (and China) are now showing more interest in ICT-related engineering subjects rather than pure sciences. In terms of tertiary enrollments in science and engineering, India has traditionally had a science/engineering ratio of 2.4, which is more in line with the Western education system (e.g., Ireland 1.2 and the USUS 1.3). On the other hand, East Asian countries have had a higher preference for engineering subjects, with China's science/engineering ration being 0.3, Japan 0.2 and South Korea 0.3 (figures for 2005) (UNESCO database accessed in December 2008).

Conditions for research and access to resources for carrying out research vary around the world, and therefore, subject to costs involved, relocation of R&D may in the long run improve the competitive position of the company (Sigurdson 1990). These observations of MNCs' behavior are also reflected in the trends of locating R&D in some developing countries, which offer access to resources with required knowledge, at substantially lower costs compared to industrialized countries (Reddy 2000).

Furthermore, S&T dynamics facilitated division of the whole innovation process into modules (activities) and/or submodules (subactivities), enabling dispersed location of different activities/subactivities and performance of these tasks by different organizations. With the pervasive influence of new technologies and their integration into traditional products, this phenomenon of divisibility of innovation process is now extended to even traditional industries such as the electrical and mechanical engineering industries.

### 2.2.1 Divisibility/Modularization of Innovation Processes

The emergence of new generic technologies is also affecting the operations of MNCs, first, by increasing the need for global sourcing of technologies, and second, by facilitating such globalization of technology development activities. In new science-based technologies the R&D need not necessarily be located in proximity to the manufacturing site or the market. This flexibility of new technologies (delinking from manufacturing) allows the R&D to be performed in locations of proximity to pools of research personnel and knowledge centers (Reddy 1997).

Further technological developments facilitated division of the whole innovation process into modules (activities) and/or submodules (subactivities), enabling dispersed location of different activities/subactivities and performance of these tasks by different organizations. This divisibility of innovation processes, which has been mainly prevalent in new science-based technologies such as electronics and biotechnology, is now extended to even traditional industries such as the electrical and mechanical engineering industries.

This new dynamics of innovation is also affecting the industry structure. Previously, innovation process required large resources, long time periods and vast accumulation of knowledge, favoring large firms as they controlled the necessary resources. But, with the divisibility of innovation processes, new innovative small firms specialized in particular modules/parts of the innovation are emerging, and several of them are directly or indirectly (e.g., in niche markets) competing with the incumbent large firms.

In the economic literature, the theories of industrial organization, such as resource-based and dynamic capabilities approaches proposed by Penrose (1995) and Chandler (1977) explained the rise of the large vertically integrated manufacturing firm and the performance of industrial R&D during the 20th century within the large manufacturing firms (Mowery, 1983). However, the dynamics of S&T further led to a technological convergence in manufacturing processes, enabling specialist suppliers to emerge in specific areas of the value chain through significant innovation activities of their own, including contract research, especially in materials analysis and testing, production of measurement and control instruments and computer-aided-design and manufacture (Landau and Rosenberg 1992). In recent years, with the extension of technological convergence extending to product technology, vertical disintegration of value chain has gone beyond the manufacturing processes and into the development of components and subsystems for complex products. The large integrated firms that traditionally designed these products sought to increase their flexibility and profits by relying on suppliers to deliver innovative components/parts based on suppliers' own R&D in technology areas that do not constitute the core competence of the contracting firms (Brusoni et al. 2001). More recently, the growing technological flexibility to delink product design from production, the modularization of the production itself and the rapid growth of contract manufacturing in several high-tech industries led to announcements of the emergence of a 'new model of industrial organization' based on modular production networks (Sturgeon 2002; Langlois 2003).

### *Drug Discovery and Development Process*

Conventional pharmaceutical industry is based on chemistry, with pharmacology and clinical sciences as supporting tools for drug development. In recent years, the emergence of molecular biology and, in particular, of genomic sciences, is having a great influence on drug discovery. These developments also demand a wider knowledge base incorporating several disciplines, which is beyond the capacity of an individual company. Evolving technological development made the innovation process in biomedical technologies more modular and even submodular in character, enabling firms to outsource some activities or subactivities to other specialized firms and universities worldwide.

The drug discovery process starts with 'target identification', i.e., identifying which molecule or protein in the body is responsible for causing a particular disease (considered to be a core competence). Next step is the 'screening of a library of compounds' against a molecular (or now protein) target to find properties that may have the potential to be developed as a medicine for a disease. Due to the technological progress, this initial screening is presently carried out in tissue culture instead of in animals. A large number of hypothetical targets are incorporated into in vitro or cell-based assays and exposed to a variety of compounds representing numerous variations on a few chemical themes or, as in more recent times, fewer variations on a larger number of themes in high-throughput configurations (Drews 2000, p. 1962). In the second stage, this 'lead compound' is subjected to further tests in animals. These tests include the performance of the drug in animals (animal efficacy), the absorption levels in the body and its effective delivery to the targeted tissue/molecule (bioavailability), poisonous content (toxicology), side effects (safety studies) and drug metabolism in the body and the duration of its stay in the body (pharmacokinetics). In the third stage, after successful completion of tests on animals, clinical trials on human beings are carried out initially on a small group of healthy volunteers to test its safety (phase I). Once the compound is proved to be safe in human beings, the efficacy tests (to make sure that the drug does what it is supposed to do) are carried out on a small group of patients (phase II) and then on larger groups of patients (phase III). The final phase involves getting approval of the regulatory authorities. Drugs may even undergo postapproval (phase IV) trials to extend the range of conditions under which the drug can be used and/or to reformulate the drug to improve its efficiency.

Until recently such a rigorous, lengthy and costly innovation process favored large companies. Therefore, successful pharmaceutical companies tended to be large, vertically integrated firms. They carried out everything from building up libraries of compounds to marketing the final product themselves. In recent years, the tools of pharmaceutical innovation have been changing, eroding the advantage of the large companies (pharmaceutical giants) in drug discovery. Companies that specialize in individual stages of drug discovery, i.e., from creating libraries to obtaining regulatory approval, are fast emerging. As result, the large pharmaceutical companies are increasingly outsourcing parts of the innovation process.

Figure 2.1 indicates the emerging biopharmaceutical drug discovery process. The main difference from the previous pharmaceutical value chain is the emergence of innovative specialized small biotechnology firms with new technology platforms at every stage of the value chain, either as R&D service providers or technology sellers.

Once the target molecule is identified, the libraries of compounds are screened to find a suitable molecule that can bring about necessary chemical changes in the target. The success, to a large extent, depends on the size of the libraries. Previously only large pharmaceutical companies could afford these libraries of a few hundred thousand compounds. But, now the new technology, in the form of *combinatorial chemistry (through microtiter plates),*

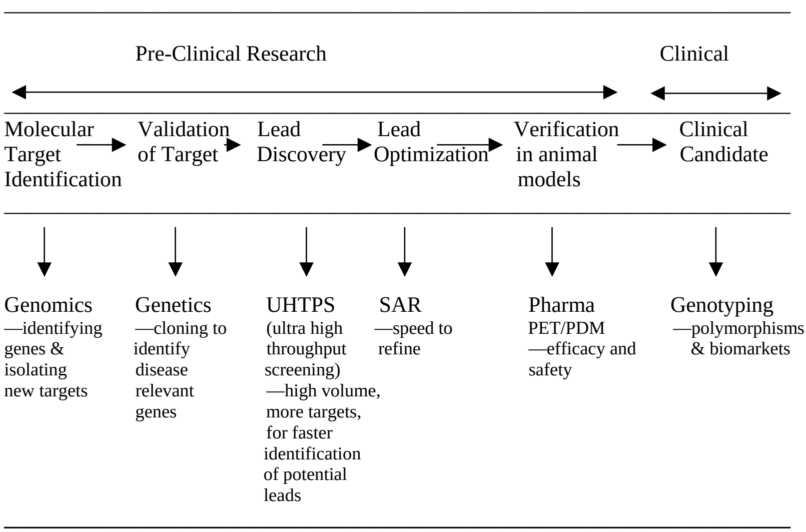


*Figure 2.1* Drug discovery and development process.
*Source*: Adapted from Bowonder et al. (2003).

opened up new opportunities for smaller players. This technology treats all but the smallest organic molecules as consisting of modules, which can be put together in several different combinations, generating a large number of molecules from a small number of modules. In the past a chemist could only create about 50 to 100 new compounds a year. Now, with combinatorial chemistry one can create about a couple of thousand new molecules a year, and the advanced versions of this technology even permit creation of up to 50,000 new compounds a year.

Small companies such as AxyS Pharmaceuticals, US, which focuses on drugs that affect the action of protease enzymes, have been able to generate their own libraries with the help of combinatorial chemistry. AxyS created a library of about 200,000 compounds. Similarly, there are also specialist combinatorial chemistry firms offering on hire their libraries of compounds. For example, Pharmacopeia, US, is one such specialist company. Even the screening of these large libraries is now done through a new technology called *high-throughput screening*. This new technology allows screening of over one million compounds against a single target protein. In the emerging method of combinatorial chemistry, the reactions will take place in a *silicon chip* (rather than in the microtiter plates) through simulations on computers creating virtual laboratories. After the promising molecules and their structure are identified through simulations, the chemists will perform the actual drug development activities. For instance, Agouron Vertex, US, designed, and launched, in 1997, the drug 'Viracept,' an HIV-protease inhibitor through this method, and the entire drug development process took only six years, which is about half the industry average (*The Economist* 1998, pp. 12–13).

After a lead compound is identified, the animal tests will indicate the modifications to be made in the molecular structure. These preclinical trials are not very expensive but are time-consuming. There are also other pressures on the companies to reduce the animal testing (e. g., animal protection groups). So new technologies are gradually emerging in this stage of the drug discovery process. A number of small outsourcing service providers have emerged in this stage of the drug discovery value chain.

Clinical trials are the next stage of drug discovery. This stage is the most expensive and time-consuming. Now, specialized contract research organizations (CROs) have emerged to perform this process. With regulations becoming tighter, the clinical trials are becoming difficult to handle for pharmaceutical companies themselves. For instance, up to the early 1990s, the number of trials required for approval in the USUS was 40; now the number is 60. Drug companies prefer to conduct simultaneous trials among a variety of ethnic groups of patients and in wider geographical areas. Quintiles and Covance, both USUS-based MNCs, are well-known CROs specializing in clinical trials. What CROs do is basically efficient management of the trials. For instance, Covance's software helps in making decisions on the trials to be continued by gathering biochemical assay data from patients faster. It also helps in determining the number and the size of trials that will be needed to test the drug to an appropriate level of rigor.

### *Semiconductor Chip Design and Development Process*

Chip design activities typically consist of routine functions (i.e., design implementation) and conceptualization through stages of design (i.e., system specification). The design has become more complex "in terms of (1) the linewidth of process technology, measured in nanometers; (2) the use of analog and mixed-signal design, which are substantially more complex than digital design; (3) the share and type of system-level design, such as system-on-chip, system-in package, structured Application Specific Integrated Chips (ASICs); and (4) the number of gates used in these designs" (Ernst 2006, p. 24).

The semiconductor chip design process is becoming increasingly complex, mainly due to two factors: (1) progress in manufacturing technology (miniaturization) has made it possible to fabricate millions of transistors on a single chip. This requires to be matched by significant improvement in design productivity; and (2) the convergence of digital computing, communication and consumer devices has increased the complexity of design process for electronic systems, which need to be increasingly smaller, faster, cheaper and more energy efficient, but at the same time support growing multifunctionality. At the same time companies face pressures to speed up time-to-market due to rapidly shortening product life cycles (ITRS 2004).

The complexity for chip design itself basically arises from two sources: (1) silicon used on the chip; and (2) integration of the system. The 'silicon complexity' arises from the malfunctions that may result from the growing density of the circuit and the use of new materials or design architectures.

The 'system complexity' arises from the increasing number of functions that need to be integrated on the chip (e.g., smart phones). As a result of this growing design complexity, verification of the design for yield and performance becomes critical, accounting for about 60 to 70 percent of all system-on-chip hardware design, with cost and time implications (ITRS 2002, pp. 82–83).

Until the mid-1980s, the system companies and the device manufacturers carried out almost all their semiconductor chip design by themselves in-house. But, technological development since then resulted in vertical specialization enabling firms to disintegrate the design process into activities and subactivities and disperse it geographically (see Figure 2.2). Since the beginning of the 1990s, vertical specialization within design networks has

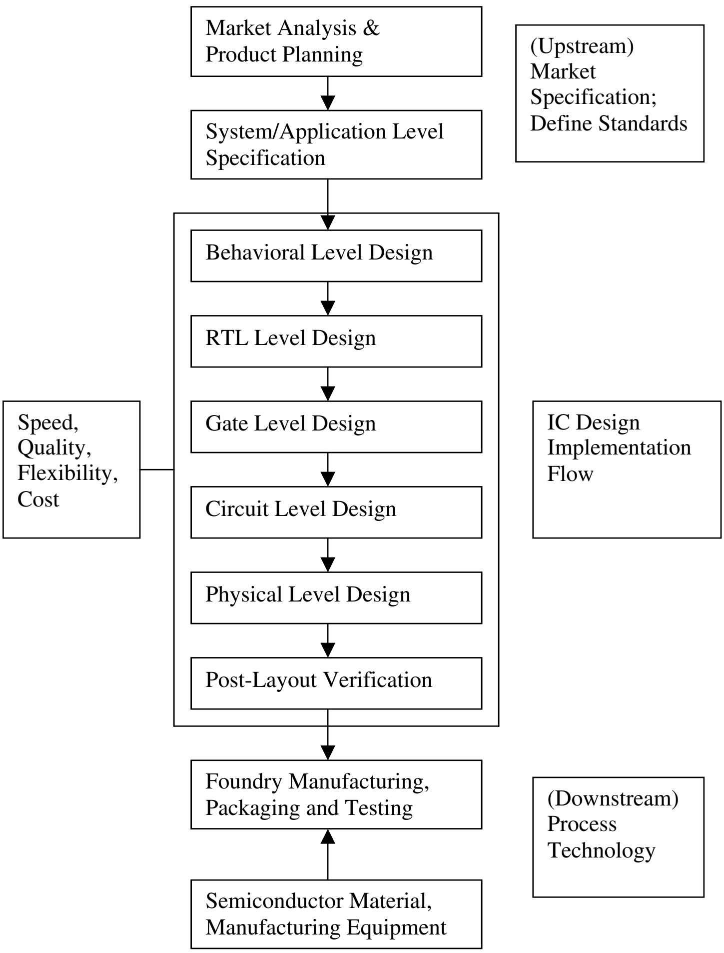


*Figure 2.2* Chip design flow chart.

*Source*: Adapted from Ernst (2005b).

transformed the semiconductor industry structure, just as in the case of the biomedical industry. Now the design of a typical system-on-chip requires interfaces with at least six types: system designers, silicon intellectual property providers, software developers, verification teams, electronic design automation tool vendors and foundry services (fabrication), who are geographically spread across the world (Ernst 2005a).

### *Product Design and Development Process in Engineering Industry*

With the technological developments, the divisibility of innovation process and geographically dispersed division of labor is not confined only to science-based technologies, but is now extended to even conventional industries that require long industrial experience and accumulated knowledge, as they contain a large component of 'tacit knowledge.' Engineering services perform those functions that deal with or are related to the core engineering processes. There is a distinction between engineering functions and engineering service functions. For instance, an engineering function involves manufacturing of an auto engine, but a related engineering service function deals with the designing of that engine. At a broader level, the following steps are involved in engineering product design and development:

1. Idea phase—Identification of a problem or an idea (e.g., a new model automobile);
2. Design phase—Analysis of the idea or problem and design of solutions to meet the requirement, under certain guidelines;
3. Test phase—Application of the design to a model test. This occurs frequently with the product design and development;
4. Manufacturing phase—Supervision of the manufacturing processes or improvements to a plant, operating system;
5. Product completion or production—Service provider may simply hand product over to the client (i.e., electrical device), may sell product (i.e., scientific instrument), may actually operate the product (i.e., power plant), or may teach the operation to the user (Simpson 2004).

Engineering design services are complex as they revolve around technical skills, domain expertise and good engineering judgment. A wide range of engineering services has been outsourced for many years, but most of these outsourcing assignments have been with onshore or near-shore partners/vendors. Offshore outsourcing of engineering services, which are part of the innovation, is a relatively new phenomenon, and only a small subset of activities are currently being offshored, e.g., computer-aided-design (CAD) for a range of design-intensive industries; automobile and other product designing, testing and analysis of the products for various parameters and characteristics. In recent years, some service providers have begun to make a mark by successfully using the skill sets, tools and experience from IT software and services, to evolve from providing basic data conversion, through 2D and 3D CAD/computer-aided-manufacturing (CAM)/computer-aided-engineering (CAE) to advanced simulation, prototyping, testing, product design (engineering), process engineering, plant automation and asset management services.[2]

Some of the innovation activities and/or subactivities that are now being outsourced and/or offshored in aerospace and automotive industries are indicated below:

*Aerospace*

- *Aero structures:* Concept to component solutions in areas like fuselage, wing, empennage, vertical tail plane and stabilizers, secondary structures (doors, latches);
- *Aero engines and derivatives:* Concept design to product realization and support for the entire life cycle of aero engines and derivatives including all major subsystems/accessories;
- *Aero systems:* Offerings across the product life cycle for aero systems and various subsystems, including interiors, hydraulic systems, landing gear, electrical systems and fuel systems;
- *Avionics:* Complete system solutions across the spectrum of civil and military avionics for aerospace prime suppliers/OEM, defense majors, covering safety and mission-control software, hardware, firmware and electronics manufacturing;
- *Technical publication services:* Technical writing, illustrations and animations based on aerospace domain knowledge and experience;
- *Radio frequency identification (RFID):* Solutions for effective supply chain management with real-time and accurate information.[3]

***Automotive Industry***

- *Automotive engineering design:* Product design and development for Body-In-White (BIW), chassis, power train and driveline. Testing and analysis for thermal management, engine simulation, vehicle crashworthiness, fatigue and durability analysis, meshing, plastic design and mold design validation;
- *Automotive electronics and embedded systems:* Vehicle electronics, diagnostics, safety and security for areas like On Board Diagnostics (OBD), emission certification, air bag controls, seat belt controls and remote keyless entry systems; infotainment solutions for navigation, in-car entertainment and communication; communications protocols; verification and validation;
- *Automotive shop floor services:* Digital manufacturing services for power train, BIW, paint shop; control systems solutions for press, body shop, paint shop, assembly, material handling and production control;

- Automotive manufacturing solutions: Manufacturing Execution System (MES); adaptive manufacturing;
- *Engineering IT for automotive industry:* Knowledge-based Engineering (KBE); vehicle tracking system.

## 2.3 IMPLICATIONS FOR CORPORATE OPERATIONS

### 2.3.1 Global Competition

The first and foremost impact of the global techno-economic changes, discussed earlier, on the corporate operations has been reflected in the increased 'global competition' that companies are facing. Since the 1980s, global competition, in several industries, has been intensifying rapidly, mounting pressure on the profitability and survival of the companies. The characteristic features of the internationalization process have been considerably affected mainly due to two factors: the deregulation of economies both for FDI and portfolio investments; the emergence of new technologies that enabled as well as compelled moves toward increased globalization.

The ongoing processes of economic liberalization and technological changes, as Porter (1986) predicted, are leading to growing international competition and widespread globalization of industry scope:

- *Growing similarity of countries*. Countries are becoming similar in terms of availability of infrastructure, distribution channels and marketing approaches. Similar products and brands are being marketed worldwide, reflecting the convergence of customer needs in different countries. The economic differences among developed countries and some emerging economies are narrowing in areas like income, factor costs and energy costs. Part of the reason for this development is the aggressiveness of MNCs in diffusing technologies around the world.
- *Falling trade barriers*. Successive rounds of international agreements resulting in the establishment of the WTO led to the lowering of tariff levels and other trade barriers. Regional economic groupings such as the European Union (EU), North American Free Trade Area (NAFTA) and Association of South East Asian Nations (ASEAN) are also facilitating trade and other relations among different countries.
- *Emergence of new large-scale markets*. Traditionally the USUS has been the strategic market for global competition because of its large size. But with the liberalization of economies in countries such as China, India and Russia, they are emerging as huge markets with a number of implications. With these countries' control of access to their markets, their domestic firms may become major global players. Therefore, gaining access to these markets may become a crucial

strategic factor in the future because of the scale economies it provides to the successful firm.

- *Technological restructuring.* Several industries have been significantly affected by some technological revolutions, such as microelectronics, information systems and advanced new materials that are reshaping competition. These technological developments are redefining industry structures and opening up unprecedented opportunities for shifts in industry leadership in international markets.
- *Emergence of new global competitors.* The forces leading to dramatic shifts in international competitive positions have resulted in some new firms, mainly from East Asia, establishing themselves as fully fledged international competitors within the space of a decade. These new players have exploited the new competitive conditions and the cross-cutting technological changes to leapfrog even well-established rivals. The intensity of competition has also risen, setting higher standards for success.

According to Levitt (1983), technological developments over the last few decades have combined to create a unified marketplace in which companies must capture global-scale economies to remain competitive. He argued that the world's needs and preferences had become homogenized, leading to the standardization of products, manufacturing and trade. If the artificial trade barriers were removed, the global reach would be greater.[4]

In many industries, radical technological innovations also brought changes in industry economics and allowed companies to develop and manufacture products on a global basis, e.g., quartz technology has transformed watchmaking into a scale-intensive global industry. In some industries that were not affected by external forces of change, companies started attempting to achieve global economies, by rationalizing their product lines, standardizing parts and specializing their manufacturing operations. Such internal rationalization of operations led to a second wave of globalization in a range of industries such as automobiles, construction equipment and machine tools (Bartlett and Ghoshal 1991).

Over the past decade, such forces have also been increasing the need for worldwide learning and innovation. In a period of rapidly changing technology and shortening product life cycles, a company's ability to develop and diffuse successful innovations has become a key competitive strength. Companies are increasingly recognizing the importance of internationally diversified inputs into the R&D process.

> Coupled with the convergence of consumer preferences worldwide, the diffusion of technology has significantly influenced both the pace and the locus of innovation. No longer can U.S-based companies assume, as they often did in the decades just after World War II, that their domestic environment provides them with the most sophisticated

> consumers and the most advanced technological capabilities, and thus the most innovative environment in the world. Today, the newest consumer trend or market need can emerge in Australia or Italy, and the latest technologies may be located in Japan or Sweden. Companies see that they can gain competitive advantage by sensing needs in one country, responding with capabilities located in a second, and diffusing the resulting innovation to markets around the globe. (Bartlett and Ghoshal 1991, p. 12)

Bhattacharya and Michael (2008), Boston Consulting Group, studied the rapidly developing economies (RDEs)-based companies that are 'staying home' and dominating their domestic markets by adopting innovative business models. The issue of how to compete with these innovative companies in their own domestic markets has become a challenge for many of the global MNCs. For instance, in Brazil, TOTVS is the leader in enterprise resource planning (ERP) software and a significant competitor to global leader SAP. Brazilian companies using TOTVS software also tend to use computers manufactured by Grupo Positivo, Brazil's leading computer manufacturer, which has a larger local market share than the MNCs Hewlett-Packard and Dell combined. Interestingly, 10 of the 50 companies on Boston Consulting Group (BCG)'s list cater to the poorer segments of the population that most companies tend ignore altogether. In this respect, companies from India lead the trend, demonstrating that companies can be profitable even while catering to the poorer market segments provided they use the right business model. For instance, Titan Industries produces more than seven million watches a year, and its number one seller, the Sonata brand, sells for less than $25, comes with a one-year warranty, and the watches are water-resistant. Titan's success comes from understanding that just because people have limited purchasing power does not mean that they would like to sacrifice quality or style. Before Titan came into the market, the only watches that were available at the low end were of poor quality, without warranties and service networks. The Sonata brand is very popular, selling more than three million units a year. Titan also produces solid gold watches that sell for more than $1,000, and it also claims to have produced the world's thinnest watch (Bhattacharya and Michael 2008, p. 13).

Prior to the 1980s, much of the internationalization of corporate R&D was confined to the industrialized countries, which have more or less similar technological strengths and cost structures. However, since the mid-1980s, some MNCs started locating some of their globally strategic R&D outside the industrialized world. Developing countries such as India and Singapore and transition economies such as Russia and Hungary were the initial locations that attracted such R&D-related FDI. By the onset of the new millennium 2000, this development became an established trend, with MNCs locating strategic innovation activities in emerging economies that include India, China, Russia, Hungary, Poland and the Czech Republic.

Such relocation of R&D is taking place, not only through FDI, but also through technological alliances and outsourcing to companies and research institutes outside the industrialized world.

Friedman (2006) argues that the techno-economic forces have flattened the earth or compressed the globe, leading to a blurred distinction between the developing and developed world, and compelling as well as enabling companies to access inputs for innovation from across the globe, including the emerging economies. He identified 10 such forces that emerged in progressive phases:

1. The New Age of Creativity: When the Walls Came Down and the Windows Went Up—End of the Cold War and Liberalization of Economies Worldwide;
2. The New Age of Connectivity: When the Web Went Around and Netscape Went Public;
3. Work Flow Software;
4. Uploading: Harnessing the Power of Communities;
5. Outsourcing: Y2K;
6. Offshoring: Running with Gazelles, Eating with Lions;
7. Supply-Chaining: Eating Sushi in Arkansas;
8. Insourcing: What the Guys in Funny Brown Shorts Are Really Doing
9. In-forming: Google, Yahoo!, MSN Web Search;
10. The Steroids: Digital, Mobile, Personal and Virtual.

## 2.4 CORPORATE STRATEGIC RESPONSES

The changing pattern of global competition, coupled with rapid technological changes leading to the shortening of product life cycles, placed innovation as a key source of competitive strength. Companies are adopting a variety of strategies to attain this technological edge and thus maintain their competitiveness. As a result, MNCs are increasingly transcending national boundaries, not just in marketing and production activities, but also in R&D activities. R&D, the cornerstone of technological and thereby competitive strength of companies as well as nations, is becoming an international activity (Reddy 2000).

The conventional concept of 'comparative advantage' is viewed as a rising from differences in factor cost or quality among countries, leading to production in locations with advantages in a specific industry and export of these products to other countries. Hence, the comparative advantage is expected to be derived from the location where firms perform their activities. Unlike the conventional views that confine comparative advantage issues to production activities, the concept applies also to other activities in the value chain, such as R&D and distribution. Comparative advantage becomes specific to the activity and not the location of the entire value chain. The manufacture of components may be located in Taiwan, software development may be located in India and basic R&D may be performed in the USUS. Such intrafirm international specialization and arbitrage of activities are made possible by the growing ability to coordinate and configure globally (Porter 1986).

In a parallel development, the R&D activities in new technologies are increasingly becoming science-based. In the generation of new technologies there is now a greater need for inputs from different disciplines of S&T. This requirement for innovation is compelling firms to source technologies, not only by geographically dispersing in-house R&D worldwide, but also externally from universities and other firms, both at home and abroad.[5]

In a study of Norwegian firms, Narula (2002) analyzed the propensity of firms to concentrate R&D activities at home or extend such activities abroad using the systems of innovation (SI) approach. According to him, the firm's tendency to keep R&D in the home country, which he calls 'R&D inertia,' is linked to the structural inertia of the national systems of innovation (NSI), resulting in 'systemic lock-in,' which could pose challenges when the existing NSI may not be able to respond adequately when new discontinuous technologies emerge. Firms can use a 'voice' strategy in attempting to modify the appropriate institutions in the existing NSI or an 'exit' strategy by seeking alternative sources of innovation, which more closely fit their needs (p. 795).

According to Cantwell (1992, p. 77), MNCs adopt an internationally integrated approach to technology development for two reasons: (1) to take advantage of the distinct features of innovations in different national innovation systems and thus gain access to complementary technologies; (2) to gain access to new lines of innovation. The blurring of boundaries between different disciplines is compelling firms to access a broader technology base through an international strategy.

### 2.4.1 Rationalization of Global Corporate Structures

In the face of changing currents in the global competition, companies have been rationalizing their activities, including those of production and R&D activities. Prominent among such rationalization efforts has been the alteration of the earlier 'multidomestic' approach, in which MNCs established subsidiaries that were more or less replicas of the parent but on a much smaller scale. These subsidiaries produced products mainly for the local markets in their respective host countries. Such subsidiaries mainly depended on the parent company for their technology requirements, which were in turn adapted to suit the local conditions. These subsidiaries produced most, if not all, of the product range of the parent. However, the subsidiaries, being small in size, often had difficulties in reaching the optimal scale of production (Pearce 1989).

According to Porter (1986, pp. 17–19), the pattern of global competition is different for different industries. In their competitive scope industries fall into a spectrum from 'multidomestic' to 'global.' (1) In multidomestic industries, the competition occurs on a country-by-country basis. MNC makes a one-time transfer of know-how, which is adapted to the local conditions. In multidomestic industry, MNC manages its international activities like a portfolio, because its strategy in a country is largely determined by the competitive conditions in that country. Therefore, each subsidiary is allowed substantial autonomy and control of all the important activities needed to do business in that industry. Industries in which this pattern of competition is prevalent include retailing, consumer packaged goods, distribution, finance and chemicals. (2) In global industry, on the other hand, a company's competitive position in one country is significantly affected by its position in other countries or vice versa. The global industry is a series of linked domestic industries in which the rivals compete with one another on a worldwide basis. In global industry, a company must find ways to integrate its activities on a worldwide basis to capture the linkages among countries. In global competition a company has to perform some activities in each of the countries in which it competes. This type of competition is seen in industries that include commercial aircraft, TV sets, semiconductors and automobiles. Companies are increasingly moving away from the multidomestic approach toward a new approach in which each subsidiary forms an integral part of the global strategy, where subsidiaries are assigned specialized tasks in the activities planned and organized from the center.

Bartlett and Ghoshal (1991, pp. 48–53) also have a similar categorization of the organizational approaches of MNCs: 'multinational,' 'international' and 'global.' Companies are rapidly moving from all these approaches toward what they call a 'transnational' approach. In a transnational approach the strength of the configuration comes from its fundamental characteristics: dispersion, specialization and interdependence. The ability to sense diverse market needs, technological trends and competitive actions remains crucial, however, because such stimuli represent an important source of innovation. A dispersed configuration allows MNCs to capitalize on factor cost differentials. They not only have access to low-cost labor and materials, but also can tap into an international pool of increasingly scarce technological and managerial resources. By specializing operations and giving them a broader mandate, MNCs can capture minimum-scale efficiencies and yet retain a dispersed structure. The viability of this approach has been greatly enhanced by the latest generation of technologies.

One version of a rationalized structure of an MNC is what Pearce (1989, pp. 119–121) calls 'rationalized product subsidiary.' In this type of structure, an individual subsidiary is assigned the task of producing only a part of the parent's product line, which perhaps is not even relevant to the host country's domestic market. Such output is mainly meant for export markets, whereas part of the local demand not catered to by the subsidiary's production will be met through imports from the company's global network. Such specialization allows achievement of a greater level of efficiency and optimal scale economies. A common form of such a rationalized structure involves subsidiaries specializing in the production of specific components or parts for final products or executing a specific stage in a vertically integrated production process. R&D in rationalized product subsidiaries relates to the range of specialized products produced by the subsidiary. Such R&D being part of the global strategy, the results will be shared with the other partners in the network.

Another form of subsidiary that is emerging is what is termed ‘world product mandate subsidiary’ (Poynter and Rugman 1982; Bonin and Perron 1986). In this form, the parent assigns exclusively to a subsidiary the entire responsibility for R&D and production activities for a particular product to be marketed worldwide, either by the affiliate itself or with the help of the parent’s global network. In other words the subsidiary becomes the international center for that product. In its product development activities, the subsidiary may also draw from the basic research of the group.

In their efforts to rationalize their global activities, MNCs are locating even higher-order activities such as R&D in some developing countries that have the required resources. Earlier location of such higher-order activities was confined to the industrialized countries (Reddy 1993). A truly global approach may require the company to locate production or R&D facilities in other countries to take advantage of lower wage rates, to gain market access or to take advantage of foreign technology (Porter 1986). Apart from upgrading the operations of their affiliates in developing countries, in industries where R&D activities can be geographically de-linked from production activities, MNCs are also establishing standalone R&D affiliates, subcontracting/outsourcing R&D to local firms or research institutes and sponsoring basic research in universities in developing countries (Reddy 1997).

The main factors providing economic justifications for enhanced R&D in developing economies today are: (1) the recognition that they are themselves growing markets for advanced products; and (2) their ability to produce advanced manufactured products for export in global markets. There are large reserves of scientists and engineers in the developing world. With the extensive facilities created by MNCs through FDI over the last decade, many S&T personnel in the developing world are exposed to the requirements for competitiveness in world trade (Fusfeld 1995).

In an effort to analyze the level of R&D performed in emerging economies and to gauge its distance from the world-frontier, Amsden and Tschang (2003) suggest a new classification of R&D activities. It consists of two aspects: the actual types of R&D categories, and the complexity characteristics of those categories. They identified five types of R&D: pure science (uncover new scientific principle); basic research (uncover new scientific principle, but with applications that are unknown or diffuse); applied research (transform, variegate and reapply known concept for new application); exploratory development (implement concept as engineered system); and advanced development (reduce costs, uncertainties of manufacturing). According to them, in the case of industrialized countries who are at the world frontier, the core issue is how to make conceptual knowledge more market-oriented or how to move from pure science and basic research to more applied and developmental work. In contrast, the problem in developing countries is how to move from advanced or exploratory development, focused on manufacturability and material substitution, to the generation of at least a differentiated product through better design. Using cases from Singapore, Amsden and Tschang suggest that moving into applied research is a major hurdle for a latecomer to industrialization, as the techniques used in applied research tend to involve more science and engineering. Overcoming this hurdle is a major challenge to emerging economies wishing to integrate into global R&D networks.

In addition to rationalization of their internal operations, MNCs are also linking up with other firms/organizations for their innovation requirements through technology alliances.

### 2.4.2 Global Interorganizational Strategic Alliances

As part of the phenomenon of globalization of corporate R&D, interorganizational technology cooperation is becoming an important element worldwide. Such cooperation or alliance exists not only between the firms, but also between the firms and academic establishments. Interfirm cooperation as such is not a new phenomenon. Joint ventures between firms have been in existence for many decades. However, since the 1980s the number and the variety of forms of interfirm alliances grew significantly.

Teece (1992, pp. 19–20) defines a strategic alliance as a web of agreements whereby two or more partners share the commitment to reach a common goal by pooling their resources together and coordinating their activities. A strategic alliance denotes some degree of strategic and operational coordination. Such agreements take a variety of forms ranging from non-equity agreements associated with one-way or two-way licensing, through to joint venture agreements, equity participation or consortium. The activities range from pre-competitive, basic research agreements to competitive R&D and technology cooperation, manufacturing and marketing, i.e., covering the whole range of R&D to commercialization process (Chesnais 1988b).

According to Mytelka (1990), these interfirm cooperative agreements in R&D are distinct from traditional modes of joint venture and licensing because these new forms of agreement (a) focus on knowledge production and sharing in contrast with one-way transfer of technology. Knowledge in this context includes R&D, design, engineering, marketing and management capabilities. (b) There is little or no equity involvement by participants and (c) such partnerships are a part of the long-term strategy of the firms rather than an opportunistic response to short-term financial gains.

Mowery (1992, p. 211) defines international collaborative venture as "interfirm collaboration in product development, manufacture, or marketing that spans national boundaries, is not based on arm's-length market transactions and includes substantial and continual contributions by partners of capital, technology, or other assets." He distinguishes between four types of technology-focused collaborative agreements: (1) those involving collaboration among firms in research alone; (2) those relating to the exchange of 'proven' technologies within a single product line or across multiple products, e.g., most widely in practice as cross-licensing in global microelectronics industry; (3) joint development of one or more products, e.g., common in commercial aircraft and engines, telecommunications, microelectronics and biotechnology; (4) collaboration across different functions, with one firm providing a new product or process for marketing, manufacture or application in a foreign market by another.

According to Hagedoorn and Schakenraad (1989), the reasons for technology cooperation agreements between firms include: the extremely high costs and risks of R&D in high-tech industries; quick pre-emption strategies on a world scale, even at the cost of loss of potential monopoly profits; technology transfer and complementarity; exploration of new markets and market niches; reducing the time lag between discovery and market introduction; monitoring the evolution of technologies and opportunities.

Broadly speaking there are two schools of thought that analyze firm behavior, competitive strategy and the inter-firm collaboration—(1) the 'competitive forces' (Porter 1980) analysis of firm strategy in which a firm's performance is mainly dependent on the structure of the industry within which it operates, such as the five forces: entry barriers, substitutes, bargaining power of suppliers and buyers and intraindustry rivalry. The key determinants of a firm's behavior, including its decision to form alliances with other firms are molded by the external forces rather than on the firm's internal managerial, technical, marketing and other resources. (2) On the other hand, the 'resource-based' analysis of the firm treats the firm as a collection of 'sticky and difficult-to-imitate' resources and capabilities. These resources may be physical, such as product designs and production processes, or intangible, such as brand equity. They include knowledge of specific markets or user needs, decision-making process or management systems and complex networks for marketing and distribution of products (Mowery et al. 1998, p. 508). The sale or acquisition of such resources through arm's length market transactions is difficult to organize and vulnerable to high risks of failure (Teece 1982). In the resource-based framework interfirm alliances are seen as mechanisms designed to combine the features of both markets and intrafirm organization and thus facilitate firms' access to these capabilities (Kogut 1988; Hamel 1991).

### 2.4.3 Outsourcing and/or Offshoring of R&D Activities to Emerging Economies

As companies seek sophisticated services of higher value from outside suppliers either for cost or resource flexibility and/or improving the time-to-market, innovation has become a prime candidate for offshoring/outsourcing. Traditional theories of internationalization of business say that companies don't outsource the core activities or competences that distinguish them from competitors. But what constitute core activities or competences keep changing with technological progress and economic development. Consequently, innovation activities are becoming global, with pockets of technological expertise available at competitive costs in Asia, Eastern Europe and even Africa. Companies are reconfiguring their processes and 'innovation footprint' (the physical network of operations) to take advantage of such new opportunities (Dehoff and Sehgal 2007, p. 1).

Location of global R&D activities in emerging economies is facilitated by the following factors: first, availability of large pools of qualified scientists and engineers in emerging economies. In comparison to industrialized countries, the availability of research personnel in fields such as ICT, biotechnology and chemistry that are particularly relevant to the globalizing companies is larger in emerging economies, mainly because qualified personnel in these fields of expertise are employed in other sectors of the economy in the industrialized countries (Arora and Gambredela 2004). Conversely, even though there is a larger stock of scientists and engineers in the industrialized world, shortages are particularly prominent in the fast-growing fields; Second, the divisibility of innovation process into activities and subactivities allows MNCs to offshore and/or outsource some innovation activities (core or noncore) to emerging economies. This allows companies not only to access much required research personnel at highly competitive costs, but also enables concentration on core or higher value-added R&D activities at home (Reddy 2000). Third, innovation activities in science-based technologies do not seem to require long years of industrial experience. This is mainly because much of the required knowledge is codified. There is a shift from a 'learning-by-doing' type of paradigm toward a 'learning-by-training' paradigm. This is reflected in young university graduates being employed as R&D personnel in science-based industries, whereas R&D employees in conventional industries such as engineering and electrical tend to be those with accumulated experience on the shop floor in manufacturing (tacit knowledge is greater). Consequently, science-based industries facilitate qualified personnel and companies from emerging economies to participate in global innovation activities; Last, emerging economies are also home to some of the internationally acclaimed universities and research institutes in terms of their research and publication activities. Therefore, companies, including MNCs, can not only recruit graduates from these universities, but also use these organizations for outsourcing of innovation activities.

Mathews (2006), with East Asian firms in perspective, argues that it is changes in the character of the world economy, particularly its globally interlinked character (what he calls the *worldwide web for inter-firm connections*) that are mainly responsible for driving the new patterns of internationalization. Firms, particularly those that lack substantial resource base, are adapting the strategies of linkage and leverage. They are perfect strategies for latecomer and newcomer firms, and for SMEs, rather than for large incumbent firms. As newcomers and latecomers, these firms from emerging economies had to find innovative ways to make space for themselves in markets that were already crowded with very capable firms. They did so through offering contract services, through licensing new technologies, to forming joint ventures and strategic alliances. It was through the implementation of these strategies that are "complementary" to the large incumbents that newcomers and latecomers were able to find a place in the global economy. It is not on the basis of their existing strengths, but on the basis of their capacity to leverage resources from the strengths of others, through making international connections (Melin 1992). These internationalization strategies that were designed to enhance a firm's resource-base rather than to exploit existing assets "represent a fundamental departure in thinking by firms about what 'globalizing' means and how it can be accomplished" (Mathews 2006, p. 14).

A study by Booz Allen and NASSCOM examined the market for outsourced engineering R&D services, i.e., product and component design, plant design, process engineering and plant maintenance and operations, across a number of sectors, such as automotive, aerospace, technology/telecommunications, utilities and construction and industrial machinery, which together accounted for the bulk of the global corporate R&D expenditures. Among the findings of the study are (Dehoff and Sehgal 2007, pp. 3–4):

- The growth in global spending on engineering services has two main driving forces: (i) the growing demand for increasingly complex consumer and industrial products, particularly in India and China; (ii) the increased electronic and software content in everything from toys to airplanes that requires more offshored and/or outsourced engineering work.
- The industrialized world is facing a severe shortage of S&T workers. Among the reasons for this are: an aging workforce due to prevailing demographic conditions; and fewer students in the USUS and Europe are choosing S&T professions.
- China is producing far more technology workers than is the USUS (650,000 a year in China versus 220,000 in the USUS). India produces 95,000 graduates a year in electrical, information technology and computer-science engineering—the fields in highest demand—while the USUS produces 85,000 a year. As the Booz Allen/NASSCOM study estimated, there are as many as six million engineers available in emerging economies to take on R&D tasks of all sorts (28 percent of them in India and 11 percent in China).
- As the market expands, however, new entrants such as the Eastern European countries, South Africa, the Philippines and Vietnam are

expected to play an increasingly important role in catering to outsourcing markets.

- The outsourced R&D activities performed today for aviation and automotive industries tend to be very basic (e.g., documentation, basic simulations and computer assisted design and engineering), but upstream activities such as composite structure design and thermo-mechanical analysis for aerospace companies, could be commonly outsourced.

Such progression of offshoring and/or outsourcing of R&D activities to emerging economies is already being witnessed. For instance, a major automotive component MNC is aggressively expanding its network into China and India. At its R&D unit in Bangalore, India, 3,000 employees are working on high-end electronic control units, tools and diagnostics, and a second unit will be being opened in another city in India, by 2010, where 6,000 employees will work on software and engineering. The importance of emerging economies for global innovation is reflected in the US-based MNC, Cisco, getting the most USUS patents for new products developed at its Indian R&D operation of all the regions in its global network (Dehoff and Sehgal 2007, pp. 4–5).

Moreover, the markets are growing faster in emerging economies than in the industrialized world. Consumers in these markets tend to demand equally sophisticated products as their counterparts in the industrialized world, in terms of multifunctionality, but at much lower prices. This calls for newer business models than the traditional Western business models of creating value-addition without consideration of additional costs for innovative products. The Western business model, of 'profit-margin-on-product,' perhaps needs to be replaced by a 'profit-on-volume' model. Emerging economies do require application of advanced S&T knowledge to design and develop products that have all the sophisticated features, but with cost-effectiveness, and this requires a paradigmatic change in Western management philosophy. Companies from emerging markets seem to better understand this phenomenon (e.g., the Tata Nano car and the growing market share of Huawei in telecom networks). These are considered ***emerging products for the emerging markets***. With successful deployment of such products, the companies from emerging economies may in the future also satisfy the hitherto-unsatisfied demand from the marginalized and low-income consumers in the industrialized world, giving them the scale and profit volumes to become MNCs by themselves in direct competition with the traditional MNCs.

# 3 Globalization of Innovation
## A Conceptual Framework

Almost all the past studies on globalization of R&D relate to happenings within the industrialized world. Only a few studies (Reddy 1997 and 2000; UNCTAD 2005) have been carried out on the location of strategic R&D in developing countries by MNCs. Developing countries were considered to have a certain competitive advantage in manufacturing activities due to their low labor costs, but R&D continues to be viewed as being out of their capability. This study, on the other hand, deals with the new trend of locating strategic innovation activities in some developing countries, which are considered as emerging economies. Therefore it becomes relevant to begin by a brief review of some of the theories pertaining to internationalization of production. The reasons for this are twofold. First, internationalization of production is temporally and logically expected to take place prior to internationalization of R&D;[1] Second, the involvement of developing countries in international production activities is far greater than their involvement in international R&D activities. Hence, a few theories relating to internationalization of production are first analyzed to see whether they could be integrated with those relating to R&D, to arrive at a broader framework of the process of globalization.

### 3.1 THEORIES OF INTERNATIONALIZATION OF PRODUCTION

In the 1960s several studies, beginning with Hymer's doctoral dissertation, analyzing foreign direct investments (FDI) were carried out. These studies explained FDI as a natural growth process of an oligopolistic firm (i.e., an MNC) that has some sort of superior advantages (which the local firms do not possess) that could be used to gain access to overseas markets. These advantages more than compensate for the disadvantages that an MNC faces in a foreign market, vis-à-vis local firms. All firms are not equal in their ability to operate in an industry; some have considerable advantages in particular activities, and the possession of these advantages may cause these firms to have extensive international operations. Such advantages may be that a firm can acquire factors of production at a lower cost than others can, or it may have knowledge or control of a more efficient production function or may have better distribution channels or a differentiated product. Of all these, 'the knowledge or technological advantage' over local firms is the most important (Hymer 1976).

Extending this argument further, other studies argued that imperfections in markets are important additional factors that ensure successful exploitation of their specific advantages through discriminatory pricing (Kindleberger 1969; Caves 1971; Horst 1978). In Caves's (1971) model, firms expand abroad through horizontal and vertical extension or conglomerate diversification. In 'horizontal extension,' a firm produces the same product in several countries. In 'vertical integration' across nations, the firm gets directly involved in other stages of the production process, (whether backward and/or forward stages), connected with the products it already produces. Other types of expansion abroad are called conglomerate diversification, where a firm deals with a wide variety of products, even unrelated to one another. Horizontal expansion takes place because of the possession of a special asset, which once acquired by the firm can be utilized in additional activities at little or no cost. Firms resort to FDI to exploit these oligopolistic characteristics. The investments involving vertical integration are motivated by the need to avoid oligopolistic uncertainty and the erection of barriers to the entry of new competitors. In his later work, Caves (1982) favored 'transactional costs' as an explanation for FDI. Vertical integration means internalization of the market for intermediate products for reasons of contracting costs and uncertainties. He extended his analysis of vertical integration investments to include those that involve 'sub-dividing production processes' and 'relocating the labor intensive' processes abroad. It is transactional costs that determine the decisions regarding the allocation of different production processes between internal facilities and facilities abroad.

Combining these oligopolistic characteristics with the theory of international trade, Vernon (1966) proposed his 'product life-cycle' theory. In his product life cycle there are three stages—'innovation,' 'growth' and 'maturity' of the product. In the innovation stage, the design of the product often changes, technology is not stable and the market is not familiar with the product. At this stage, countries with 'abundant skilled labor' would have an advantage in the production of these products. During the growth stage, sales of the product increase, a mass production system would be introduced, the industry attracts more entrants and competition among producers increases. In the final maturity stage, technology and product parameters become standardized, while managerial skills and production costs become more important than innovative skills. Consequently, manufacturing usually shifts to countries with 'low costs of production.'

Vernon (1974) further developed the link between location of production, multinationality and oligopolistic structures. There are three stages of oligopoly: First is 'innovation-based oligopoly,' where the barriers to entry arise from new technologies. Hence, the first location of production of new products is likely to be the country where R&D takes place, usually the home country. The second stage is 'mature oligopoly,' where the barriers to entry are erected not by innovation, but by scale of production, transportation or marketing. The search for equilibrium in the mature oligopolies leads to geographical concentration of investment, which cannot be explained on the basis of comparative costs. In situations where economies of scale are not a strong enough barrier, oligopolistic equilibrium is maintained through cartels or product differentiation. The third stage, 'senescent oligopoly,' is a situation where such strategies are not successful and the equilibrium is fragile, making the firm look for cost advantages.

The R&D implication of the product life cycle theory suggests location of an extensive centralized R&D in home countries. However, later studies showed that in some industries at least, the changes in the attitude of MNCs, both as a result of internal pressures from the well-established subsidiaries and external environment in the form of inducements from the host country government, have led to the product cycle becoming 'highly compressed' (Giddy 1978, p. 92), leading to a program of near-simultaneous innovations in several major markets (Pearce 1989; Terpstra 1977). In a later paper, Vernon (1979) himself analyzed the applicability of the product cycle model to the scenario of the late 1970s and 1980s and admitted to its shortcomings. He analyzed two main factors to arrive at his conclusions: (a) the degree of internationalization and diffusion of new products; (b) the changes in the European macro environment. As MNCs increasingly adopted a global approach, the spread of their operations increased, and the overall time lag between the introduction of a new product in the US and its diffusion into other locations decreased dramatically. By the late 1970s, there were a number of changes in Europe's macro environment, closing the gap between Europe and the US.

Dunning's (1977) eclectic paradigm attempts to synthesize different theories of international production in a general framework of analysis that accommodates both the trade and investment theories. There are three sets of factors, which enable internationalization of production. First is 'ownership advantages,' which are specific to a particular firm and enable it to exploit the investment opportunities abroad. There are three types of ownership advantages: (a) those that accrue from the ownership of proprietary or intangible assets and need not arise due to multinationality; (b) those that a subsidiary enjoys from belonging to an established large firm over the others producing in the same location; (c) those that accrue from multinationality. Second is 'locational advantages,' which are specific to a country and make it attractive to foreign investors. Third, 'internalization advantages' are benefits that are derived from internal markets and allow firms to bypass external markets and costs associated with them.

There are three conditions for FDI to take place. (1) The firm concerned must possess net ownership advantages vis-à-vis other firms serving the same market. (2) The firm must perceive benefits from internalizing the use of its advantages rather than selling them in external markets, e.g., licensing. (3) The host country must offer locational advantages to be used in conjunction with those deriving from ownership and internalization. A country's competitive position depends not only on its locational and ownership advantages, but also on the desire and ability of firms to internalize the resulting advantages. The motivation for internalizing comes from the existence of market imperfections that confer special advantages to internal markets as opposed to external ones. Such market imperfections may be 'structural' (e.g., barriers to competition) and 'cognitive' (lack of knowledge on the part of seller as well as buyer about products and processes). Differing policies among countries create incentives for internalization across national boundaries, and internalization further helps firms to acquire and enhance those assets that give them an ownership advantage (Dunning 1977).

Dunning's concepts of locational and ownership advantages can be applied to partially explain how R&D is internationalized. A country's locational advantages, such as availability of large pools of S&T personnel and existence of reputed universities, may attract R&D-related FDI of particular types into the country. MNCs may combine these with their ownership advantage of the ability to organize R&D through global networks. However, the model cannot be applied to explain other important factors such as why R&D needs to be internationalized, the changes in driving forces and the emergence of new techno-economic paradigm. Nor can it be applied to explain the differences in factors required and the driving forces for locating different types of R&D activities abroad (Reddy 2000).

In relation to the developing world, a country may have locational advantage in one factor, such as availability of trained personnel, but it may lack other advantages such as communication and infrastructural facilities. Therefore, even if a firm wants to internalize the advantage it finds in a location, the lack or inadequacy of complementary assets required may prevent it from doing so. Moreover, the eclectic paradigm is also based on market imperfections providing the primary motivation for MNCs' operations abroad, whereas one of the major driving forces for internationalization of R&D seems to be the competition for accessing S&T resources. In internationalization of production a firm exploits an existing ownership advantage, whereas in internationalization of R&D a firm attempts to create or acquire an ownership advantage (Reddy 2000).

Mathews (2006, pp. 18–20), based on East Asian companies, whom he calls 'dragon multinationals,' proposes a complementary framework to Dunning's paradigm, which is grounded in the present globalization (including the interfirm strategic alliances as a mode of entry into global markets). According to him, a firm's international expansion is driven by resource Linkage, Leverage and Learning (LLL):

- Linkage—The critical starting point for the latecomer firms is that it is focused not on their own advantages, but on the advantages that can be acquired externally from other organizations. Thus, a global market orientation from the beginning becomes a source of advantage for these firms. A global market orientation carries higher risks and uncertainties than a conservative domestic market focus. In such situations, joint ventures and other forms of collaborative partnership as a mode of entry into the foreign market become a crucial strategic option;
- Leverage—Next, the focus of latecomer firms will be on the ways in which the links can be established with incumbents or other partners so that resources can be leveraged. These firms will be concerned with the issues of accessibility to such resources, with their imitability, or transferability or substitutability;
- Learning—Repeated use of linkage and leverage processes results in improved performance of such operations by the firm (organizational learning). An entire region may learn to carry out the processes more effectively, as they master the intricacies of cluster development (or formation of more effective R&D alliances). The latter process may be termed 'economic learning' (Mathews 2003).

Theories of the internationalization of production offer only a partial explanation for the location of R&D abroad, because of their narrow treatment of R&D as an exogenous factor that contributes to the oligopolistic advantages of the MNC. These theories do not provide satisfactory explanations for the issues of globalization of R&D as a strategy in the organization of MNCs. However, the changes in the macro environment, which Vernon (1979) discussed, may be taken as the starting point in analyzing the driving forces behind the internationalization of R&D.

## 3.2 INTERNATIONALIZATION OF R&D—EARLY STUDIES

The early signs that MNCs might be performing some R&D abroad were indicated in the pioneering surveys of MNCs' operations in some industrialized host countries. These survey studies include Dunning (1958) for the UK, Brash (1966) for Australia, Safarian (1966) for Canada and Stubenitsky (1970) for The Netherlands. In addition to these host country studies, the benchmark survey of US Direct Investment Abroad by the US Department of Commerce in 1966 showed that US-based MNCs performed some R&D activities abroad (The US Tariff Commission 1973). An analysis of this data by Craemer (1976, pp. 2–3) revealed that 86 percent of the 500 largest US manufacturers in 1966 incurred foreign R&D expenditures, which accounted for 97 percent of the total R&D expenditures abroad by US-based companies.

MNCs tended to confine R&D activities to their home countries; however, when the necessity arose they performed abroad R&D related to adaptation or in a few cases product development for the local market. Even these limited R&D activities were mostly confined to industrialized countries and a few large developing countries. Such R&D was considered an additional and inevitable cost of technology transfer; hence a reduction of R&D costs was not a motive for locating R&D abroad. Studies in the late 1970s (Craemer 1976; Ronstadt 1977; and Behrman and Fischer 1980) confirmed these practices.

Ronstadt's (1977) survey of R&D abroad by seven US-based MNCs, which had 55 R&D units abroad in total, distinguished between four types of foreign R&D units: (1) Technology Transfer Units (TTUs); (2) Indigenous Technology Units (ITUs); (3) Global Technology Units (GTUs); and (4) Corporate Technology Units (CTUs). TTUs were closely linked to manufacturing units and were established when the product and process technologies needed to be adapted to the local conditions, and when there was a need for continuous support of technical services. This was more cost-effective than sending R&D missions from headquarters. ITUs were R&D units set up to develop new products for the local markets and were established when the subsidiary was able to identify locally distinctive opportunities and convince the parent company of its ability to implement such new product development. GTUs were established when a single product was envisaged for the global market. In such cases, the allocation of R&D tasks to foreign subsidiaries tended to depend on two influences: First, an MNC might allocate parts of the product range to a particular manufacturing subsidiary abroad; therefore, it might be beneficial to carry out R&D relevant to that part of the product range in the same place. Second, developing a globally competitive product range may necessitate utilization of the resources available in the subsidiaries abroad by organizing a decentralized but integrated R&D program. The main function of a CTU was to generate new technologies of a long-term or exploratory nature exclusively for the parent company in order to protect the firm's future competitive position. CTUs were often established abroad to recruit top scientists, who could not be relocated to the US on a long-term basis.[2] Although four distinctive kinds of R&D units, each serving a purpose, were established abroad by the US-based MNCs, over time however, all the four types tended to depart from their original character and follow a common pattern of evolution with overlapping functions. Ronstadt's study showed that even the TTUs were concentrated in the industrialized countries. Only India, among the developing countries attracted two TTUs, because the host country had the potential for a large market with unique characteristics.

Behrman and Fischer (1980) surveyed 31 US and 17 European companies during 1977–1978. They found that some MNCs located R&D facilities in the more advanced developing countries among which the most important were Brazil, India and Mexico. However, MNCs' R&D activities in these countries were limited to adaptations, local technical services (TTU type) and, in a few cases, product development for the local markets (ITU type). Most of the R&D performed abroad by MNCs was found to be applied R&D, and this varied significantly depending on the market orientation. 'Home market' companies are those whose foreign subsidiaries mainly support the companies' home market operations, either by supplying raw materials to the parent or manufacturing a particular component for it, or performing a specialized stage in a vertically integrated production process. The nature of such activities limits the subsidiary level R&D to marginal product and process adaptations to suit local operating conditions. 'Host market' companies are those whose subsidiaries abroad are predominantly oriented to servicing the domestic markets of the countries in which they operate. Such subsidiaries often need to adapt the products and processes to suit the local demand and conditions or sometimes even create distinctively new products for the local market. 'World market' companies integrate their subsidiaries abroad into a centrally coordinated program to service standardized world markets. R&D in the subsidiaries of world market companies may similarly be assigned a specialized role in a centrally co-coordinated program. Such R&D is often motivated by the availability of required scientific and technical skills in the host country.

Burstall et al. (1981) link the evolution of an R&D center's capability from a limited unit to that with a comprehensive research capacity to the scientific and industrial capacity of the host economy. They, in turn, relate this with the technological capacity of a foreign subsidiary moving from a 'first order capacity' unit, which only receives and adapts research and technology, to a 'second order capacity' unit, which can develop and transmit new technologies to other subsidiaries.

Another classification of R&D laboratories abroad, which is complementary to Ronstadt's classification, was made by Hood and Young (1982): support laboratory (SL); locally integrated laboratory (LIL); and international interdependent laboratory (IIL). The primary function of SL is to assist the production and marketing facilities in the host country through technical services and adaptation of products and processes to suit local conditions. The LIL also caters to the local markets and production by developing products that are more than marginal adaptations of the existing product range of the parent company. Its work is likely to be oriented to original development work rather than a fully independent creative process. The IIL is primarily geared toward the global R&D activity of the parent rather than toward the other activities of the parent in the host country. IIL undertakes the centrally assigned tasks in an R&D program, which may involve R&D units in several other locations.

With the relevance and the important characteristics of overseas R&D having been established by the pioneering studies discussed above, later studies attempted to analyze the issue of the determinants of overseas R&D by using industry- or firm-level data. Among the determinants tested were economies of scale in R&D, the extent of overseas sales and production and R&D intensity and product characteristics.

Lall (1979) investigated the relationship between the US-based MNCs' propensity to perform R&D abroad and the overall R&D intensity of their industries. In his view, the extent to which R&D can be shifted abroad depends on the 'linkages' between R&D and other activities. Research of a basic nature is not likely to have close links with other functional areas of a firm's operations. On the other hand, the minor development work of adapting them to specific material and marketing needs in each manufacturing unit is closely linked with production but not with the strategic planning at headquarters. The need for development work varies between industries, being most prevalent in engineering industries where detailed design is an integral part of the production process. Because such adaptive R&D is likely to be carried out in the majority of subsidiaries, it may result in a high absolute value of foreign R&D, as well as high R&D in relation to sales, but not in a high propensity to perform overseas R&D. He also observed that R&D functions could be more easily 'delinked' in process industries than in engineering industries. In 'process industries,' there is little need to adapt the product to individual markets, therefore R&D in these industries is not drawn for market-related reasons. Therefore, in the process industries group, research intensity and the propensity to undertake foreign R&D are positively related. On the other hand, engineering industries require continuous interaction between all activities in the innovation process itself and between R&D and other functions such as procurement, production and marketing. This need for strong linkages between functions within the organization and the need for feedback from the users make R&D in engineering industries difficult to internationalize.

Another set of theories focuses on 'supply-side' requirements of R&D in order to fulfill its role as a factor in the competitive advantage of MNCs. The main issue of analysis has been the complexity of organizing R&D at multinational level compared with firms at national level, rather than the broader issue of the globalization process itself. The ability to tap into pools of S&T personnel and the attraction of low-cost research bases have been considered key elements in this process. The importance of international recruitment of scarce S&T talent is not a new phenomenon (Liebenau 1984). Such moves by MNCs to tap the scientific talent on a global basis were seen as a reflection of the wider process of a 'new international division of labor' (Frobel et al. 1980). In the late 1980s itself, MNCs were seen as seeking to exploit valuable supplies of scarce skilled labor as well as the much larger supplies of low-skilled and low-cost workers in the more general production process (Schoenberger 1988). An additional factor on the supply side is the

MNCs' attraction for low-cost but competent research capacity abroad (Howells 1990).

## 3.3 GLOBALIZATION OF R&D—STUDIES SINCE THE 1980s

The above studies provided valuable insights into the organization of overseas research activity. However, they were based on observations and trends of MNCs' R&D in the 1970s and before. A number of major changes have been taking place since the 1980s in the nature and scope of R&D activities performed internationally by MNCs. This changing dynamics of R&D being performed abroad has given rise to concepts of 'internationalization' and 'globalization.' Different researchers use these concepts somewhat differently. According to Petrella (1992), internationalization involves joint R&D between two or more firms from different countries; multinationalization involves establishment of R&D activities by a firm in countries other than its home country; and globalization involves development of a global R&D strategy by the corporation both at the internal level (in-house R&D) and the external level (R&D alliances, mergers, acquisitions, university contracts) in all R&D areas (basic, strategic, applied). Casson and Singh (1993) consider internationalization as an approach in which overseas R&D units are given a small and usually subordinate role in corporate research activity, whereas globalization involves a greater commitment to overseas R&D, based on systematic division of labor between laboratories in different countries. Internationalization is usually motivated by the need to support overseas production and marketing, whereas globalization is independent of such motives.

Selection of the location of R&D by MNCs depends on several criteria. These include: proximity to a manufacturing site; availability of local universities and professionals; ability to build up a critical mass of local researchers (most important for global technological research); attractiveness of sources of technical excellence, e.g., universities, customers or suppliers; and availability of excellent communication systems (De Meyer and Mizushima 1989). The choice of location of R&D also depends on the type of technology to be developed and the advantages of national scientific capacity. For instance, the UK has been attracting significant R&D-related FDI in the pharmaceutical industry, because of the high-quality British science in the life sciences and in chemistry. Similarly, Germany has been a center for foreign R&D activities in the electrical engineering and electronics industries, reflecting German excellence in these areas (Wortmann 1990). Even in the selection of low-cost locations, it is observed that MNCs followed the same criteria. Although emerging economies are lagging behind the developed countries in industrialization, some of them have internationally reputed academic institutions. MNCs consider them to be almost on a par with the academic establishments in the industrialized world.

Dörrenbächer and Wortmann (1991) analyzed the motives for internationalization of R&D on two different levels: First, if the R&D is performed at the location that is most efficient within the framework of the corporate R&D system, then it is regarded as 'R&D-related motive.' Second, if the overseas R&D serves purposes not related to an improvement of the company's R&D system, then it is considered 'R&D-unrelated motive.' There are basically two kinds of R&D-related motives: The first type is the R&D that supports the local production. In such centers, technology transferred from the parent company to the subsidiary is adapted to local market and production requirements. The second type of R&D is aimed at the generation of new technologies that will be used by the entire company. In the context of R&D-unrelated motives, there could be requirements of national governments aiming at the preservation of R&D potential in their countries. Such motives also include improving the image of the company not only vis-à-vis the government or other customers, but to attract qualified personnel who want to work for 'interesting' companies that provide career opportunities.

According to Håkanson (1992), based on the dominant motive for their establishment, foreign R&D units can be grouped into five categories: (1) political factors, (2) production support, (3) market proximity, (4) monitor research, and (5) multimotive units. Except for the last one, each category of an R&D unit is predominantly associated with a specific type of establishment process: (a) acquisitions, (b) evolution of activities in greenfield subsidiaries, and (c) `direct placement´ of R&D units.

According to Granstrand et al. (1992), the reasons for internationalization of R&D can be organized into two groups: (1) 'demand-oriented' factors, i.e., circumstances leading to establishment of R&D abroad to better serve the foreign national markets; and (2) 'supply-oriented' factors, referring to 'characteristics in the local foreign environment that enhance the efficiency of R&D by providing, for instance, access to technical expertise, perhaps at a lower cost than elsewhere or access to universities and other research establishments.

Bas and Sierra (2002), using a matrix of the firm's strengths and weaknesses relating to its R&D-related FDI and the technological profile of its home and host countries, classify four types of MNCs' strategies with respect to globalization of R&D. Among them the 'technology-seeking' type of R&D-related FDI is aimed at compensating for the home country's weaknesses in a given technical field by locating R&D in a host country that has proven capabilities in that field. Patel and Vega (1999) call such a strategy as 'host-country-exploiting' type of R&D-related FDI.

Whereas the globalization of R&D has become a necessity, the primary motives for such moves differ among companies. From the literature survey,[3] the motives for location of R&D abroad can be summarized as follows: market-related (size, proximity and importance); technology-related (to tap into foreign S&T resources); cost-related (to exploit cost differentials); technology monitoring (to monitor new developments in science and technology, competitors' analysis); and non-R&D-related (pressures by national governments, improving the company's image). However, these motives are not mutually exclusive, and an MNC may locate R&D abroad for more than one motive (Reddy 2000).

Over time, technology-related motives are observed to have become more important than market-related motives (Cantwell 1992). The impetus for the globalization of R&D is increasingly being provided by the need for 'knowhow' rather than 'knowwhat' to develop (Dunning 1992). In recent years, supply-related factors, i.e., the availability of highly skilled scientists and engineers, and a dynamic scientific infrastructure, have become more important for globalization of R&D than demand-related factors, i. e., the need for customer contact and market proximity to adapt products and processes (Håkanson 1992).

Tapping foreign S&T resources is the primary motive for establishing GTU and CTU types of R&D abroad. However, faced with the increasing R&D intensiveness of technologies and decreasing profits, MNCs are increasingly concerned about reducing R&D costs. This has to be achieved without compromising the primary objective of generating new technologies and improving the innovativeness of the company. One way of achieving these twin objectives is to carry out R&D, at least some parts of it, in low-cost locations that have the required S&T capacity (Reddy and Sigurdson 1994). In the generation of new technologies, the innovative potential in the foreign host country does not necessarily have to be more advanced than the potential in the MNC's home country, i.e., industrialized countries. Technology expertise can be complementary (Dörrenbächer and Wortmann 1991).

In the context of the changing dynamics of global R&D, analysis of these motives assumes greater importance. The type of R&D performed abroad is closely linked to the motives for globalization of R&D. The past research studies have neglected to take this key relationship into account. An analysis of the relationship between the type of R&D performed abroad and the driving forces (primary motives) for globalization of corporate R&D suggested that market-related motives lead mostly to the TTU, ITU and RTU types of R&D activities, whereas technology-related motives are more important for GTU and CTU activities, followed by the cost-related motives (Reddy 1997).

## 3.4 IMPACT ON HOST COUNTRIES

A few studies have been carried out on the impact of MNCs' R&D activities on the host country. Whatever implications are suggested by these few studies, they tend to be postulated hypotheses. Whether the performance of R&D by MNCs contributes to the enhancement or retardation of independent technological capability of the host country remains a complex issue and would depend on the innovation capacity of the host country and the nature of R&D carried out by the MNC.

According to Dunning (1992), there have been two opposing views regarding the impact of R&D in MNCs on the host countries. One view considers inward R&D-related FDI to be beneficial to economic growth, as it brings in new technology and managerial skills, which in turn create indirect positive effects for the host country at a lower cost. These positive effects include technical support to local suppliers and customers, contract jobs from foreign R&D units to local R&D organizations and so on. The counterview argues that R&D activities by foreign firms tend to tap into unique local R&D resources with little or no benefit to the host country. Concentrating on problems of little relevance to the local economy, they may be little more than disguised 'braindrain,' diverting scarce technical resources from more useful purposes.

However, in the context of developing countries, where the S&T resources are underutilized, the counterview may not hold much strength. The benefits are larger, while the costs involved may be marginal. In the case of developing host countries, the cost factor may be that such R&D activities may create islands of 'high-tech enclaves' with little diffusion of knowledge into the economy. But, knowledge and skills cannot be isolated over the long term. The mobility of researchers and the need for local procurement of materials are bound to diffuse technologies throughout the economy. One of the most important benefits has been that global innovation activities are promoting 'entrepreneurship' among young scientists and engineers in developing host countries (Reddy 2000).

In general an R&D subsidiary is expected to benefit the host country in three ways: (a) by adapting products and processes to local conditions, it improves the efficiency of the local manufacturing facilities. This, in turn, may benefit the host country by increasing the size of output, employment and tax revenue, and the consumers would have access to products better suited to their requirements, perhaps at a lower price. (b) By assisting the local manufacturing subsidiary to introduce a new product, R&D may help improve the export performance of the subsidiary; (c) through its linkages with the local S&T community an R&D unit derives benefit as well as contributes to the widening of the scope of capabilities of local S&T resources (Pearce 1989).

While analyzing the implications for the host countries, it is important to consider the type of R&D being performed, as its direct and indirect effects on the host country vary. Each type of R&D unit displays distinctive linkages with the global intracorporate network and the local systems of innovation (SI). The local ties are virtually nonexistent for a TTU, whose main technology links are with the parent; somewhat strong for an ITU, which may to some extent draw on the local SI to develop products particularly designed for the local market; stronger for a GTU; and strongest for a CTU. In these two types of R&D units, the primary motive being that of exploiting local sources of S&T that cannot be accessed easily from outside the country, strong local linkages are established (Westney 1988; Reddy 1997).

According to Granstrand et al. (1993), depending on the situation, globalization of R&D may result in three kinds of scenarios: first, situations that create positive-sum games for the MNCs, the home countries and the host countries; second, situations of zero-sum games; and last, situations of negative-sum games. If the national systems of innovation in both home and host countries are well developed and capable of reaping positive allocative effects, foreign R&D will result in positive externalities. If the host country's system lacks such a capability in a particular industry, it could be built up by providing 'infant innovation system protection.' However, such a policy may not be effective in cases where FDI in that industry has already reached a significant level. If a foreign firm acquires R&D resources in another country for less than its local opportunity cost and uses these resources to outcompete the local industry, there will be negative effects on the local economy. In order to increase the positive host country effects of global R&D activities, the interaction with local SI must be ensured.

## 3.5 SYSTEMS OF INNOVATION (SI)

The concept of 'national systems of innovation' (NSI), as an analytical tool, was first used more or less independently and around the same time by Freeman (1987), Lundvall (1988) and Nelson (1988). Freeman (1987) used the concept in analyzing the success of Japan over the postwar period. He attributed Japan's success to certain key and distinctive elements in its national system of innovation. He defined the concept as "the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies" (p. 1).

Lundvall (1992, p. 12) defines the concept at two levels, where the narrow definition of an NSI includes the organizations and institutions involved in searching and exploring, such as R&D departments, technological institutes and universities. The broader definition encompasses "all parts and aspects of the economic structure and the institutional set-up affecting learning as well as searching and exploring—the production system, the marketing system and the system of finance present themselves as sub-systems in which learning takes place."

The view that an innovation system is confined to the national boundaries, however, did not appeal to many scholars, and so they started to use the concept of 'systems of innovation' (SI) as an analytical tool to explain the developments at international, regional (subnational) and sectoral or technology levels. Freeman (1995) used the term 'upper' regions ('triad' and continental regions), and 'nether' regions (regional and local systems). Carlsson and Stankiewicz (1995) used the term 'technological systems' approach to explain that innovation systems can be specific to particular technologies and/or sectors. A few scholars, however, argue that even in these cases where the particular technologies and sectors have their own dynamics, the national factors play an important role. As Nelson (1993, p. 518) puts it, "[I]f one focuses narrowly on what we have defined as 'innovation systems' these tend to be sectorally specific. But, if one broadens the focus the factors that make for commonality within a country come strongly into view, and these largely define the factors that make for commonality across sectors within a country." The existing institutional factors in a national system may facilitate or block innovation and growth in a particular sector of a national economy (Howells and Neary 1995, p. 245). Archibugi et al. (1999a) argue that the concepts of national (geographically limited) and technological systems (sectorally specific) should not be perceived as mutually exclusive. By integrating both concepts the broader SI can be analyzed.

The concept of NSI raises another issue, namely, the 'globalization of innovation activities' and how to reconcile one with the other. According to Archibugi et al. (1999b, pp. 534–535), the conceptual frameworks on SI and globalization have developed independently of each other. So they suggest an analysis of the technology dynamics that allows a better understanding of the globalization process, as there is a mutually reinforcing interplay between the two. New technologies become channels for rapid diffusion of information relating to 'best practices' across geographically wider areas. At the same time, the process of generating new technologies and diffusing them has been further strengthened by the flows of people, products and capital. This implies that the technology-based innovation systems will be characterized by common technological regimes, irrespective of the geographical location in which the related production is carried out.

However, even in the context of globalization, the location-specific advantages continue to play an important role, as evidenced by the MNCs' investment activities that are increasingly seeking to exploit the location-specific advantages that are linked to certain regions or areas. The international distribution of technological and production activities is reflecting more sectoral differentiation. Globalization is resulting in increased division of labor, with each country specializing in selected industries and resorting to international trade for others (Archibugi et al. 1999a).

In this study a broader interpretation of the term 'innovation' is adopted from Nelson and Rosenberg (1993, p. 4) "to encompass the processes by which firms master and get into practice product designs and manufacturing processes that are new them, if not to the universe or even to the nation." Such a broader definition is more appropriate for this study for several reasons: First, the firms in emerging economies are often not at the forefront of the innovation in the sense of Schumpeterian innovator. They are mainly involved in improving products or processes. Second, the focus on innovation is strongly connected to the broader issue of achieving economic growth. As some of the Asian developing countries have shown, it is not always necessary to be able to generate fundamentally new knowledge in order to achieve higher economic performance. Third, the first firm to bring new innovative products into the market may not be the firm that appropriates most economic rents from the innovation.[4]

Edquist (1997), in his review of literature on SI, analyzed that whereas there are several commonalties among different approaches, there is also a high degree of diversity among them. Among the core characteristics of the SI approach are—innovation and learning; holistic and interdisciplinary nature; natural inclusion of a historical perspective; differences between systems and nonoptimality; emphasis on interdependence and nonlinearity; inclusion of product as well as organizational innovations; the central role of institutions; conceptually diffuse nature; and focus on conceptual constructs rather than on a theoretical framework.

Whatever may be the approach, as Mytelka (2000, p. 17) states, "A system of innovation consists of a network of economic agents together with the institutions and policies that influence their innovative behavior and performance." According to her, as an analytical framework it provides a better understanding of innovation as a process in which there is continuous interaction among firms, support institutions and organizations. In the present global business environment the competition faced by firms is based more on innovation dynamics rather than on the static elements of relative comparative advantage. In order to meet such competition, new strategies and policies are required. "These will necessarily differ depending upon the knowledge base (competencies), habits and practices of the firms and the domestic institutional and the global competitive environments in which they are embedded" (p. 16).

According to Edquist (2005), organizations and institutions are the main components of SI. He defines 'organizations' as formal structures that are established for an explicit purpose. The important ones among them are firms, universities, venture capital funds and public agencies responsible for innovation policy, competition policy and regulation. The 'institutions,' on the other hand, refer to common habits, norms, routines, established practices, rules and laws that regulate the relations and interactions between individuals, groups and organizations. For instance, the patent laws and the rules and norms influencing the relations between universities and firms come under institutions. Furthermore, he states that an analysis of the SI must not only focus on its constituents, but also on 'activities' that take place in the systems. The activities are those factors that influence the development and diffusion of innovations. They are equivalent to determinants of the innovation processes. A list of such main activities (which have subactivities under each of them) is categorized as: (i) the provision of knowledge inputs to the innovation process, (ii) demand-side activities, the (iii) provision of constituents of systems of innovation and (iv) support services for innovating firms.

Furman and Hayes (2004) employ the term national 'innovative capacity' "to describe a country's potential—as both an economic and political entity—to produce a stream of commercially relevant innovations" (p. 1330). This term is organized "into three main elements: (1) a common pool of institutions, resource commitments and policies that support innovation, referred to as the common innovation infrastructure; (2) the particular innovation orientation of groups of interconnected national industrial clusters; and (3) the quality of linkages between the two" (p. 1335). The common innovation infrastructure provides resources for innovation throughout an economy, but it is the firms in specific industrial clusters that introduce and commercialize specific innovations. Therefore, the innovative capacity of an economy depends on the degree to which a country's industrial clusters support and compete on the basis of innovation. Based on the "diamond" framework developed by Porter (1990), Furman and Hayes note the importance of four key elements of the microeconomic environment: (i) the presence of high quality and specialized inputs; (ii) a context that encourages investment and intense local competition; (iii) pressure and insight drawn from sophisticated local demand; and (iv) the presence of a cluster of support industries. There is also opportunity for productivity-enhancing knowledge to spill over across industrial clusters. The extent to which the innovation potential "is translated into specific innovative outputs in a nation's industrial cluster will be determined by the quality of linkages between these two areas. In the absence of strong linking mechanisms, upstream scientific and technical activity may spill over to other countries more quickly than opportunities can be exploited by domestic industries" (p. 1336).

## 3.6 NEW TECHNOLOGIES AND CATCHING-UP OPPORTUNITIES

Conventional wisdom states that the most viable point of entry into the industrialization process for developing countries to be in mature technologies because of low production costs and low skill requirements. But, according to Perez and Soete (1988), these are industries that have already exhausted their technological dynamism. Countries adopting this strategy may face the risk of getting caught in a low wage and low growth pattern. The 'catching up' process, on the other hand, involves acquiring the capacity to improve upon the old and generate new technologies rather than simply being able to use them. Conventional theories perceived technology to be cumulative unidirectional process, and development was seen as a race along a fixed track, where catching up depended on the 'relative speed.' While speed is an important and relevant aspect, history is full of examples of how successful overtaking has been mainly based on running in a new direction. In other words, a change in the techno-economic paradigm opens up new windows of opportunity for the latecomers to industrialization.

One of the main weaknesses of the product life cycle theory had been that it assumes that products are independent of one another. Every new product is regarded as a radical innovation, and the successive improvements to it and to its production process are the incremental changes, which bring it to maturity. The next product is again a radical innovation following a similar evolutionary path. In practice, however, each product cycle develops within a broader family, which in turn is part of an even broader technological system. Successive products within a technological system are equivalent to incremental innovations to a product (Freeman and Perez 1988).

According to Perez and Soete (1988), the life cycles of the technology systems approach are more relevant for development strategies than that of the product life cycle approach, because the former facilitates the identification of those families of products and processes that will provide better opportunities for learning and catching up, as conceptualized in the following phases:

> *Phase I (introduction)*, involves original design and engineering, with the product in focus. Therefore, the S&T knowledge required will be high, whereas relevant skills and investment required will be low. The level of locational advantages required may be high for successful introduction.
>
> *Phase II (rapid market growth),* with the product development completed, the focus shifts to the production process and improvements to the product. Because the technological solution is already embodied in both product and production equipment, the S&T knowledge required will be low, but the skills and investment required will be high. Locational and infrastructural economies generated by the innovation itself would also grow, making them more easily available to the late entrants.
>
> *Phase III (productivity and firm's growth),* the focus will be on managing the firm's growth and capturing market share. Scaling up the plant and incremental innovations to improve productivity become important. The capital costs and management skills required can be very high. Entry at this stage for new entrants will be extremely difficult. By then the S&T knowledge required will have become low. The importance of locational advantages will also be low.
>
> *Phase IV (maturity),* the whole system is by now standardized and further investments in technological improvements result in diminishing returns. Firms would be willing to sell the technologies to others. Firms and locations with low costs of production will become competitive, but fixed investment costs will be high. The threshold of entry at this point is low, even though costs of entry could be high.

Phases I and IV are potential entry points for entrants, but with vastly different costs and requirements. But for the need for a high level of externalities and of S&T knowledge, entry into the new technologies is easier for developing countries during Phase I, because of low capital and experience requirements. This partially explains the cases of some innovations in electronics and biotechnology occurring outside the industrialized countries. However, as the system evolves, it may require not only constant technological effort, but also a growing flow of investment to generate synergies for self-sustained growth processes. This implies that, if a developing country has adequate reserves of well-qualified university graduates, a window of opportunity opens for relatively independent entry into new products in a new technology system in its early phases (Perez and Soete 1988).

The technology systems, in turn, constitute the elements of a techno-economic paradigm, which also evolves through different phases and is composed of a series of interrelated technology systems. Each new techno-economic paradigm requires, generates and diffuses new types of knowledge and skills and creates an environment for an easier entry into more products within these systems. Mature industries and products get redefined, new products and industries appear, giving rise to new technology systems based on 'new types of knowledge, skills and new locational and infrastructural advantages.' The firms and nations that are well-established leaders in old technology systems would find it expensive to get rid of their experience and acquire new skills. But the new firms and latecomer countries, for whatever reason, acquire the new knowledge and skills more quickly. "That is why these periods of paradigm change have historically allowed some countries to catch up and even surpass the previous leaders" (Perez and Soete 1988, p. 477).[5]

The emergence of new technologies has changed the rules of the game in global competition by transforming the industrial production system. Because of this change in the technological paradigm, no country or firm, however well-entrenched in the global markets, is certain of maintaining its competitive lead. The threats posed to the MNCs by the emerging high-tech start-up firms in the electronics and biotechnology sectors are an evidence of this phenomenon. For instance, Nokia of Finland, which was new to the business field, emerged as the first largest supplier of mobile telephones worldwide (Reddy 2000).

## 3.7 EVOLUTION OF GLOBALIZATION OF R&D—A CONCEPTUAL FRAMEWORK

Studies that have been discussed in the previous sections have contributed to the better understanding of the determinants of internationalization R&D by MNCs. However, they also tended to analyze the subject from the perspective of the firm and the management of geographically dispersed R&D, rather than an integrated analysis of the process of globalization as a macro concept, the changing dynamics of the driving forces behind it and the type of R&D performed abroad and its implications. Moreover, all the research related to globalization of corporate R&D that has been carried out so far pertains to the happenings within the industrialized world.

Developing countries were not considered as potential locations for carrying out innovation activities. The academic research relating to globalization of R&D did not recognize the changes in innovation environment in some of the developing countries (emerging economies). This study is an attempt to develop a conceptual framework in an integrated manner, for better understanding of the globalization processes relating to innovation.

Figure 3.1 shows the relationship between the actors involved in the phenomenon of globalization of corporate R&D, i.e., MNCs, home countries and host countries. The quantity and quality of R&D performed abroad by an MNC, i.e., the degree of globalization, depend on the type and cost of knowledge available abroad that is complementary to the MNC's operations, i.e., the degree of complementarity. The greater the degree of complementarity available abroad, the greater would be the degree of globalization. Similarly, the degree of integration of an MNC's activities in a host country depends on the degree of complementarity provided by that country. The greater the degree of complementary knowledge or skills available in a host country that is specific to an MNC, the greater would be the degree of integration of that MNC's operations in the host country. An MNC tends to locate R&D in countries that offer a knowledge base that is complementary to its home country's knowledge base. This is mainly because home country still remains the main base for innovation activities, and an MNC by relocating its R&D either seeks to overcome shortages of specific inputs in the home country or expand its knowledge base into related activities. So the greater the degree of complementarity between the home and host countries, the greater would be the degree of globalization from home country and greater would be the degree of integration with the host country (Reddy 2000).

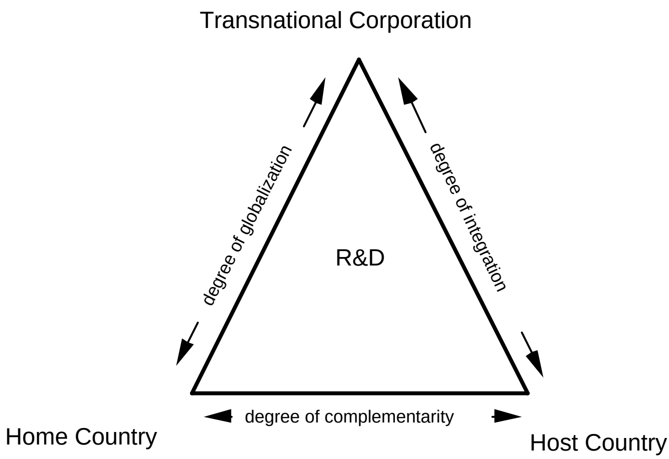


*Figure 3.1* Globalization of corporate R&D—actor network.
*Source*: P. Reddy (2000, p. 51).

With the emergence of a new techno-economic paradigm discussed earlier, MNCs are finding that some countries outside the industrialized world are in a position to provide complementary knowledge at a competitive cost. So such countries, which are called 'emerging economies' in this study, are now getting integrated into the global corporate R&D networks. It is reflected in the technology fields in which MNCs are performing some of their strategic R&D in emerging economies, which are mainly in the technology areas belonging to the new techno-economic paradigm, i.e., microelectronics, biotechnology, software and so on.

Ronstadt (1977) classified international corporate R&D activities into:

1. Technology Transfer Units (TTUs)—to facilitate the transfer of parent's technology to subsidiary and to provide local technical services;
2. Indigenous Technology Units (ITUs)—to develop new products for the local market, drawing on local technology;
3. Global Technology Units (GTUs)—to develop new products and processes for major world markets;
4. Corporate Technology Units (CTUs)—to generate basic technology of a long-term or exploratory nature for use by the corporate parent.

According to Reddy and Sigurdson (1994), corporate R&D structure has also undertaken an additional function:

5. Regional Technology Units (RTUs)—to developing products for the regional markets.

While markets worldwide are integrating in terms of standards and technologies, some regional clusters have also emerged. National markets in these regional clusters share some common features and needs for specialized products. Examples of this could be found in biotechnology—food processing (special types of food, taste and so on), pharmaceuticals (drugs for regional diseases) or agricultural pesticides—or in microelectronics—(special software applications). To cater for such regional markets, MNCs have been establishing RTUs.

This study builds the analytical framework for globalization of R&D in terms of waves (phases). Such a framework helps in comprehensive understanding of globalization as a broader process, by analyzing the driving forces in each time period, the type of R&D located abroad and the potential impact on the host countries. Each wave represents a set of distinctive characteristic features, yet reveals the continuation from one wave to the other (Reddy 2000).

## The Beginnings of Internationalization of R&D—First Wave Prior to the 1970s[6]

The number of firms performing R&D abroad in the 1960s and earlier was extremely small. Most of the R&D performed abroad prior to the 1970s was that of TTUs. The driving force for internationalization of R&D during this *first wave* was to gain entry into a market abroad. This needed adaptation of the product and process technologies to local conditions and the need for continuous support of technical services. The establishment of TTUs was considered a more cost-effective way of dealing with technical problems than sending R&D missions from the headquarters. The categories of industries involved in this process were mostly mechanical, electrical and engineering, including automobile industries.

## The Growth of International Corporate R&–D—Second Wave in the 1970s

By the 1970s, firms had started performing R&D abroad in a significant way. The main driving force was to increase the local market share abroad. This required increased sensitivity to local market differences to enhance competitiveness and the firms' general move toward world market orientation. This was reflected in the fact that a large proportion of firms with R&D units abroad have gained them through acquisitions of companies abroad.[7] Moreover, the host country governments started pressurizing the MNCs for more technology transfer by means of industrial policies defining the 'local content requirements,' 're-export commitments,' 'plant location requirements' and so on. These driving forces triggered what can be considered the *second wave* of internationalization of R&D, with a characteristic difference from the earlier wave. ITU types of laboratories were set up to develop new and improved products for the local markets. This type of activity was predominant in branded packaged consumer goods, chemicals and allied products and so on.

## From Internationalization to Globalization of R&D—Third Wave in the 1980s

A number of major changes have been taking place since the 1980s in the nature and scope of R&D undertaken abroad by MNCs. Increasingly higher-order R&D, such as RTU, GTU and CTU types, had been located abroad in what can be regarded as the *third wave* of globalization of R&D. Such R&D abroad is carried out as a part of long-term corporate strategy and is often carried out through interorganizational collaboration. Hence, the change in the term from internationalization to globalization, reflecting the characteristic differences from the earlier waves. The main driving forces for this phenomenon had been: first, the increasingly globalized basis of competition, aided by the convergence of consumer preferences worldwide, creating a need for worldwide learning; second, the increasing science base of new technologies, necessitating multisourcing of technologies; third, the rationalization of MNCs' operations, which assigned specific global roles to their subsidiaries abroad. These trends are visible mainly in the industries relating to microelectronics, pharmaceuticals, biotechnology and new materials. The improvement of ICT and the flexibility of new science-based technologies, which allow de-linking of R&D and manufacturing activities, vastly facilitated this globalization process.

## The New Patterns of Globalization of R&D—Fourth Wave in the 1990s

The key driving forces for globalization of R&D in the 1990s have been the increasing demand for skilled scientists and the rising R&D costs. These forces are triggering the *fourth wave* of globalization of R&D, encompassing non-OECD countries (emerging economies) as well. The mismatch between the outputs of universities and the needs of the industry is giving rise to shortages of research personnel throughout the industrialized world, especially in engineering fields related to electronics, automation and CAD/CAM,[8] compelling companies to widen their research networks in order to tap more geographically dispersed scientific talent. MNCs are also sensitive to variations in the cost of R&D inputs from country to country.[9] This move by MNCs is facilitated by the availability of large pools of S&T manpower in these countries at substantially lower wages vis-à-vis the industrialized countries. The categories of industries involved are microelectronics, biotechnology, pharmaceuticals, chemicals and software.

## The Evolving Patterns in Globalization of R&D—Fifth Wave in the 2000s

Since the 2000s, emerging economies have been witnessing rapid economic growth rates, increasing the incomes of their populations. Consumers in these markets are demanding more sophisticated products as the consumers in the industrialized world, i.e., qualitative products that contain all the functionalities. But these consumers are not willing to pay high prices like their counterparts in the industrialized world. To meet this demand and derive economies of scale, MNCs need to substantially change their business models, designing and developing products that are cost-effective, but contain all the functionalities (e.g., the new generation of low-cost mobile telephones). Such products are labeled by the industry as 'Emerging Products for Emerging Markets.' MNCs find it necessary to locate R&D for such product development in the emerging economies themselves. These products are not meant just for local markets, but global markets, where such market segments exist. The category of industries involved includes both conventional and new technologies ranging from automobiles through ICT to biopharmaceuticals.

Figure 3.2 conceptualizes the evolutionary process of the globalization of corporate R&D. In each of the phases the driving forces acting on are categorized as supply-side and demand-side forces. As a response to these driving forces, the type of R&D performed abroad by MNCs and corollary implications for the host country are indicated. In the 1960s, corporate R&D was mainly concentrated in the home countries. This was mainly because of the 'stickiness' of the R&D activities, such as the need for co-ordination of different functions and scale economies. These factors are categorized as the demand-side forces in the figure. These forces coupled with the supply-side forces such as technologically advanced and sophisticated home markets ensured that R&D activities remained in the home countries.

By the late 1960s, the situation changed, as can be noticed from the new demand- and supply-side forces. MNCs responded by locating the TTU type of R&D abroad. By the early 1970s, MNCs felt the need for expansion of their

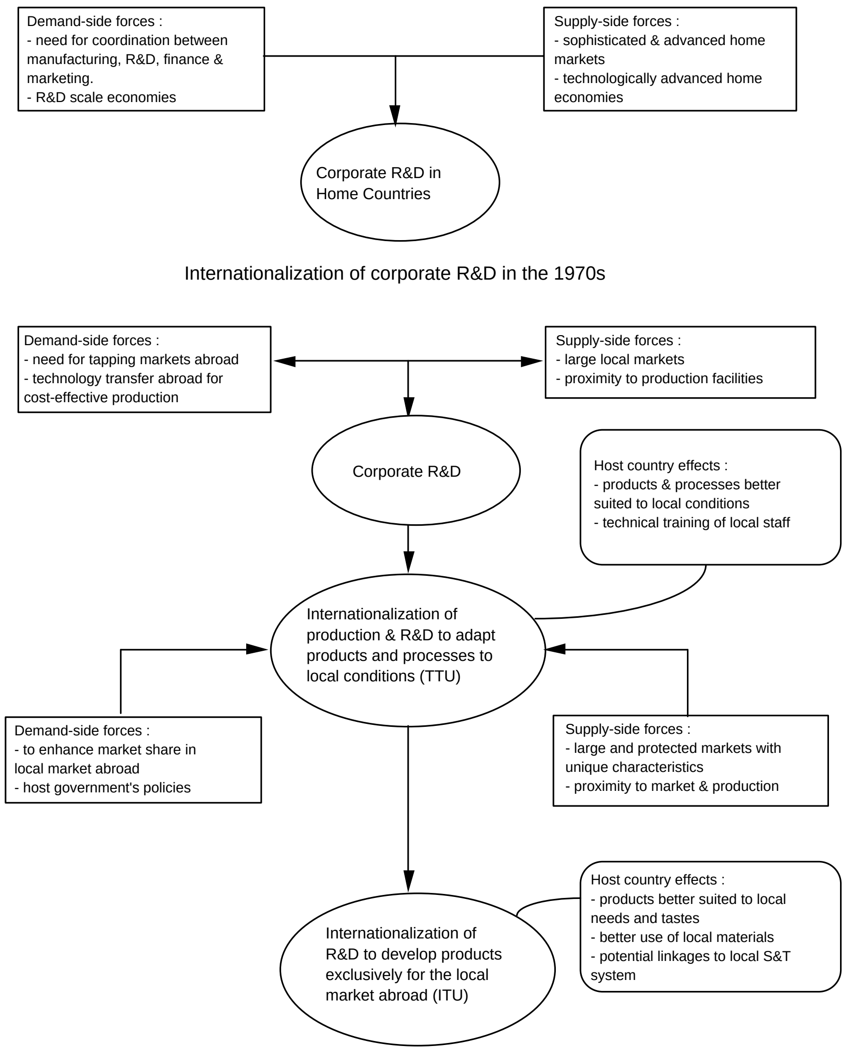


*Figure 3.2* Internationalization of corporate R&D in the 1960s and the 1970s.
*Source*: P. Reddy (2000, p. 54).

overseas markets, and added to it the host country's policies influenced MNCs to locate the ITU type of R&D abroad. As could be seen from the figure, the host country benefits are greater in ITU type of R&D than the TTU type.

Figure 3.3 suggests that by the time the 1980s arrived, the phenomenon was transformed from internationalization to globalization of corporate R&D. This is also the period when the pervasive effects of new technologies

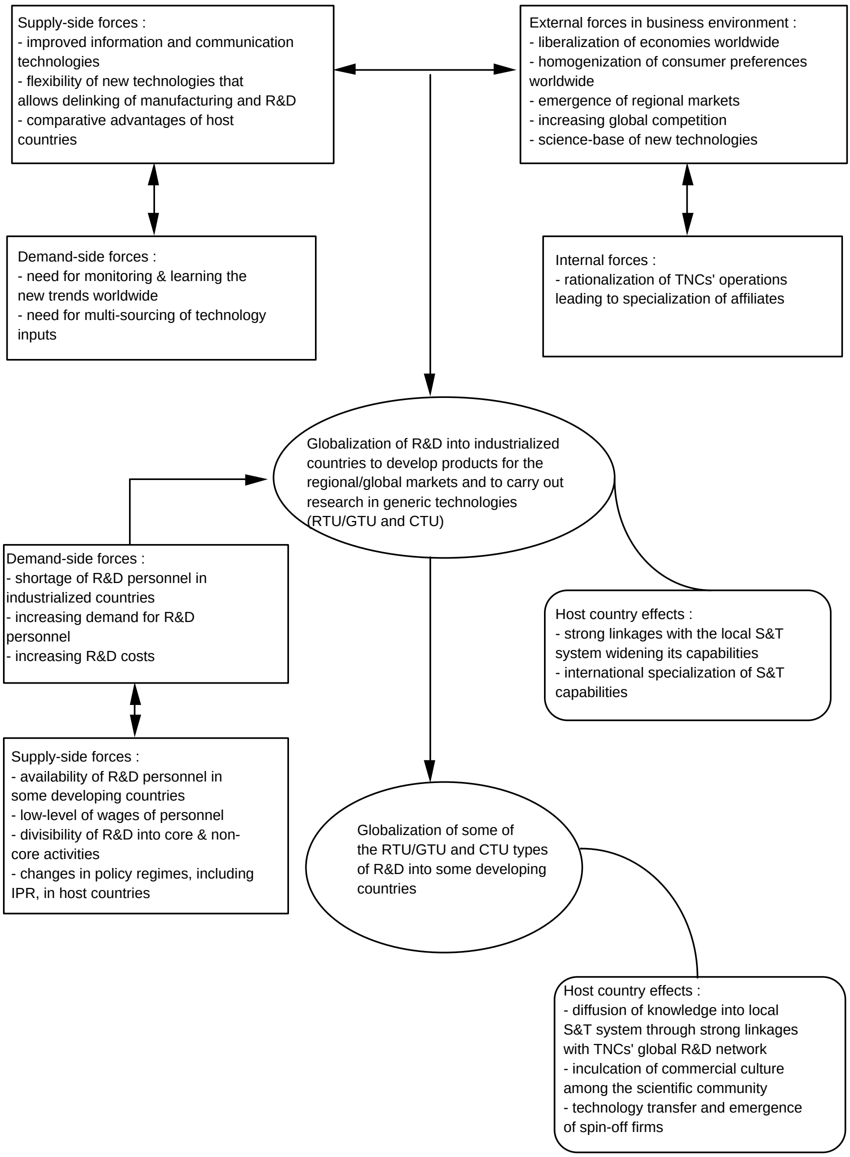


*Figure 3.3* Globalization of corporate R&D in the 1980s and the 1990s.

(i.e., ICT, microelectronics, biotechnology and so on) began to be felt. So a new set of supply-side and demand-side forces started influencing MNCs' operations. In addition, the changes in the general business environment started exerting external pressures, which necessitated rationalization of MNCs internal operations. In combination all these driving forces influenced globalization of corporate R&D. MNCs started performing their strategic R&D outside their home countries, but mainly within the industrialized world.

By the mid-1980s, MNCs started feeling the need for expanding their R&D-intensive activities and thereby the need for tapping into larger pools of research personnel. Simultaneously the R&D costs started increasing significantly. These forces made MNCs look for suitable R&D locations outside the industrialized world. Such a move was facilitated by the supply-side forces emanating from some developing countries (emerging economies).

# 4 Innovation Environment in Emerging Economies

This chapter provides an overview of the innovation environment in emerging economies. The discussion here does not focus on the structure of the innovation system as such, but on its dynamic aspects such as characteristic features, linkages, strengths, weaknesses and ongoing changes that provide a conducive environment for innovation. This chapter focuses only on developing countries that are emerging as locations for global innovation, particularly the countries chosen for this study.

Many emerging economies have an innovation environment characterized by dualism. In these countries, the industrial and education policies of the 1960s and 1970s have led to the emergence of an advanced segment that is small, but in terms of features and quality is comparable to the innovation systems of some of the industrialized countries. The larger part of the S&T environment in these countries, however, remains highly underdeveloped in comparison to the industrialized world. MNCs as well as some local companies are attempting to utilize this advanced segment for their innovation activities.

Goldman Sachs, the global investment firm, coined the term 'BRIC countries' in 2003 (Wilson and Purushothaman 2003), while analyzing the future potential of Brazil, Russia, India and China in the global economy. Since then these countries have attracted the attention of policymakers and investors worldwide. According to Goldman Sachs's report, assuming that everything stays on course, in less than 40 years, the combined GDP of BRICs economies in US dollars terms could be larger than the combined GDP of G6 countries (US, Japan, UK, Germany, France and Italy—developed economies with GDP over US$1 trillion). The value of combined GDP of BRICs in 2003 was only about 15 percent of that of G6, but by 2025 it would be over half the size of the G6. The growth of BRICs is likely to slow significantly toward the end of the period, with only India attaining growth rates significantly above three percent by 2050. However, individuals in the BRICs would still be poorer on average than individuals in the G6 economies, with the exception of Russia and China, whose per capita incomes could be within the range of what the industrialized economies have now (about US$30,000 per capita).

As early as 2009, the annual increase in spending by the BRICs economies in US dollars would be greater than that by the G6 economies and more than twice as much in US dollars terms as it is now. By 2025 the annual increase in US dollar spending by the BRICs would be two times that of G6, and by 2050 four times higher. Consequently, the relative importance of the BRICs economies as engines of new demand growth may increase dramatically. Higher growth may lead to higher returns and increased demand for capital in these economies, increasing the weight of the BRICs in investment portfolios sharply. Rising incomes in these economies is expected to increase the demand for different kinds of products because of changes in local spending patterns. Thus, this could become an important determinant of demand and pricing patterns for a range of commodities (as is being evidenced in the rising prices of oil, mineral and metals since 2007). For MNCs, in order to offset the slower growth in industrialized countries, investing and accessing the markets in emerging economies may become a critical strategy (Wilson and Purushothaman 2003). The follow-up studies by Goldman Sachs (2007) indicate that the BRICs countries are on the predicted path of development.

## 4.1 INNOVATION POTENTIAL IN EMERGING ECONOMIES—AN OVERVIEW

During the course of their developmental efforts, many developing countries have considered S&T education as a priority area and built up large pools of such personnel. Among them some, including the large countries like Brazil. China and India, took to building up capabilities in basic science as the starting point (mainly for defense-related reasons), from which they expected downstream activities of applied research, product design and development and manufacturing to flow smoothly. To their dismay, they have come to realize that the path from basic research to downstream activities is not an easy one and have failed to establish proper linkages between different stages of the S&T system. As a result, these countries now have large pools of highly qualified scientists and engineers in theoretical sciences, whose knowledge and skills have not been fully exploited for economic growth. These scientific personnel are available for R&D work at substantially lower wages.

On the other hand, a few other developing countries such as Singapore, South Korea, Taiwan and Hong Kong, which have been named the newly industrializing economies (NIEs), attempted to build up S&T capabilities by concentrating on downstream activities first. As a result they have built up strong competencies in product design and manufacturing and have now started moving toward upstream activities of basic and applied research. To enable them to do so, these countries took up S&T education as a priority.

However, globally R&D performance is still concentrated in a few industrialized countries. In 2002, global R&D expenditures totaled about US$813 billion. About one-third of this world total was incurred by the US, the largest country in terms of domestic R&D expenditures, and 45 percent of global total was accounted for by the two largest performers of R&D, the US and Japan. Industrialized countries, generally represented by OECD Member countries, perform most of the world's R&D, but in recent years, R&D expenditures have grown rapidly in several developing countries. In 2004, Brazil spent an estimated US$14 billion on R&D. In 2000, India spent an estimated US$21 billion, making it the seventh-largest country in terms of R&D in that year, ahead of South Korea (UNESCO 2007). In 2000, China had the fourth-largest expenditures on R&D (US$45 billion), following Germany's US$52 billion. In 2005, it is estimated that US$115 billion was spent on R&D by China, making it the third largest investor in R&D (NSB 2008, pp. 4–35).

Among the developing countries that have been pursuing conscious policies to build up S&T capabilities, countries in the Asian region have been at the forefront. According to the data compiled by the US National Science Foundation (NSF 2007, p. 15), between 1991 and 1995, R&D in Asia (limited to Japan, China, Singapore, South Korea and Taiwan) grew at an annual rate (7.9 percent), much faster than in the EU (3.4 percent) and in the US (3.3 percent). The quantum of R&D activity in Asia had surpassed that of the EU in 2002 and by 2003 was nearly 10 percent higher than the EU level. In 2003, the Asian R&D level was about 79 percent that of the US. China's annual growth rate of R&D from 1995 to 2003 (20 percent) exceeded that of all these other R&D performers, followed by Singapore at 15 percent. R&D growth rate in Taiwan averaged 10 percent and in South Korea seven percent. The ratio of R&D to GDP in Asia has recently reached 1.92 in 2003, whereas the EU ratio was 1.81 and 2.68 in the US. Although China's R&D to GDP ratio was the lowest among the five Asian economies in 2003 (1.13), it has increased dramatically since 1995 and showed further growth in 2004 to 1.23 (NSF 2007, p. 19).

The growth in the Asian region's S&T systems is being fueled by the huge investments in education, research institutions and infrastructure, which is reflected in the creation of new sources of national competitive advantage. The number of Asian-authored science and engineering (S&E) articles, including those from Japan, grew from 51,000 in 1988 to 130,000 in 2003, approaching the EU's 1988 output level of 135,000. Japan, with 25,600, and China, with 24,600, accounted for roughly equal shares of the rise in Asia's article output from 1988 to 2003, South Korea and Taiwan together accounting for another 20,100 articles. The number of articles from India grew much less, from 8,900 to 12,800 (NSF 2007, p. 21).

The S&E articles of Asia are more concentrated in the physical sciences and engineering/technology than those of the EU and the US. In

2003, 60 percent of the Asian-authored articles were in these fields, compared with 40 percent of EU articles and 30 percent of US articles. The EU and the US have greater focus on life sciences. “Within Asia, the S&E portfolio is marked by several distinct patterns: relative stability in India, Japan, and Taiwan; sharply declining life sciences proportions in China and Singapore because of growth in the physical sciences and engineering; and expanding life sciences in South Korea” (NSF 2007, p. 23).

A study by Sir David King, the UK’s chief scientific adviser, published in *Nature* in July 2004, assessed national research performance of several countries based on a range of criteria, including the share of the top one percent of highly cited publications. India was ranked 22nd, with a total of 77,201 publications between 1997 and 2001, of which only 205 were in the top one percent of highly cited publications. In comparison, these figures for China and the UK were 375 and 4,381, respectively, in the top one percent. India was ranked at the very bottom of the study’s sample when citation achievements were analyzed in the context of national wealth measured by GDP (King 2004). Mashelkar (2006), using the same data, turned King’s paper around by analyzing the relationship between citations and GDP per capita, by which reckoning India came at the very top of the rankings (see Tables 4.1, 4.2 and 4.3). King’s analysis showed India as a country performing well below its potential, whereas Mashelkar showed that India’s science is hugely successful for a country where most people are poor (Leadbeater and Wilsdon 2007, p. 14).

*Table 4.1* Scientific Publications and GDP per Capita

| *Country* | *SCI Publications (1997–2001)* | *GDP per Capita US$* | *SCI Publications per GDP per capita/ per year* |
|---|---|---|---|
| India | 77,201 | 487 | 32 |
| China | 115,339 | 989 | 23 |
| USA | 1,265,808 | 36,006 | 7 |
| Germany | 318,286 | 24,051 | 3 |
| UK | 342,535 | 26,445 | 3 |
| Japan | 336,858 | 31,407 | 2 |
| Canada | 166,216 | 22,777 | 1 |
| Italy | 147,023 | 20,528 | 1 |
| S. Korea | 55,739 | 10,006 | 1 |
| France | 232,058 | 24,061 | 2 |

*Source*: Mashelkar (2006) based on data presented in King (2004).

*Table 4.2* SCI Citations and GDP per Capita

| *Country* | *SCI Citations (1997-2001)* | *GDP per Capita US$* | *SCI Publications per GDP per capita/ per year* |
|---|---|---|---|
| India | 188,481 | 487 | 77 |
| China | 341,519 | 989 | 69 |
| USA | 10,850,549 | 36,006 | 60 |
| UK | 2,500,035 | 24,051 | 19 |
| Germany | 2,199,617 | 26,445 | 18 |
| Japan | 1,852,271 | 31,407 | 12 |
| Canada | 1,164,450 | 22,777 | 10 |
| Italy | 964,164 | 20,528 | 10 |
| S. Korea | 192,346 | 10,006 | 4 |
| France | 1,513,090 | 24,061 | 1 |

*Source*: Mashelkar (2006) based on data presented in King (2004)

*Table 4.3* Number of US Patents and GDP per Capita

| | *Country* | *US Patents* | *GDP per Capita* | *US Patents per Capita* |
|---|---|---|---|---|
| 1. | USA | 50,000 (est.) | 36,006 | 1.389 |
| 2. | Japan | 36,889 | 31,407 | 1.175 |
| 3. | India | 444 | 487 | 0.913 |
| 4. | China | 724 | 989 | 0.732 |
| 5. | Germany | 12,960 | 24,051 | 0.539 |
| 6. | S. Korea | 4,246 | 10,006 | 0.424 |
| 7. | France | 4,906 | 24,061 | 0.204 |
| 8. | Canada | 4,368 | 22,777 | 0.192 |

*Source*: Mashelkar (2006) based on data presented in King (2004).

The Asian region's innovation systems are deriving benefits also from the large inflows of FDI, both in manufacturing and R&D. MNCs activities in the region, while utilizing the local S&T resources, are in turn generating beneficial externalities. Between 1998 and 2002, foreign subsidiaries of US-based MNCs increased their R&D expenditures in Asia at an average annual rate of 28.6 percent, compared with 9.6 percent overall and 4.8 percent in the EU. Japan's share of US-based MNCs' R&D expenditures in

Asia dropped from 74 percent in 1998 to 40 percent in 2002. R&D expenditures of US-based MNCs in China witnessed a phenomenal growth, rising from US$7 million in 1994 to US$52 million in 1998 and US$646 million in 2002. In comparison, their R&D-related FDI in India was more modest, rising from US$5 million in 1994 to US$80 million in 2002 (NSF 2007, pp. 19–20).

In the Asia-Pacific region (which also includes Australia and New Zealand), the share for Japan in R&D expenditures of US-based MNCs decreased further to 35 percent in 2004, even though Japan remains the largest host of US-owned R&D in the region. In contrast, the shares of China and Singapore increased from 0.4 percent and 0.9 percent, respectively, in 1994 to 12.6 percent and 14.4 percent, respectively, in 2004. Other countries with sizable shares within this region in 2004 include Australia (9.5 percent), Taiwan (7.4 percent), Malaysia (6.1 percent), and South Korea (5 percent). The subsidiaries located in India doubled their R&D expenditures from US$81 million in 2003 to US$163 million in 2004, increasing India's share within this region to 3.3 percent. "Brazil and Mexico have represented around 80% or more of R&D expenditures by US MNCs in Latin America since 1994. Finally, Israel and South Africa represent virtually all of the R&D expenditures by MNCs in their respective regions, over the same period" (NSB 2008, pp. 4–54).

In the 1990s, the number of S&E bachelor's degrees rose significantly in Asia, with China doubling the number of graduates from 1990 to 2002 and increases in other countries ranged from 40 percent to over 200 percent. At the level of doctoral degrees, which signify achievement at a high level of training and indicate the availability of human resources with the capacity to generate innovations through advanced research, Asia conferred as many doctorates in S&E in 2001 (24,900) as the US during 2001–2003 (26,000–27,000), with the EU (40,000–42,000 annually for 2001 to 2003) in the lead (NSF 2007, pp. 3–4).

In 1998, China produced only about 1,000 doctoral candidates in S&E, but by 2001, it conferred more than 8,000 S&E doctoral degrees, compared with 7,400 in Japan and an estimated 5,400 in India. In 2003, China conferred 12,200 new S&E doctoral degrees. In the Asian region, among S&E doctoral degree recipients in 2001, the proportion of engineering doctorates was about 45 percent of the total, compared with 26 percent for the EU and 20 percent for the US (NSF 2007, p. 4). The only exception to this in Asia has been India, which consistently produced more doctoral degrees in sciences than in engineering fields. For instance, in 1989, out of all the S&E doctoral degrees (4,209), the engineering doctoral degrees were only 586 (about 12 percent of total S&E doctoral degrees). Similarly, in 2003 the total number of new S&E doctoral degrees awarded by India was 6,318 of which 779 were awarded in engineering fields (about 12 percent). On the other hand, China awarded 12,238 doctoral degrees in S&E in 2003 of which 6,573 (more than 50 percent) were awarded in engineering fields.

Japan, South Korea and Taiwan show a pattern similar to China (author, based on NSF 2007, p. 5).

Asian students also form the largest group among those pursuing studies abroad, particularly in the US. Between 1989 and 2003, foreign students were conferred nearly 40 percent of US S&E doctoral degrees, with Asians accounting for about 55 percent of this group. Among the Asian students, those from China constituted the largest number, with about 34,000 S&E doctorates from 1989 to 2003, followed by Taiwan with 14,800 and South Korea and India with about 14,500 each. These four economies accounted for nearly 90 percent of all Asian recipients of S&E doctorates in US (NSF 2007, p. 6).

Asians also constitute a major proportion of the S&T workforce in the US, gaining valuable experience and many of them becoming conduits for technology transfer to their countries of origin. In 2000, 23 percent of S&E employees in the US were foreign born, and half of those employees came from Asia. The most prominent countries of origin for such workers in US S&E occupations in 2000 were India (4.9 percent) and China (3.1 percent). Doctoral degree holders from the two largest Asian countries (China and India) accounted for almost 14 percent of all employees with a doctoral degree in US S&E occupations in 2000, with China accounting for nearly nine percent of all US S&E doctorate holders and India five percent. But, as of 2000, India remained the single largest source country for all degree levels combined (NSF 2007, pp. 10–12).

In terms of S&T capabilities in emerging economies, the building up of Brazilian and Indian national systems of innovation (NSI) occurred through the import substitution (IS) regime for industrialization. At least until the end of the 1980s, both were built within a relatively closed economic environment, both at micro and macro levels. Although, they have many common characteristics in their industrial and trade policies and their NSI, Brazil and India also show some markedly different approaches. For instance, Brazil has always had relatively more liberal policies regarding FDI and has been more open to MNCs than India. However, Brazil, instead of seeking transfer of technology or technological spillovers to local firms through FDI, was mainly driven by the objective of reducing import dependence (balance of payments issues). As a result, Brazil did not attract the best techniques available in the relevant industries of high and/or medium technologies. Until the early 1980s, the Brazilian and Indian governments targeted specific industries for promotion, by prioritizing basic and heavy industries, such as capital goods, chemicals and basic infrastructure, with state-owned sector playing a key role. Until the beginning of the 1990s, enterprises in India operated in a much more protected and restrictive environment than those in Brazil (Nassif 2007). For example, before 1990, the Indian import tariffs were 106 percent on agricultural products, 128 percent on manufacturing products and 128 percent on the whole economy (Srinivasan 2001, p. 46). Correspondingly, Brazil's import tariffs were 17.0 percent, 69.7 percent and 39.6 percent, respectively (Nassif 2007, p. 5).

Table 4.4 provides data on the Brazilian and Indian exports of goods according to technological-intensity. An analysis by Nassif (2007, p. 24) indicates that Brazil has not taken the full advantage of technological changes and innovation opportunities since the late 1980s. Compared to the East Asian export performance, during 1989–2004, there has been a significant reduction in the Brazilian labor-intensive manufacturing exports in the total exports. At the same time, this was not accompanied by any significant increases in the manufacturing exports of medium and high technologies in the same period. However, Brazil's export of primary products and manufacturing based on natural resources has been on the rise.

The data in the table also suggest that India's export performance was not better than Brazil's in the same period. The data show that India's export of manufactured goods of high technology was less than that of Brazil (in percentage points). India seems to be better at exporting manufactured products of medium technology, which grew from 11.7 percent in 1989 to 18.6 percent in 2004. A much better performance, however, has been the growth of Indian exports of commercial services, especially software. As per the Reserve Bank of India's data, during the period 1990–2005, India's exports of goods registered annual average growth rates of 10.76 percent in real terms. During this period, the Indian exports have increased from US$16,612 million to US$163,335 million, and exports of commercial services reached US$60,610 million in 2005, of which US$23,600 million (38.9 percent) were related to software services. The IT and software services are usually classified as being of either medium- or high-technology intensity, so one can conclude that the technological sophistication of the

*Table 4.4* Technological Intensity of Brazilian and Indian Exports (%) (1989–2004)

| *Product* | *Brazil* | | | | *India* | | | |
|---|---|---|---|---|---|---|---|---|
| | *1989* | *1994* | *1999* | *2004* | *1989* | *1994* | *1999* | *2004* |
| Primary Products | 11.16 | 10.78 | 11.07 | 13.77 | 6.72 | 5.20 | 5.05 | 4.43 |
| Manufactured | 97.89 | 88.08 | 88.73 | 85.31 | 93.14 | 94.66 | 94.78 | 95.37 |
| - resource-based | 32.78 | 34.61 | 36.05 | 34.65 | 19.54 | 17.82 | 13.93 | 21.72 |
| - low-technology | 28.05 | 25.22 | 20.84 | 19.29 | 57.41 | 59.33 | 61.77 | 49.71 |
| - medium-technology | 21.61 | 23.72 | 22.81 | 24.07 | 11.68 | 13.83 | 14.24 | 18.61 |
| - high-technology | 5.45 | 4.53 | 9.03 | 7.30 | 4.51 | 3.68 | 4.84 | 5.33 |
| Other Transactions | 0.95 | 1.14 | 0.20 | 0.92 | 0.14 | 0.14 | 0.17 | 0.20 |
| Total Exports | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

*Source*: Comtrade, UNCTAD as Calculated by Nassif (2007, p. 24). Classification is based on Lall (2000).

Indian total export structure is much greater than what the data in Table 4.4 suggest (Nassif 2007, p. 26).

### 4.1.1 Research Personnel in Emerging Economies

There are several reasons why MNCs locate R&D in emerging economies. The main reasons among them are: to gain access to scientific and technical personnel and to expand their market share in growing markets. The location of strategic R&D outside the industrialized world is mainly driven by the twin factors of the availability of research personnel and their costs (A. S. P. Reddy 1993). For more than a couple of decades now, companies in industrialized countries have been finding it difficult to recruit qualified personnel in critical numbers, at least in certain fields of science and engineering (e.g., molecular biology) for their R&D activities. Such shortages have become common across most countries in the industrialized world. This also pushes up the cost of recruiting the few available people in the home countries. For example, it has been estimated that the European Union will have a shortage of 700,000 scientists and engineers to meet its target of spending three percent of GDP on R&D (the Lisbon Agenda) (*Financial Times* 2005).

Frost and Sullivan's (2004) study of R&D in Asia, citing a response, says "one main reason for offshore outsourcing is that very often there isn't enough talent in the company's own home country . . . the personnel available for specific tasks does not have the sufficient qualifications, where programmers and scientists from countries such as India do have the right qualifications and skills to match the outsourcers' needs" (p. 8).

The location of global R&D in emerging economies is mainly because of the large countries (e.g., BRICs) that have large pools of qualified manpower. However, not all tertiary students in S&T in these countries may be suitable for global R&D activities. A McKinsey Global Institute's (2005) analysis of the supply of skilled people in various emerging economies (including the new EU members) found that only a small proportion of potential job candidates in 'degree specific' occupations (includes engineers, finance and accounting specialists, generalist professionals, life science researchers and quantitative analysts) were suitable for work in MNCs. The study, which was based on interviews with human resources managers in 83 MNCs, found large differences among the countries investigated. For example, while 50 percent of engineers in Poland and Hungary were suitable to be employed in MNCs, the corresponding figure for India was about 25 percent and for China and Russia only 10 percent. However, the report also reveals that the present supply of suitable engineers in low-wage countries is equal to as much as three-quarters of the suitable engineering talent pool in industrialized countries. This ratio is significantly higher than the 44 percent share of low-wage countries in the total supply of suitable young professionals in industrialized countries. Furthermore, McKinsey predicts that by 2008 low-wage countries would have the same

*Table 4.5* Annual Cost of Employing a Chip Design Engineer* (US$), 2002

| *Location* | *Annual Cost* |
|---|---|
| USA (Silicon Valley) | 300,000 |
| Canada | 150,000 |
| Ireland | 75,000 |
| South Korea | <65,000 |
| Taiwan | <60,000 |
| India | 30,000 |
| China (average across cities) | 26,000 |

*Including salary, benefits, equipment, office space and other infrastructure.

*Source*: Adapted from Ernst (2005b), whose data are based on PMC-Sierra, Inc. Burnaby, Canada (for Silicon Valley, Canada, Ireland, India) plus interviews (Taiwan, South Korea, China).

number of suitable engineers as in industrialized countries (Farrell et al. 2005). In addition, particularly from the R&D perspective, there are also a number of people returning to emerging economies, such as China, India and Russia, after studying and working for a few years in the West and other industrialized countries.

In the analysis of innovation environments of different countries, it is also important to consider the cost of accessing the S&T resources, particularly relevant when accessing resources for corporate R&D, which in turn depends on demand for and supply of qualified people. Table 4.5 gives the annual cost of employing a semiconductor chip design engineer for selected countries. The data clearly show that the cost of these personnel is several times lower in developing countries. It is this cost differential that MNCs are attempting to exploit by performing R&D activities in emerging economies that have the required innovation environment.

### 4.1.2 Emerging Economies in High-tech Sectors

Brazil, Russia, India and China (BRIC) as a group are also making their presence felt even in the most science-intensive sectors such as the pharmaceutical and biotechnology industries. Their impact on the broadly defined biopharma sector has become one of the industry's much discussed issues over the past few years. In the case of India and China, some analysts predict a shift toward offshoring of clinical and chemical development as well as production, whether it is drug substance or drug product, to these countries. In China, the policies have traditionally focused on basic building blocks and commodity types of active ingredients, which are manufactured by a large number of state-owned plants for the domestic market, but the excess output is often sold through traders on the export markets at very low prices. Now the Chinese pharmaceutical fine chemicals (PFC) industry is increasingly moving toward more sophisticated segments such as 'early-phase' development services and 'custom synthesis.' China has already achieved a global leadership position in product groups such as beta-lactam antibiotics. Similarly, in India the original focus was on off-patent active pharmaceutical ingredients (APIs) for the domestic market. Given the peculiarities of the Indian economic system, a myriad of small- and medium-sized enterprises (SMEs) emerged, and several of them also produce the dosage-form pharmaceuticals. Gradually, the supply structure consolidated as some companies have been forced out because of intensive competition (the same API can be offered by 50—if not more—suppliers). Over the years, the Indian industry has responded to mounting competition from China by reducing emphasis on the basic building blocks and shifting instead to 'custom synthesis' and 'early-phase' development services (Polastro and Tulcinsky 2004, p. 39).

Because of the capabilities of China and India there is growing interest among Western customers and fine chemical producers. A survey by the consultancy firm Arthur D Little indicated that most pharma MNCs are planning to increase their share of outsourcing of fine chemicals from China and India to 20 to 30 percent by 2006–2007, compared to the figure of 5 to 10 percent in the early 2000s. Pharma MNCs are looking to source not just basic building blocks or generic APIs, but also 'early phase' development services as well as more 'advanced intermediates.' For instance, companies such as Eli Lilly and Merck are offshoring part of their medicinal chemistry activities to India and China and entering into long-term contracts with local service providers. The general opinion has been that China and India are far more cost competitive than industrialized countries for fine chemicals. For instance, the full-time equivalents (FTEs), the rate at which early-phase development work is priced, are 30 to 40 percent of those prevailing in the West (Polastro and Tulcinsky 2004, pp. 39–40).

## 4.2 INDIA—INNOVATION ENVIRONMENT

India, like Brazil, has been one of the few developing countries that adopted a scientific policy as early as 1958. Since independence in 1947, through its five-year development plans and import-substitution (IS) strategy, India has built up capabilities in a range of S&T fields. But IS strategy also implies no focused efforts on building up international competitiveness through leading-edge technologies in any specific field. China also suffers from a similar paradox. In recent years, the policy focus has been on health-related technologies, biotechnology, electronics, computers, education, oceanography and environment.

India's NSI, like in most countries, consists of (a) universities and 'institutes deemed to be universities'; (b) research institutes and laboratories managed by the central and state governments; (c) the industrial sector, both public and private enterprises. Each of the components has achieved building up significant capabilities and successes; however, until the recent decade, the scientific potential has remained confined within the individual components, without linkages and knowledge flows among them. The university system has been assigned the primary task of supplying theoretically trained manpower, whereas most of the research efforts have been concentrated in the national research institutes, without linkages to industry and economy. Industry, on the other hand, had been mostly dependent on imported technologies, with little inclination for development of proprietary technologies. The government had been more focused on regulating the economy rather then developing it. As a result, all the components of NSI, though performing their spheres of functions creditably, failed to appreciate their interdependence. The functioning and structure had been somewhat similar to that of the NSI in the former Soviet Union.

As Krishna (2001) pointed out, academic science enjoyed a position of higher esteem and commitment to the advancement of knowledge in the pre-independence period. But, the later periods lowered its position due to the low level of funding, infrastructure, status and support compared to the governmental agencies (i.e., national research institutes) that carried out the mission-oriented science. In the 1940s about 90 percent of scientific research related to advancement of knowledge and higher training at Ph.D. level was carried out in the universities. The rise of 'governmental science' and the decline of academic science after the independence in 1947 raised the question of how to organize the scientific research. The National Institute of Sciences (NIS) organized a symposium on this question in 1943. But in 1944 the A.V. Hill Report on 'Scientific Research in India' was submitted to the colonial government. As it happened, the NIS symposium and the Hill Report presented two different 'models' of organizing science. The NIS preferred constituting a National Research Council (NRC) outside the direct control of government, and the Hill Report advocated different boards of scientific research directly under the control of the government. After independence, Nehru, the then prime minister of India, preferred Hill's model.

The post-independence period began a phase of 'policy for sciences.' with the main emphasis on creating a basic infrastructure for S&T including the expansion of the university system for the supply of required human resources. During this period the five Indian Institutes of Technology (IITs) were planned, as centers-of-excellence. Major Mission Oriented Science Agencies (MOSA), such as the Department of Atomic Energy (DAE) and Council of Scientific and Industrial Research (CSIR), and Defense Research and Development Organization (DRDO), were either established or rapidly expanded during this period. "The locus of the scientific research base which was in the university and private academic settings shifted to these MOSA under the auspices of the government in the post-independence period. Major scientific research institutions which were known for their contribution to academic excellence and in advancing scientific knowledge lost much of their eminence after 1947. Given the low-level budgetary support they could not sustain the earlier eminence" (Krishna 2001, pp. 238–239).

### 4.2.1 University System

At the time of independence, India had only 20 universities, and by 1994 these had grown to 183 universities, with 7,513 colleges affiliated to these universities (DST 1994). In 2006, India had 229 universities, 96 deemed universities, 13 institutions of national importance, 16,000 affiliated colleges, with a total of about 10 million enrolled students in them and teaching faculty strength of 457,000. Unlike in Europe, where even the undergraduate students go to the main university, in India affiliated colleges cater mainly to undergraduate students, under the supervision of the main university (e.g., common curriculum setting and examinations/evaluation of the students). Except for a few national universities, the university system is under the jurisdiction of the state governments. Within the university system the notables are the Indian Institutes of Technology (IITs), with a curriculum focused on science and engineering. These institutes are funded by the central government, with sufficiently large budgets to buy modern equipment and recruit talented staff. As a result, they have attained high standards that are comparable to the technical universities in the industrialized countries. The nationwide stiff competition among students to enroll in the IITs enables the institutes to recruit the best talent. There were originally six IITs, located in Bombay, Delhi, Kanpur, Kharagpur, Chennai (Madras) and Guwahati. In 2006, two of the technical institutions, Banaras Hindu University (BHU) and Roorki Engineering College, have been converted into IITs. In 2008, eight more IITs have been established. Among the other important units within the university system for education and research, especially for S&T disciplines, are the IITs, the Indian Institute of Science (IISc), the regional engineering colleges (RECs), which are now renamed the National Institutes of Technology (NIT) and the central universities located in different regions of the country.

The IITs were established on the lines of the Massachusetts Institute of Technology (MIT), US, and IIT graduates are trained to become engineer-scientists, in contrast to the engineer-manger training style of other engineering colleges. With the desire to be on a par with the best institutes in the West and to remain abreast of the latest in the field of technology, the IITs devised their syllabi at a high level of sophistication. The faculty also comprised mostly people who were educated in the American universities, and this led to a situation of graduates getting acquainted with the kind of technology that was not well diffused in the country, since Indian industry had been operating in obsolete pre-Second World War technologies. However, IITs earned a good national and international reputation for education. So when the IIT graduates applied for higher education, the universities abroad, especially in the US, offered them places, and after completion of their education they were offered jobs in universities and industry. Thus, most of them stayed on abroad. Those who returned found themselves unsuitable for Indian conditions, because they were trained to do advanced technological work, including designing, whereas the Indian industry required only maintenance personnel (Singh 1995).

However, with the changes in the Indian economy since 1990, Indian industry is realizing the importance developing modern technologies itself, and IIT graduates are finding better opportunities within the country. They are the most sought-after R&D personnel by the MNCs, who are setting up global R&D facilities in India. These new opportunities are to some extent arresting the brain drain from the IITs, and in a reversal of earlier brain drain, many IIT graduates who settled abroad for many years are also returning to India either as entrepreneurs or as representatives of the MNCs.

With respect to the larger part of the university system, however, the situation remains more or less the same as Long (1988) observed more than two decades ago:

> The quality of India's colleges and universities proper is exceedingly variable. The several major universities in large cities, most of which have a few nearby colleges directly associated with them, are of relatively high quality, and all are extensively involved in research and in graduate training of scientists and engineers. Their nearby associated colleges also tend to be of much above average quality. In stark contrast, the isolated colleges in small towns far from the urban areas can be virtually incapable of giving adequate training in science or engineering. Often they have only the bare bones of laboratories and minimal scientific equipment and library facilities. (Long 1988, p. 400).

In the evaluations of India's R&D programs, the research activities of universities are generally not taken into account. This situation is similar to that of the US universities before the 1950s, i.e., before the government support for research in the universities became significant. Even though the research activities of the US universities in science and engineering were substantial, they were not recognized explicitly in the budgetary provisions. The university research was categorized under training of graduate students, and this has several disadvantages: first, by not recognizing the research contributions that universities make, the university groups are less likely to be brought into collaboration with other research organizations; second, this makes it difficult to raise adequate funding for Indian universities, especially for library and research equipment; third, 'it implicitly lends support to the feeling of many bright graduates of Indian colleges that they must go abroad to get a first class training in science and engineering' (Long 1988).

According to Forbes (2003), the higher technical education (HTE) in India today faces at least three challenges: First, the last two decades have seen very rapid growth in private HTE institutions, with the number of engineering colleges and engineering enrollment growing at 20 percent a year. While they have contributed to India's abundance of engineers in general and software professionals in particular, there is a rising concern about the quality of their education; Second, select HTEs, such as the IITs, have provided a world-class technical education at the undergraduate level; however, as the Indian industry seeks to move up the value chain in technical competence, it increasingly needs graduate engineers with more advanced knowledge. This requires performance of research at HTEs, where they presently have a poor track record; Third, India was an early investor in scientific research; most of its research is carried out in autonomous national research institutes. This is often justified on the grounds of potential benefits to Indian industry, but in reality such research made very limited contribution to industrial development and competitiveness. The fact is that within Indian firms, the role of R&D covers a range of activities from indigenizing imported components to catching up with more advanced forms to improving existing products to providing low cost R&D contract research. The role of research itself has been very limited in industry in most countries, especially in an emerging economy like India. India's real need for scientific research lies in using it as a means of producing better qualified technical graduates. This requires combining public research with teaching in universities and not confining research to national research institutes.

### 4.2.2 National Research Institutes

The central government supports the largest proportion of national R&D efforts through its scientific agencies. Each of these agencies supports a number of R&D units. Most of them are primarily focused on development, but several of them are mainly involved in mission-oriented basic research. The Council for Scientific and Industrial Research (CSIR) was established in 1942 as an autonomous body with responsibility for scientific and industrial research and development in India. It maintains a network of 40 national laboratories, two co-operative industrial research associations, and 80 extension or field centers, totally accounting for about 10 percent of the central government's expenditure on R&D. To facilitate the transfer of R&D results from the national R&D laboratories to industry, the National Research and Development Corporation (NRDC) was established in 1953 as a public sector corporation. Although, NRDC was seen as a vital link in the innovation chain, its success has been somewhat limited. Its comparative lack of success can be partly explained by the attitudes of Indian industry toward indigenous technologies and their preference for imported technologies (P. Reddy 2000).

In recent years S&T institutions in India have been strongly criticized for pursuing research that is of little relevance to industries and the economy.

Consequently, the Indian government through various measures is now encouraging scientists to work closely with industry. These measures include incentives such as bonuses and a share of royalties from products created through their research. While offering such incentives, the government is also reducing its budgetary support to the research programs, compelling institutions to find alternative sources of funding. The government directive now compels CSIR laboratories to earn at least 33 percent of their budget from external sources (Reddy 2000).

By the mid-1990s, there have already been several cases of universities and research institutes having strong linkages with industry. For instance, the Department of Chemical Technology in Bombay University received about US$600,000 over five years since 1990, mostly from domestic industry. Its faculty members have also been providing consultancy services to the industry. One-third of such consultancy earnings by its faculty go to the department. One of the faculty members of the department designed a novel gas-liquid reactor for catalytic hydrogenation, a process used to produce industrial chemicals. The demand for this reactor is surging because the savings from the catalyst it uses have covered the cost of the entire system in only three months. Similarly, the National Environmental Engineering Research Institute (NEERI), a part of the CSIR network, earned about 65 percent of its US$1.7 million annual budget by selling its products and services (*Science* 1995b).

To facilitate, promote and strengthen interaction between the research institutes under the CSIR and industry, in May 2006, the government of India announced several measures. These measures include permitting scientists of the research institutes under the CSIR to take up assignments in industrial units and a provision to permit the research institutes to form alliances with industry for knowledge generation in new areas of S&T. The scientists will now be given permission to take up assignments in companies without any break in their service at the research institute and to retain their seniority, position, housing quarters and other benefits provided by the CSIR.

As part of the new initiatives, CSIR will set up 'technology incubation centers' within the campuses of its research institutes. Innovators will be allowed to set up pilot plants for converting research findings into useful commercial products. The first of such technology incubation centers will be set up at the National Chemical Laboratory (NCL) and gradually within two years in at least 15 other research institutes. The entrepreneurs will be allowed to use the incubation centers for undertaking development work on research findings from any organization and not just those emerging from the CSIR laboratories. The start-up companies can utilize the laboratory facilities and the help of the scientists at the research institutes. The aim of these new measures is to promote joint projects between the research institutes and the industry on topics at the cutting edge of technology.[1]

The CSIR also launched its New Millennium Indian Technology Leadership Initiative Program to promote and strengthen collaboration between private companies, national research institutes and academia. At the end of

2006, the program had 37 ongoing projects covering a wide range of areas, with a total expenditure of INR 2,200 million (about US$50 million) over two to three years. The program involves 240 partners, with 175 in the public sector and 65 in the private sector (Frew et al. 2007).

During 1998–1999, the Indian Ministry of Science and Technology launched a novel program called 'Technopreneur Promotion Program (TePP)' to tap the innovative potential of Indian citizens. The program's objective is to support individual innovators, particularly from informal knowledge systems, so as to enable them to become technology-based entrepreneurs (technopreneurs). The program provides financial support to individual innovators and small 'start-ups' to convert an original idea or innovation into a working prototype or process. Since its inception, the TePP has supported more than 115 projects, out of which about 50 projects have been completed and 25 projects have been commercialized. The program has resulted in granting of Indian patents to more than 10 innovators and US patents to three innovators (Gupta and Dutta 2005, p. 2).

### 4.2.3 Industry Sector

It is generally considered that, until recently, Indian companies did not carry out much R&D. They mainly depended on transfer of technology from abroad and only where necessary carried out adaptation of imported technologies. However, the liberalization of the economy since the late 1980s increased the competition, compelling Indian companies to re-examine their R&D activities. Katrak (2002), however, had observed that even prior to the liberalization of the economy, a number of Indian companies had started to make and sell some products based on their own R&D efforts. These products have usually been additions to those in the company's existing portfolio of products that were being made using standardized or imported know-how technologies. These companies have been multiproduct enterprises.

In a study, Kumar and Aggarwal (2005), using the database of the Center for Monitoring Indian Economy (CMIE), analyzed the determinants of R&D behavior of Indian companies during the 1990s in the light of the reforms of 1991. Their analysis suggests that although the average level of investment on R&D has fallen, the increased competition spurred local firms to rationalize their R&D and make it more effective. R&D investments increased more than proportionally with the firm size after a certain threshold level. Local firms focused their R&D efforts mainly toward absorption of imported technology and toward aiding their outward expansion either by way of exports and/or FDI. MNC subsidiaries, on the other hand, concentrated on exploiting India's strengths as an R&D location for their corporate use.

#### *ICT Industry*

Kumar and Joseph (2004) analyzed the factors that led to India building up significant capabilities in the ICT industries. According to them the policies initiated by the government have played a key role in facilitating India's success in ICT. Among others, such initiatives included support for higher education in S&E disciplines, creation of an institutional infrastructure for S&T policy, establishment of centers-of-excellence and several other institutions for technology development, and setting up software technology parks has been very helpful for ICT exports. A number of other studies (Arora et al. 2001; N. Singh 2003), however, argued that India's ICT success has been a result of free market forces coinciding with a benign governmental neglect.

Kumar and Joseph (2004), however, also acknowledge the combination of governmental initiatives and private-sector entrepreneurialism for India's success in ICT. For instance, from the governmental side, in terms of R&D capability building, the Department of Electronics (DoE) gave priority to the development of computer software by supporting research at different national research institutes and select universities since the early 1970s. These research programs have led to the building up of technological capabilities and also provided experienced manpower for the rapid development of the industry. As an illustration, the Center for Development of Advanced Computing (C-DAC), set up by the government in the 1980s, has developed India's first supercomputer—'Param'—and has also developed software for script for Indian languages. The government has also stimulated R&D by industry through tax and other incentives. At the same time, the industry associations, particularly the National Association of Software and Service Companies (NASSCOM), played an important role in projecting India's image in the global ICT markets.

### *Biopharmaceutical Industry*

Until the 1980s, the main demand for Indian companies in all categories came from the domestic market. The demand condition, particularly for the pharmaceutical industry, was to produce low-cost drugs within the quality standards set by the Indian drug control authorities. The Patent Act of 1972 that disallowed 'product' patents for drugs initiated a surge of innovation and entrepreneurship. Several private manufacturing companies emerged in the late 1970s, mainly started by former employees of the state-owned pharmaceutical companies and some scientists from the national research institutes. With the emergence of small companies (over 20,000 manufacturers) the market witnessed an intense competition. This led to further innovation in improving the processes to bring down the cost of production. Some large companies focused on innovations in selected therapeutic areas and in manufacturing high-quality products. In the absence of competition from the MNCs (which left the market after the Patent Act of 1972), local companies built up their own 'branded' products in the Indian market.

The profit margins were low; hence, companies had to build up volumes. In the 1980s, the large Indian companies started exporting to other Asian countries and former communist-block countries, where similar market conditions prevailed. Many companies added manufacturing plants for producing active pharmaceutical ingredients (APIs) and started exporting APIs for generic drugs to the Western markets by the early 1990s. These manufacturing plants were upgraded to the standards applied in the regulated markets (industrialized countries). By 2006, India had over 70 USFDA-approved manufacturing plants, the highest number outside the US. By the mid-1990s, technologically the large Indian pharma companies, such as Dr. Reddy's Laboratories and Ranbaxy, attracted by the profit margins, have achieved sufficient capability to even improve on the original drugs, in terms of efficacy and delivery systems. The revenues from these markets are now able to finance novel drug discovery research. Thus, for an industry whose origin was based on domestic demand and market conditions, the foreign market demand and conditions have become more important for innovation activities.

According to estimates, Indian firms spent a total of US$80 million on R&D in the year 2001, and approximately 90 percent of the Indian R&D investments come from the top 11 companies (Ernst & Young 2004, p. 13). There have been a few discoveries of new chemical entities (NCE), such as Dr. Reddy's and Ranbaxy's compounds that have been licensed to MNCs for further development. For instance, in June 2002, Ranbaxy licensed its NCE, codenamed Rbx-2258, for the treatment of benign prostate hyperplasia to Schwarz Pharma AG of Germany.[2]

Since the liberalization of the Indian economy got underway in the 1990s, affluence has increased. The middle class population is estimated to be around 150 million to 200 million. This segment of the population has started to demand more sophisticated biomedical products and also suffers from similar diseases as its counterparts in the developed world. Added to it, the government had to change its patent regime to comply with the Agreement on TRIPS. Several MNCs that left India in the 1970s started coming back into the Indian market due to the changed business environment. The MNCs are, by their very nature, governed more by global demand and market conditions than by a national market, where the profit margins continue to be low. So they focused, at least initially, on utilizing the technological strengths of the Indian biomedical sector by locating R&D activities and outsourcing parts of innovation and manufacturing. This global demand opened up new business opportunities, such as contract and clinical research services and biometrics, for Indian companies.

Bioinformatics is a new area of opportunity for India. Given the international recognition of the technological strength of Indian information technology (IT) industry, particularly in computing and software, it is not surprising that this new area of opportunity has emerged. Here again the product segment is driven more by global demand rather than local demand. For instance, in 1998, AstraZeneca added a biometrics research unit to its existing R&D portfolio in India. Novartis and GlaxoSmithKline established biometrics centers in India.

Large Indian IT companies are also competing in the global markets with biometric products and services. For instance, at the BIO 2004 Annual International Convention (June 2004) in San Francisco, the Tata Consultancy Services (TCS) announced launching of its Tata Bio-Suite, a portable, versatile software package for life sciences and drug discovery. It is a comprehensive suite of algorithms and computational methods that addresses all aspects of computational biology in drug discovery, ranging from sequence analysis and comparative genomics to structure-based drug design. Bio-Suite is aimed particularly at small- and medium-sized biotech discovery companies and academic groups.[3]

The rapidly growing economy, scientists and engineers returning from the industrialized countries and growing international reputation of India's biopharmaceutical industry have started attracting global venture capital (VC) firms to India. International investment banks like the Bank of America and City Bank have started funding R&D projects in established and start-up Indian biomedical companies. APIDC Venture Capital Ltd. is India's first biotech-dedicated venture capital organization. Based on the recognized need for venture capital in India, the first national VC fund for biotechnology was initiated as a joint venture between the Dynam Ventureast Group and Andhra Pradesh Industrial Development Corporation (APIDC) in the early 1990s. Several national and international financial institutions, including the International Finance Corporation (IFC), have invested in APIDC VCL. Realizing the financial challenges faced by the small companies, in 2005, the government of India (Technology Development Board—TDB of the Department of Science and Technology) has also established the Pharmaceutical Research and Development Support Fund (PRDSF) and the Drug Development Promotion Board (DDPB).

Apart from venture capital funding, some novel sources of funding innovation have also emerged in India. For instance, in 2006, Glenmark Pharmaceuticals entered into a royalty deal worth US$27 million with the Paul Capital Partners' Royalty Fund, an international health care investment fund. The deal will finance the development of 16 dermatological products by Glenmark for the US market. Some Equity Fund organizations have also started financing innovation activities in Indian biomedical companies.

In recent years, governments at the state level, particularly the Southern Indian States, have played an active role in fostering biotechnology industry in their respective states, through public-private partnerships (PPP) in creating science parks. For instance, in partnership with the government of Andhra Pradesh State, the ICICI Bank has established the 'ICICI Knowledge Park' in Hyderabad. The park occupies a 200-acre area provided by the state government as its equity. Aimed at the life sciences industry, ICICI built a mix of ready-to-use multitenanted modular wet laboratory blocks (innovation corridors) with in-built flexibility around some common, shared facilities and services, as well as developed land for customized R&D facilities. Among its tenants are Pharmacopeia, and Albany Molecular Research Center, both US-based, and Helvetica Industries of Switzerland.

## 4.3 CHINA—INNOVATION ENVIRONMENT

China, like India, has built up significant technological capabilities in a broad range of industrial sectors, but has no specific areas of international competitiveness derived through cutting-edge technological strength.

In a study Hu and Mathews (2008) studied China's national innovation capacity (NIC) defined broadly "as the institutional potential of a country to sustain innovations." Following Suarez-Villa (1990), they measured it in terms of China's patenting rates in the US. According to them the East Asian countries have been increasing their patenting activities at USPTO in terms of average growth rates as well as in per capita terms. Taiwan is the third-highest per capita patenting economy in the world, and South Korea is in the fifth place just behind Germany. China, a new player in the game, started from a low base and has been growing faster than others. China registered the highest growth rate over the period 2001 to 2005. The analysis also shows that China has a large reliance on universities as sources of innovative activity and on enterprises spun off from universities and academies. The public sector enterprises in China have so far played only a limited role in building China's innovative capacity. Some of the most important findings from these analyses include: the rapid rise of patenting by the private sector after 2000; the evidence of greater efficiency and impact of the patenting activity—whether measured by the falling cost of each patent, rising impact via forward citation or diminishing cycle time (fast turnover); and the rising level of linkage with the science base (i.e., rising level of citations by patents in the science literature).

The prominent role played by the public research organizations (PROs) in the chemical and petrochemical sector is particularly noticeable. Within the university system, Tsinghua University emerges as the dominant innovator. A few private-sector firms such as Huawei in telecom are also significant patentees. Although foreign MNCs have been active in China since 1992, they did not participate in China's innovation system until the beginning of the 2000s and were in the second place in 2005. Since 2003, China's private enterprises overtook the PROs and other players to become China's foremost patentees in the USPTO. The dramatic increase in innovative activity of private enterprise (or at least in patenting activity) may be partly due to the fact that many of the PROs have been transformed into private technology service enterprises by the government initiatives (NRCSTD 2003). China's two most innovative telecommunications equipment companies, Huawei Technologies and ZTE (Zhongxing Telecom Equipment Corporation, have established intensive relationships with China's PROs. Huawei

Technologies, which was established in 1988, rose to become the fourth-largest patent applicant in the world under the WIPO's Patent Cooperation Treaty (PCT) in 2007. In addition to its six overseas R&D centers, Huawei operates another six domestic R&D centers, and all the domestic centers work closely with restructured PROs, such as the Research Institute of Telecommunications Transmission, the China Academy of Telecommunication Research, Xi'an Electronic Engineering Institute and Beijing Design Institute. Similarly, ZTE, established in 1985, now has six R&D centers abroad and another eight located in China. The China centers work closely with about 50 local research institutions through a variety of R&D collaborative projects (Hu and Mathews 2008).

How did China achieve such rapid developments in S&T in such a short period of time? China has throughout its history given a great attention to S&T, which until the early 1980s remained completely within the government domain. Now, even though the corporate sector conducts a major portion of R&D, most of the research-intensive companies are still state-owned and maintain close links with the state sector (Sigurdson 2005). Since the early 1990s, China's S&T system has been undergoing major changes. Among the changes are: (i) emphasis on the coordinated development of S&T; (ii) increased efforts in R&D in applied science and technology; (iii) establishment of horizontal links between scientific research institutes, industries and local governments; (iv) acceleration of commercialization of scientific research results; and (v) restructuring of the funding system to encourage research institutes to undertake R&D oriented towards economic development (Yuan 1995).

As a result of these changes, the S&T system is moving from bureaucratically controlled resource allocation to competitive research grants. In an effort to persuade scientists to make direct contributions to the economy, the government has reduced the operating budgets of the institutes of the Chinese Academy of Sciences (CAS) by 70 percent. At the same time, the government through the Natural Science Foundation of China (NSFC), founded in 1985, is attempting to foster a competitive environment through an investigator-initiated grant system for research projects. NSFC is organized into six departments: math and physical sciences, chemical science, life science, earth science, materials and engineering science and information science (*Science* 1993; *Science* 1995a).

In terms of the structure, mainly three organizations manage China's S&T system: (1) The Chinese Academy of Science, similar to the National Science Foundation (NSF) in the US and the Royal Society in the UK, performs an advisory role on science policy, apart from controlling numerous research institutes of the government; (2) The Ministry of Science and Technology (MOST) is the central government department that directly coordinates all S&T activities. It formulates and launches programs to strengthen R&D and technology development. MOST is also the main source of funding for scientific activities across the country.

(3) The National Natural Science Foundation of China (NSFC) also provides funds, mainly for peer-reviewed basic and applied research in the natural sciences (Forster 2006).

China's NSI has some unique features. The most prominent among them are: first, the series of major S&T programs, initiated and funded by the government, which provides the major thrust in terms of capability building and infrastructure; second, the program for setting standards for products and services in a range of technologies, which the companies wishing to operate in China have to adhere to. This program reduces dependence on foreign technologies and payment of licensing fees, while promoting innovation among domestic companies.

### 4.3.1 Science and Technology (S&T) Programs

Since the beginning of the reform period China has launched five major S&T programs: The first, called the Key Technologies R&D Program, was launched in 1982 to foster industrial development by concentrating resources on specific technologies that are needed for industrial upgrading. The program's substance continues to evolve as the economy grows. It is currently focusing on information technologies and biotechnology (Sigurdson 2005). In 1984, the Chinese government initiated a program called 'State Key Laboratories.' with an objective to strengthen a few laboratories for a breakthrough into the forefront of global science. There are 80 such laboratories managed by several ministries and they are achieving successes. For instance, the Beijing Electron Positron Collider (BEPC), a 5.8-Ge V ring, China's first high-energy particle accelerator, was built in just four years at a cost of only US$350 million. The laboratory gave a jump-start to China in many advanced technologies such as superconducting magnets and klystrons and electronics and has recorded the world's best measurement of the tau lepton mass. As spin-off benefits, BEPC has also developed several commercial products such as superconducting magnets for medical magnetic-resonance imaging machines and high-vacuum technology for integrated circuit manufacturing (*Science* 1993; *Science* 1995a).

The second program, called the Spark Program, was launched in 1986 to develop the rural economy through S&T and to initiate technological upgrading in village-and-town enterprises (VTE). The program supports technical projects that utilize rural resources and appropriate technologies, with low investment requirements and early returns. The program also establishes demonstration zones to stimulate regional development and supports industries that derive their comparative advantage from regional resources. The Ministry of Science and Technology (MOST) has the overall responsibility for the program, but much of its management is decentralized to province, district and country levels. The Spark Program became a development model for many developing countries and international organizations (Sigurdson 2005; Walsh, 2003).

The third program, called the High-Tech Research Development Program (863), was launched in March 1987. The main missions of the program have been to monitor the global trends in advanced technologies and propose corresponding national projects, in order to reduce the gap between China and industrialized economies in important areas and to achieve breakthroughs in areas where has China a competitive advantage. The program covers eight priority areas: biotechnology, information, automation, energy, advanced materials, marine, space and laser fields. China attributed its ability to join the international human genome-sequencing project to the capabilities developed during an earlier 863 project (Sigurdson, 2005).

The fourth program, called the Torch Program, was launched in 1988 with the specific objective of developing new-technology industries in China. This program includes a number of activities, apart from providing a legal and organizational environment for fostering high-tech industries: 1) establishment of high-tech industrial development zones, where R&D results could be converted into successful industrial production; 2) establishment of service centers that support high technology development and attract and train talented people to raise the level of expertise and management; and 3) establishment of torch projects in enterprises that could venture into new high-tech areas such as new materials, biological engineering, electronics and information, opto-electronics, energy saving and environmental protection (Sigurdson 2005; Walsh 2003).

The fifth program, which is relatively recent, is called the National Key Basic Research (973) Program and was launched in June 1997. It has been designed to stimulate research that would result in original innovations and to provide support for future technological development, with a perspective on 2010. The program has four major tasks: (1) conduct multidisciplinary research and provide scientific and theoretical foundations to solve important scientific issues that China would face in the medium- and long-terms; (2) engage in explorative research to advance the knowledge front; (3) cultivate outstanding scientists who have creative ability and can handle challenging research tasks; and (4) establish interdisciplinary research centers to carry out projects of high national priority. The projects covered by the program included material research on carbon nanotubes, the basic study of super-high-density, super-high-speed optical information storage and processing, and basic research into novel devices and novel processes such as system-on-chip (SOC) (Sigurdson 2005).

In addition, to the S&T programs, the institutional reforms also contributed to the indigenous development of more advanced technologies. In 1986, China established the National Natural Science Foundation (NSFC), on lines of the US's NSF, to promote basic research in new and critical areas, to coordinate S&T research programs and to promote professionalism among the scientific community. Similarly, in 1992, the National Engineering Research Centers (NERCs) were created to promote applied research and engineering in government-designated 'pillar industries' and other high-technology sectors. The main task of these centers is to convert the research results of the national research institutes into new and innovative products, applying new management techniques (Walsh 2003).

In addition, the government has designated more than 150 'State Key Labs.' with an aim to raise the standard of research and training in China's university and government-run research institutes. During the reform period, the Chinese Academy of Sciences (CAS) has also undergone significant institutional changes. CSA's researchers faced funding hardships and incentive programs as did other state-run institutes. In response to the reduced funding, many of CAS's departments and researchers have set up 'spin-off' enterprises, some which became leading Chinese high-technology companies, such as Legend (now renamed Lenovo), China's leading personal computer manufacturer. More recently, CAS has launched a new and broader 'Knowledge Innovation Program (KIP).' with an overall goal to achieve a knowledge-based economy by 2010. In 2001, as part of the KIP, CAS launched the 'Strategic Action Plan for S&T Innovation' (SAPI) to further promote institutional reform, and an innovation-oriented culture at the Academy (Walsh 2003). In addition, as noted by Simon (2005), by encouraging foreign companies to establish R&D centers in China, the government consciously adopted a policy of using these companies as a catalyst for sparking innovative behavior throughout the economy.

### 4.3.2 Standards Setting Program

China's industrial development has largely been driven by manufacturing for exports based on abundant and cheap labor. Although most of the world's consumer electronics products are being manufactured in China, they seldom carry a Chinese brand name or contain advanced technology of Chinese origin. In order to change this, regulation relating to standards has in recent years become a very important element of China's technology strategy. China wishes to establish its own technological platforms, in as many areas as possible, in order to gain independence from foreign high-tech companies and to drastically reduce the level of license fees paid to them (Sigurdson 2005, p. 17).

The market size of China is so large that it can easily set and impose new standards on technologies that will affect the rest of the world, and MNCs would want to be compatible with such a lucrative market (Forster 2006). For example, in the mobile telephone sector, the intense competition between rival manufacturers, such as Nokia, Ericsson, Siemens and Motorola, has resulted in these companies investing vast resources into R&D in China in the hope of participating in standards setting. Through such efforts, Nokia has been able to secure its position in the CDMA handset market and will further strengthen its market position by working closely with Chinese developers of CDMA technology (Simon 2005).

China's strategy follows the efforts in the West to have industries set standards for themselves, bypassing international organizations such as the International Telecommunications Union (ITU), which normally sets international standards in telecommunications area. Having the world's largest market status in almost any product and/or service (including mobile telecommunications), China feels that it is called upon to pay royalties on standards set by organizations in which it had no say nor role to play. Given its market size and technological competence, China sees itself as having the ability to set standards for its market and to avoid paying huge royalties to foreign companies. China can also collect licensing fees from the foreign companies that use Chinese standards. Recently, China has been successful in getting its own 3G standard for mobile telecommunications accepted as one of the three global standards by the International Telecommunications Union (ITU). It had the support of many developing countries that had no role in fixing standards of GSM or CDMA technologies, but that are compelled to pay royalties for using products that incorporate these technologies.

The Chinese government is strongly supporting the development of various industrial technology standards in a number of areas, including digital TV and the Chinese (WAPI) protocol for W-LAN. On January 1,, 2004, China announced that all products marketed in China, including those produced in the country and imported from abroad, must conform to the Chinese WAPI standards, as these involve both security and economic concerns. Presently the majority of personal digital assistants (PDAs), notebook computers and mobile handsets have built-in WiFi, which is based on the original US standard, with US companies in the market leading position. The new Chinese standards would require an agreement with domestic Chinese companies, including ZTE and Huawei, which hold strong IPRs for this technology in China (Sigurdson 2005).

### 4.3.3 University System

As part of the efforts to propel China into a knowledge-based economy, the university system in particular, and education in general, has received great attention. The universities in China, just as in India, have, until recently, not been involved in advanced research. Moreover, graduate studies were only introduced after major reforms started in late 1970s. The annual enrollment of students in higher education institutions (HEIs) was less than 300,000 in 1979, which amounted to about 1.5 percent of those entering secondary schools in the same year. However, the enrollment increased rapidly after 1998 (with over one million new students), reached a total enrollment figure of more than 9 million by 2002 and it continues to increase. More than one-third of all university students pursue engineering, and adding science students to this number, the share comes to about 40 percent. Chinese universities are expected to produce at least one million students every year in the science and engineering fields, with a special focus on electronics. The number of students enrolling for postgraduate education has undergone a similar expansion from a total annual intake of about 10,000 in 1978 to over 200,000 in 2002, with a total enrolment of 500,000. In addition, around 125,000 Chinese students were enrolled in postgraduate studies in foreign universities (Sigurdson 2005, p. 12).

In 1997 China decided to upgrade some of its universities and embarked on an ambitious reform plan that should bring a number of its universities into top global ranks in the 2000s, the National 211 Project (211 stands for the objective of bringing a number of Chinese universities into global one position in the 21st century). The selected 100 universities have been given special attention through favorable funding. Several universities were merged into more comprehensive units and were brought under the control of the Ministry of Education. With the reforms, for instance, the School of Sciences and School of Law and Liberal Arts of Tsinghua University were transferred to Beijing University, while the Engineering School of Beijing University was transferred to Tsinghua University. As a result Beijing University became focused on social sciences, while Tsinghua became a technical university. The earlier reform in 1952 followed the Soviet model, and many ministries set up their own universities (e.g., Beijing University of Post and Telecommunications) (Sigurdson 2005).

The Chinese seem to have an obsession about the issue of commercializing university research. As a result, many universities are announcing new efforts aimed at fostering entrepreneurship, and new business ventures are emerging at an increasing rate. A number of incubators have been established in the form of campus-based science parks (e.g., Beijing University Science Park—BUSP). For instance, in 2000, at the BUSP, 300 projects were evaluated, of which 30 were selected for incubation. Altogether, 400 businesses currently have operations in the park, 80 percent of which are high-tech enterprises, although there is some skepticism about the high-tech component of these enterprises. However, China's universities have produced several well-known companies in the technology sector. For example, the Beijing University Founder Group Corporation, which was incorporated in 1986, now has total assets of about RMB6000 million, with shares in 17 other companies and a controlling stake in four listed companies. Its core business has diversified from being a word-processing software development company into hardware, Internet-related products and systems integration (Sigurdson 2005, pp. 13–14).

According to Walsh (2003, pp. 82–84), the Chinese government and the universities play distinct but complementary roles in attracting foreign high-tech investments, particularly the R&D-related FDI. Foreign firms tend to partner with Chinese universities not only for their excellent ICT, engineering and science departments that provide qualified personnel and perform contract research, but also because of universities' close ties to certain Chinese government ministries. For instance, in the telecom sector, this seems to be an important factor for at least some of the several technology transfer agreements and/or joint R&D programs that MNCs have entered into with the Beijing University of Posts and Telecommunication (BUPT).

The Chinese innovation system, however, reflects several structural and organizational weaknesses. Some of these weaknesses are lack of innovation, lack of cooperation among national research institutes, disregard for IPRs and unfamiliarity with the cultural norms of international science and weakness of English language abilities among scientists. The Chinese S&T system is also dominated by secrecy. This lack of openness leads to organizational rivalries draining the strength of the scientific system. It is also difficult to understand the way individual programs are undertaken and to obtain accurate and comprehensive pictures of many aspects of Chinese R&D activities (*Science* 1995a). However, since then the picture has changed and is still evolving. Although China is making progress toward implementing an NSI, the civilian S&T sector continues to suffer from excessive bureaucracy, undermining top-level efforts to modernize the system. There is little coordination between the industry-based ministries and the Ministry of Science and Technology, which manages most of the S&T plans (Walsh 2003). Furthermore, in terms of innovation, the private enterprises play a very limited role. For a country of China's size, innovative start-up firms are not emerging in large numbers, suggesting a lack of entrepreneurship among scientists and engineers in China.

According to Xielin and White (2001), for China's NSI to work effectively, five fundamental factors are required: R&D, implementation (manufacturing), end-use (customers), linkage (between actors in the S&T sector) and education. From the government perspective, the links for creating a national S&T network have been a priority since the beginning. The government monopolies over the transfer of resources between organizations have been dismantled in almost all fields. Institutions such as engineering centers, technology markets and productivity promotion centers have been put in place to channel activities between those that carry out R&D and those that manufacture.

## 4.4 BRAZIL—INNOVATION ENVIRONMENT

Brazil is a large country both in terms of area and population (175 million). For a country of this size, unlike India and China, Brazil did not build up capacities in a wide range of industries. Such a broad industrial base may not provide technological leadership in all areas, but helps in providing a sustainable base for economic activities and in creating employment for the semi-skilled population. Brazil, on the other hand, focused on certain areas (particularly natural resource-based and defense-related) and built up in-depth technological capabilities and international competitiveness through leading-edge technologies. This is a strategy usually adopted by smaller countries, particularly in Europe.

Brazil's S&T policies originated in the 1950s with the creation of two government agencies: (1) CNPq (initially called the National Research Council and now known as the National Council for Scientific and Technological Development) for conducting research; and (2) CAPES (Coordination for the Training of Human Resources at the University Level) for training human resources. This strategy was based on the linear model of technological development that was prevalent after the Second World War, when the idea of research and development was conceived as two distinct activities (similar to the case of India). While this model proved useful in industrialized countries with strong infrastructure, in Brazil it resulted in poor communication between academia and industry. Consequently, it contributed to shaping, what has been called in 2002 by Eduardo Viotti, a 'passive national learning system.' This has been the experience of countries, particularly developing ones that do not perform innovation activities themselves, but rely mainly on copying or adapting innovations from elsewhere (Morel et al. 2007, p. 180).

In 1990, the government changed its strategy for industrial development. Acknowledging the inadequacies of the import-substitution model in developing an internationally competitive industrial sector, the government opted for a policy of opening up the market to foreign competition and thus compelling domestic companies to attain international levels of quality and efficiency. Consequently, a number of technology and industrial policy programs were announced to support the industry, but they were not implemented diligently and therefore had little impact. Even the most publicized Quality and Productivity Program (Programa Brasileira de Qualidade e Produtividada—PBQP) that pursued an innovative approach (mainly trying to build a consciousness for quality issues within firms) had only a limited impact (PBQP 1992). Brazilian policymakers and researchers tend to attribute the limited effect of technology policy initiatives to the economic crisis in the 1990s that led to low investment by enterprises. However, the main reasons were in certain structural features of the Brazilian economy and the science system (e.g., fiscal incentives and university-industry links) (Meyer-Stamer 1995).

Since the beginning of 2000, however, Brazil's research performance is improving rapidly. Brazilian scientists published 15,777 articles in indexed scientific journals in 2005, accounting for about 1.7 percent of the world's production. This figure is almost three times as many as in the early 1990s, making Brazil the 17$^{th}$-largest producer of scientific articles in the world. Brazil has shown academic excellence in many niche areas, including photonics, material science, biotechnology and tropical agriculture. There is, however, a great need for improvement, particularly in terms of converting knowledge into productivity gains in the enterprise sector. Brazil spends about one percent of GDP on R&D (including both public and private), which is much lower than the OECD average of 2.2 percent of GDP. The number of triadic patents (i.e., patents filed in the world's three main patent offices) is comparatively low. Even the royalties and license fees paid to foreigners are low, partly reflecting the economy's relatively inward orientation to business operations. Much of the published scientific research is generated in public universities. The number of scientific publications rose in conjunction with the increase in the number of Ph.D.s awarded every year, from 554 in 1981 to 8,856 in 2004. In spite of such a growing trend, Brazil still faces a shortage of higher education graduates, especially in engineering and science (Brito Cruz and de Mello 2006, pp. 5–11).

According to the Innovation survey (PINTEC) conducted by IBGE, the National Statistics Bureau, during 2001–2003, about one-third of Brazilian firms with at least 10 employees engaged in innovation activities, but only six percent of them were reported to have engaged in product-related R&D. The innovation rate has been rising relatively faster in sectors that are predominated by SMEs. For instance, in 2003, the motor vehicle and the transport equipment sectors accounted for 26 percent and 13 percent of total R&D expenditure, respectively (Brito Cruz and de Mello 2006, p. 13).

In order to address these weaknesses in NSI, Brazil adopted a new innovation policy in 2003, known as PITCE (Politica Industrial, Tecnológica e de Comércio Exterior), which explicitly focuses on the promotion of R&D activities in the business sector and aims at better integration of innovation into the industrial and trade policies. A legislation enacted in 2005 introduced tax incentives for innovation as part of a broader package for reducing the tax burden on the business sector and facilitating the sharing of proceeds from IPRs between businesses and universities/research institutions. This policy framework, however, needs to address the shortage of skills in the labor force, which is among the most important barriers to innovation in Brazil (Brito Cruz and de Mello 2006).

According to Meyer-Stamer (1995), Brazilian policymakers tend to see fiscal incentives as a key instrument of technology policy. From an economic point of view, the justification for fiscal incentives for R&D is rather closely linked to R (research) rather than to D (development). In industrialized countries, innovative behavior is a basic feature of any corporate competitive strategy, and this need not be stimulated by fiscal incentives (even though they exist in some countries). Companies fear not surviving in the market if they are not innovative. The major proportion of R&D expenditure of Brazilian companies is in development, but policymakers consider it normal to stimulate such product development efforts with fiscal incentives. On the other hand, fiscal incentives for R are more justified than for D. Corporate research activities generate externalities, and these externalities are much larger than the direct benefits to the company. Therefore, incentives for R are a compensation for these externalities.

Brazil being a decentralized federation, the states play an important role in formulating S&T policies and in financing R&D, although most support comes from the federal government. Programs aimed at human resource development and academic research accounted for over two-thirds of federal spending on R&D in 2002. This included funding for the 52 federal higher-education institutions, CNPq and CAPES (the two federal postgraduate research support agencies) and transfers to the Brazilian Agricultural Research Corporation (EMBRAPA). The states have their own S&T policies and support agencies, as well as higher education and research institutions. According to the Brazilian Ministry of Science and Technology, the states accounted for about 35 percent of government spending on S&T in 2003. The state of São Paulo has the largest state-level R&D support system and is also the largest recipient of federal funds. Nevertheless, about two-thirds of public funding for R&D comes from state sources, including funding for three state universities, 19 research institutions and FAPESP (the state's S&T support agency). The state of São Paulo is the second-largest spender on R&D in Latin America, ahead of Mexico and Argentina (Brito Cruz and de Mello 2006, p. 6).

This growing number of scientists and engineers has enabled the launching of collaborative research programs that require a large number of researchers. For instance, the Genome Project, set up in São Paulo in partnership with the Citrus Producers' Association (Fundecitrus), resulted in the DNA sequencing of a phytopathogenic bacterium, the *Xylella fastidiosa*. This enabled Fundecitrus researchers to devise ways to protect orange trees from a disease (citrus variegated clorosis—CVC) that had been responsible for considerable economic loss in the past. This joint venture project also resulted in at least two spin-off companies in the field of genomics and bioinformatics (Brito Cruz and de Mello 2006).

EMBRAPA (The Brazilian Agricultural Research Corporation) was established in 1973 to 'develop solutions for the sustainable development of the country's rural areas, focusing on agribusiness through the generation, adaptation and transfer of knowledge and technologies to benefit Brazilian society.' Under its control there are 37 research centers (including three service units and 11 central divisions) and 2,221 researchers (53 percent of them hold a Ph.D. or other doctoral degree). Most research centers carry out commodity-specific research, while some are involved in thematic research (e.g., environment, genetic resources and biotechnology, agrobiology, among others) and/regional issues. It also has two overseas laboratories located in France and the US. EMBRAPA plays a key role in technological upgrading in farming by developing techniques for biological and integrated control of harmful biological agents. It is also the coordinator of the National System of Agricultural R&D, including federal- and state-level R&D institutions, universities and enterprise, which conduct collaborative R&D projects relevant to different regions of the country.

Similarly, there have been some successes even in the pharmaceutical sector. The number of graduates and education programs in disciplines relevant to the pharmaceutical industry, particularly chemistry, has increased.

Institutes such as the Oswaldo Cruz Foundation (Fiocruz) in Rio de Janeiro and the Butantan Institute in São Paulo have become established producers of immunobiologicals and pharmaceuticals. Private companies such as Aché Laboratories, Cristália and Nortec Quimica are developing and launching new drugs and manufacturing synthetic ingredients of pharmaceuticals. The recent policy and legal changes focus on generating new drugs to treat neglected diseases. For instance, the Department of Science and Technology, which was created as part of Brazil's Ministry of Health in 2000, joined forces in 2006 with the Ministry of Science and Technology (through CNPq) to address six neglected diseases: dengue fever, Chagas' disease, leprosy, malaria, tuberculosis and the various forms of leishmaniasis (Morel et al. 2007).

Until recently, most Brazilian firms did not have R&D departments, as these firms did not confront challenges and opportunities that would have compelled them to invest in R&D or seek external research support. But this was only one reason for the clear separation between research and industry. Other reasons, according to Castro (1989), include:

- The easy availability, particularly in the 1970s, of research funds from public sources, which gave the scientific community a lot of leverage to define research priorities according to their personal interests;
- The Ph.D.s returning from abroad brought with them the kind of research ideals that led to their striving for academic reputation rather than application of their research results. Often their research was also oriented toward the line of activity of their foreign alma mater rather than domestic priorities.

In order to promote the participation of scientists and engineers in the business sector, in 2005, the government announced a deductibility of 50 percent of the spending on salaries paid to scientists from corporate income tax in order to motivate companies to recruit highly qualified scientists and engineers.

The patenting activity in Brazil is dominated by the government-controlled organization. Petrobras, the government-owned oil company, is Brazil's most important holder of triadic patents among firms. Patenting by academic institutions is also gaining momentum. Successful among them include the University of Campinas (Unicamp) and the Federal University of Minas Gerais (UFMG), as well as the FAPESP in the state of São Paulo. Unicamp is the largest holder of domestic patents, followed by Petrobras. Unicamp's innovation agency, Inova, established in 2002, is involved in licensing the university's IPRs and generating revenue for the university. Most licenses tend to be exclusive, since the licensee participates in collaborative R&D with the university. Licensing contracts were mainly in the areas of pharmaceuticals and phytotherapeutic agents, food processing and nanotechnology-incorporated products (Brito Cruz and de Mello 2006; www.inova.unicamp.br).

A unique feature of the Brazilian NSI has been the incubator movement. It represents a new direction in Latin American science, technology and industrial policies by shifting the responsibility from central government, from where policies have traditionally originated, to multiple sources of initiative. The Brazilian incubator movement emerged in the wake of the collapse of the military regime and the renewal of civil society in the 1980s. The absence of centralized projects provided considerable leverage in applying the incubator concept to a range of activities with different aims. The concept of incubator allowed Brazil to formulate a less costly development model, which utilized the available academic, industrial and government resources. "Bottom-up initiatives from universities and municipal governments converged with lateral ones from industry groups, regional associations and state governments as well as top-down program from national government. An important innovation policy was created out of the sum of these initiatives from different sources" (Etzkowitz et al. 2005, p. 412).

The interactions among industry, university and government occur in the various types depending upon objectives of the incubator. Universities are the lead initiators in high-tech incubators, where the knowledge component is high; industry takes the lead in the traditional incubators where the objective is to improve the organizational capabilities of firms; and government in the social incubators where the objective is to provide employment. However, such distinction is blurred as each of the actors plays a role in all types of incubators. For instance, the industry provides finance to the high-tech incubator, whereas the university provides training assistance in the social incubator (Etzkowitz et al. 2005).

This complexity in the nature of organizational infrastructure is concomitant with the devolution of powers from the national level to the local governments and the creation of new regional entities (Mustar and Laredo, 2002[4]). This transformation motivates universities, the industry and local governments to undertake collaborative innovation projects and increase the capacity of clusters by encouraging a broader set of 'Local Productive Arrangements' (Cassiolato et al. 2003).

The expertise gained in establishing high-tech firms in incubators has been applied to create organizational capabilities and employment in the 'favelas' (slums). The first Technological Incubator of Popular Cooperatives (ITCP) was established at the Graduate Engineering School (COPPE), Federal University of Rio de Janeiro (UFRJ), in 1995, as a cooperative of workers from the Manguinhos favela. In order to recruit participants, the project utilized retired university support staff who were also favela residents. The university provided classrooms for meetings and technical support, where training is given in basic principles of cooperativism, management, basic education and legal status of the cooperative (Pereira, 1998[5]).

According to Brito Cruz and de Mello (2006), Brazil's NSI is complex and requires a strong coordination between federal and state-level agencies. Often state and federal policies and programs are designed and implemented separately, resulting in overlapping institutional settings and fragmentation in funding. However, efforts are being made to promote effective coordination through the National Council of State Secretaries for Science, Technology and Innovation (CONSECTI) and the National Council of State Research Agencies (CONFAP), especially in the National Council for Science and Technology (CCT). At the federal level, CCT, an advisory body to the presidency, has the policy coordination role, while the Ministry of Science and Technology (MCT) acts as an executive body in association with the assistance of FINEP (MCT's financial support agency), CNPq (Coselho Nacional de Desenvolvimento Cientifico e Tecnológico) and CGEE (Centro de Gestao e Estudos Estratégicos). The industrial policy is formulated by the Ministry of Development, Industry and Trade (MDIC) through CNDI (Conselho Nacional de Desenvolvimento Industrial) and ABDI (Agéncia Brasileira de Desenvolvimento Industrial). "Coordination among these agencies is promoted by representation of MCT and MDIC in both CCT and CNDI. The sectoral funds are governed by MCT, with assistance of a technical secretariat. Each fund has a management committee and coordination is fostered through regular meetings that bring together the presidents of these committees under the purview of the MCT" (p. 17).

The Brazilian innovation agency, FINEP, established under the MCT in 1967, has been a key player in prioritizing technological innovation, funding innovative projects in the public and private sectors and forging ties between industry and the academia. Grants provided by FINEP, through the National Fund for Science and Technology, cover all aspects of ST&I development process, have traditionally been granted to research institutions and nonprofit organizations and have recently been made also available to private enterprises. In 2005, out of the 3,700 grant applications received through 26 calls for proposals, 1,021 projects were granted funding. FINEP, with financial support from the Inter-American Development Bank's (IDB) Multilateral Investment Fund (MIF), created the 'Inovar Project' in 2000. Inovar is a financial mechanism to support small high-tech start-ups through venture capital funds. The project has since established 24 funds, half of which have been invested in by the MIF. FINEP has also created the 'Inovar Seed Money Program' (Inovar Semente) to facilitate availability of seed and early stage funds for small entrepreneurs (IDB 2006).

As a private-sector initiative, the Intel Capital (of Intel Corp.), recognizing the growing importance Brazil as a technology leader, has created a US$50 million venture capital fund to promote technology growth in Brazil. The fund is used to invest in companies that can benefit from the rapid growth of technology in Brazil and to provide local businesses with capital to help nurture important technologies and products developed for local use. Such businesses include hardware, services (broadband infrastructure and mobile wireless solutions using WiMAX technology, among other services), local content developers/providers, digital health solutions, IT service providers and software solutions. Intel Capital has been a leading venture capital investor in Brazil since 1999, investing over US$35 million in 13 companies. In 2005, Intel Capital announced four local investments in Digitron, TelecomNet, Certsign and Neovia (Intel News Release 2006).

According to Cassiolato (2006), the Brazilian NSI reflects the following weaknesses:

- Weak competitive performance with significant trade fragilities in all sectors of high added value and technological content;
- Widespread loss of national ownership in many sectors, weakness and reduced size of Brazilian business groups;
- Persistent financial vulnerability of Brazilian-owned businesses resulting from very high costs of capital and nonexistence of long-term financing mechanisms.

## 4.5 SOUTH AFRICA—INNOVATION ENVIRONMENT

South Africa, with a population of 40 million, is a medium-sized country. Unlike India and China, South Africa did not build up capacities in a wide range of industries. But it focused on certain areas and built up advanced technological capabilities and international competitiveness in those industries. The reason for this partly lies in its history. During the apartheid regime, the S&T system mainly catered to only to a smaller section of the population (about five million) and thus focused only in areas where it had a competitive advantage or in areas that were required for strategic purposes. Now, perhaps, South Africa needs to revise its S&T strategy. A broad industrial base may not provide technological leadership in all the areas, but helps in providing a sustainable base for economic activities and in creating employment for the semi-skilled population, which is perhaps essential for a country like South Africa.

The South African NSI, compared to many other developing countries, is relatively mature and more developed. It has a clear set of policies, a strong network of performing institutions and funding agencies and a relatively successful track record for innovation activities. However, over the last three decades, the NSI has fallen behind relative to its peer countries (such as South Korea, India and Brazil). There are several reasons for this: first, under the apartheid regime, the NSI became fragmented and isolated. In certain specialized areas, however, internationally acclaimed technology development was undertaken (e.g., liquid fuels, atomic energy and military hardware), but these areas did not integrate with the competitive strengths of the larger economy. Second, apartheid policies resulted in a failure to develop the potential of the nation's human resources. This failure has now become a critical weakness of NSI in its efforts to support the growing economy. The output of trained human resources is inadequate in meeting the increasing demand for well-qualified scientists and engineers (NACI 2006a).

After the new government was formed in 1994, it adopted a Reconstruction and Development Program (RDP) as its basic policy framework and identified economic policy strategies across a wide range of issues and sectors. By late 1995, however, there was general disappointment in the RDP's limited growth and employment impact. Because of this and the foreign exchange crisis in 1996 that South Africa faced, the government announced a new macroeconomic policy, in June 1996, called 'the Growth, Employment and Redistribution (GEAR) Strategy.' This strategy focused on stabilizing the foreign exchange market as well as achieving growth by raising both FDI and domestic investment through credible macroeconomic policy involving tighter fiscal and monetary policy. GEAR achieved many of its macroeconomic targets (such as containing fiscal deficit), but it did not achieve the set targets of six percent annual growth and creation 500,000 new jobs by 2001. The new Accelerated and Shared Growth Initiative for South Africa (ASGISA) Program of 2004 is intended to address this issue of growth with employment, with an objective of halving poverty and unemployment by 2014, through an average economic growth rate of five percent per annum over the 10-year horizon (NACI 2006a).

According to Marais (2000), the S&T activities in South Africa can be traced to ancient times and include pigment mining (4000 B.C.E.), mummification (dating to about 2,000 years ago), iron metallurgy ($3^{rd}$ to $4^{th}$ century C.E.) and gold mining and processing ($12^{th}$ century C.E.). But, in terms of formalized scientific efforts, the establishment of the Royal Observatory in the Cape Colony in 1820 marked a beginning, and the first higher education institution (HEI), which later became the University of Cape Town, was founded in 1829. The first official initiative to support academic and industrial research dates to 1917, when the Industries Advisory Board was set up. The international response to the apartheid regime, which began in the 1960s, unwittingly helped in building up strong capabilities in certain areas. In response to the increasing isolation of the country, the South African government put a lot of efforts into both public and private S&T institutions to achieve self-sufficiency in a small set of strategic areas, including energy, liquid fuels and defense. Consequently, South Africa built up a relatively strong military-industrial complex (e.g., atomic weapons, missiles and other military hardware), and the strengthening of Sasol (for liquid fuel production) and the Atomic Energy Corporation (for nuclear power), both of which received substantial government support over that period (NACI 2006a).

In an effort to undo the negative aspects of the apartheid regime, in 1996 the White Paper on Science and Technology created the policy framework for an NSI. It consists of at least five inter-related national sectors (each comprising a set of institutions with a common objective) and four interdependent functions, all of which operate within an international context.

The national sectors are as follows (DST 2004, p. XVI):

- The Department of Science and Technology (DST), which is responsible for overseeing the resourcing and management of public NSI institutions and has direct line management responsibility for S&T;
- The Department of Education and Higher Education Institutions, the combined role of which is to provide a pool of high-level human resources and to generate new core knowledge;
- The Departments of Trade and Industry, Minerals and Energy, Environmental Affairs and Tourism, Agriculture, Water Affairs and Forestry, Health and other government departments, which both fund and perform R&D, focusing on a number of core public sector functions such as agriculture, health, weather services, the promotion of innovation within industry, energy research and environmental management;
- The business sector, including industry and state enterprises such as Eskom, where knowledge is transformed into innovation;
- The nongovernmental organization (NGO) sector, which undertakes R&D principally in areas of high public interest (social or environmental) or in the event of market failure.

The four S&T functions are:

- Policy formulation and policy advice: DST, The Council on Higher Education and NACI are the key players;
- Funding: The National Research Foundation, the Medical Research Council and so on;
- Performance;
- International relations in S&T.

### *National Advisory Council on Innovation (NACI)*

As a follow-up action to the White Paper, the National Advisory Council on Innovation (NACI) was created by legislation in 1997 to advise the Minister of Arts, Culture, Science and Technology on the role and contribution of science, mathematics, innovation and technology, including indigenous technologies, in promoting and achieving national objectives of:

- Improving and sustaining the quality of life of all South Africans;
- Developing human resources for science and technology;
- Strengthening the country's competitiveness in the international sphere.

The scope of the work of Council is organized in terms of five 'strategic themes,' each of which is a responsibility of a subcommittee of Council members. The subcommittees address critical themes within their domains and formulate advice aimed at improving the functioning of NSI. Subcommittees are responsible to:

- Advise Council on important strategic issues on which advice should be generated;
- Approve the scope and implementation of evidence gathering under that strategic theme;
- Guide the drafting of any ministerial advice on the particular strategic theme.

*Strategic Themes*

- Infrastructure for innovation promotion: the main causes for concern for the sustainability of minimum levels of innovation in developing economies have been the inadequate and obsolete physical infrastructure and low expenditure. Therefore, an important strategic focus of NACI is to provide advice on necessary dimensions and conditions defining an environment that would promote innovation.
- Human capital and knowledge base: two of the key elements of any innovation system are human resources and knowledge. South Africa is especially vulnerable with regard to the provision and spread of its human resources and the challenges posed to its knowledge base by the dual nature of its economy. Therefore, NACI focuses on the parameters of an optimal human resource- and knowledge-base, including the optimal use of both.
- Science, Technology and Innovation (STI) for competitiveness; the innovation efforts in South African industry are mainly related to adaptation of imported technologies, and industrial growth has not generated the desired number of new jobs. Hence, it is important for NACI to develop an understanding of the dynamics of innovation and competitiveness in industrial enterprises, with a view to identifying how these might be enhanced.
- Social dimensions of innovation: it is recognized that the social processes underlying innovation and competitiveness and the social consequences of innovation and competitiveness are not sufficiently understood and accounted for. Social factors (individual, communal, national) are facilitating and inhibiting the adoption of innovation in the second economy on the one hand and facilitating innovation generation in the first economy on the other.
- Position and role of NACI in the NSI: ensuring that NACI delivers on its mission in the best possible way, namely to advise the Minister of Science and Technology on issues relating to the NSI (NACI 2006b, pp. 20–23).

In the early 1990s, as the apartheid state headed for dissolution, the government reduced the levels of expenditure on ‘technology missions’ and experienced a drop in the national R&D spending from 1.1 percent in 1990 to 0.7 percent of GDP in 1994. At the same time, due to global uncertainties and other factors, the private sector also reduced its spending on R&D in South Africa. Unfortunately, the reduction in R&D spending occurred at a time when the NSI needed to expand to cope with the needs of 40 million people, as opposed to a mere five million or so in the previous regime (DST 2004, p. XVI).

In 2002, the Cabinet accepted the National Research and Development Strategy as the basis for further strengthening of NSI. The Department of Science and Technology (DST) came into being on August 1, 2002 after its separation from Arts and Culture.

### *Technology Missions*

> Expansion of innovation activities required the establishment and funding of 'technology missions.' including the two key technology platforms of the modern age: biotechnology and information technology. Two other missions are: technology for manufacturing, and technology for leveraging knowledge and technology platform, particularly to add value to the natural resources sector. Finally, we have established technology for poverty reduction (one of the key elements of this mission) to address one of scourges of our age. Seed financing is being provided in the areas of advanced manufacturing and logistics and resource-based industries such as mining and agriculture. (DST 2004, p. XVII)

In January 2002, the Cabinet Lekgotla (workshop) discussed the lack of strategic approach to the management of the state-funded portion of South Africa's S&T system. Following this discussion and the National R&D Strategy adopted by the Cabinet in July 2002, the Cabinet in 2004 approved detailed planning around a new governance framework. The new framework classifies the technology-related activities supported by government into three basic types:

1. Early-stage or highly cross-sectoral generic technology or knowledge platforms and core human capital, for which the DST would take responsibility;
2. Focused, sectoral and relatively mature technology domains, which would primarily be the responsibility of line departments, with DST assistance where required; and
3. Standard technology-based services, for which the line departments would take the responsibility (DST 2004, p. XVII).

Among the technology missions announced by the DST, biotechnology figures as a critical sector for research and commercialization. The National Biotechnology Strategy was initially published and financed at a seed level in 2003–2004. Biotechnology "falls squarely within the national innovation strategy, and is an example of one of the 'niche' industries identified by government and the private sector as worth pursuing because of South Africa's relative strengths in particular areas. Other such niche areas include: aerospace; astronomy; automotive production; mining engineering and prospecting; advanced manufacturing such as nanotechnologies; nuclear power and alternative energies; medical research into malaria, TB and HIV/AIDS; specialized pharmaceuticals; and medical technologies such as prostheses" (DST 2004, p. 68).

Following such prioritization of biotechnology, in 2003 the CSIR, through its Bio/Chemtek business unit, formed a public-private partnership with Bioventures to form Mbuyu Biotech, a black empowerment company. Mbuyu has been granted a worldwide license to further develop, demonstrate and commercialize three CSIR-developed biotechnology manufacturing processes: The first is a novel process to cater to the worldwide nutraceutical demand for natural β-carotene, found in carrots, palm oil and fruits. The second process is the conversion of low-value aloe ferax resin found in the sap of the Cape Aloe ferax plant to high-value aloesin, commonly used in the cosmetics market; and the third is the development of a process for the production of the aroma compound I-menthol from low-value raw material (DST 2004, p. 91).

Similarly, in another project, the CSIR's Bio/Chemtek business unit is launching a commercial mosquito repellent. CSIR developed a novel natural method for repelling mosquitoes, including species that carry malaria. The new product has resulted from the collaboration between Bio/Chemtek's bioprospecting program and traditional healers that began in 1998. The repellent is derived from a plant whose leaves have long been hung inside houses to keep insects at bay. After being contacted by communities in Mpumulanga province, the CSIR unit took the plant and isolated, identified and formulated its active ingredients. Tests by the South African Bureau of Standards (SABS) established that it was far more effective than other products in the market (nearly 100 percent effective compared with about 40 percent for other repellents). The indigenous plant is being cultivated and distilled by community-owned businesses in three provinces to produce the active ingredient used in mosquito-repellent candles. Bio/Chemtek signed a benefit-sharing agreement with traditional healers during 2003 that ensures future income and other benefits to communities, as owners of the indigenous knowledge that led to the research (DST 2004, p. 99).

### 4.5.1 University System

The first South African university was established in 1829. South African universities have had research as an integral mission since the early 20$^{th}$ century, and today research remains an essential component of their activities. In the last few years, there has been a rationalization of this sector through mergers between selected institutions, which has resulted in a total of 23 universities (from 36), four of which are classified as universities of technology. It is estimated that the academic staff spend approximately 20 percent of their time on R&D work. The higher education sector accounts for 23 percent of research expenditure and 33 percent of full-time equivalent (FTE) human resources engaged in research. There are approximately 50,000 postgraduate students enrolled at South African universities. In 2003, higher education institutions (HEIs) produced some 3,500 publications (NACI 2006a, p. 32).

According to the Council on Higher Education (2004), the HEIs in South Africa are facing a number of challenges within the present system: First, in principle, universities are the main locations of fundamental and basic research and postgraduate education; universities of technology are associated with industry-specific applied research; and the public research institutions (PRIs) predominantly undertake national mission-oriented or strategic research, with a market-focused approach. However, this division of work is undergoing a transformation as financial constraints compel both universities and PRIs to seek private and international donor funds. Second, the higher education sector is the nexus of reorganization through mergers, with a reduction in the number of universities. At the same time, there has been a sharp growth in student numbers (from 522,658 in 1994 to almost 718,000 in 2003). Moreover, the higher education sector is a key player in addressing the goals of racial equity in the postapartheid era. The compound effect of these three forces is causing considerable stress on the productive capacity of the system (NACI 2006a).

### 4.5.2 Public Research Institutions (PRIs)

There are currently 12 major PRIs, which are R&D performing institutions. The first and largest PRI, the Council for Scientific and Industrial Research (CSIR), was established in 1945. The other PRIs are the Agricultural Research Council, the Human Sciences Research Council, Mintek (for mineral processing research), the Medical Research Council, the South African Bureau of Standards, South African Weather Services, the Council for Geoscience, the South African National Energy Research Institute, the South African National Biodiversity Institute, the Marine and Coastal Management division (a division of the Department of Environmental Affairs and Tourism) and the Africa Institute of South Africa. In principle, the funding of the PRIs consists of a budgetary grant by the government (on average 50 percent of the total budget of the institution) and income generated through contract activities, which accounts for the rest of their budgets. The science councils account for 17.3 percent of total national expenditure on R&D and employ 23 percent of the total FTE R&D workforce (NACI 2006a, pp. 33–4).

### 4.5.3 Business Sector

Unlike in other developing countries (including emerging economies), the business sector is the major performer of R&D in South Africa. In-house R&D in the business sector accounts for 58 percent of total national R&D performance and 45 percent of expenditure and 25 percent of all R&D workers employed. Within the business sector, manufacturing is the largest investor in R&D expenditure (44 percent of total business sector expenditure on R&D). In the past, certain segments of the business sector were strongly supported by government, particularly within certain strategic sectors, such as energy (Eskom, Atomic Energy Corporation and Sasol), defense (Armscor) and mining, but now much of this highly focused funding has been terminated (NACI 2006a, p. 34).

In South Africa, there are mainly three ways of supporting business R&D: (1) funding in direct support of R&D projects (the Innovation Fund, the Technology and Human Resources for Industry Program and the Biotechnology Regional Innovation Centers); (2) funding for technology transfer and similar initiatives (Godisa and Tshumisano trusts); and (3) indirect support through tax rebates (NACI 2006a).

The international success of Sasol, South Africa's largest industrial company, in the past decade owes much to its innovative and competitive technologies in the energy and chemical sectors. Sasol was founded in the 1950s as a strategic industry and entrusted with the task of supplying oil to a country that was becoming increasingly isolated by international disapproval of apartheid. As there were no known natural petroleum reserves in South Africa, Sasol adapted the pre-war German Fischer-Tropsch process for refining oil from coal. Sasol's success with this innovative technology turned it into the world's only mass producer of oil from coal. With the change in regime and liberalization of the economy, Sasol seized the opportunity to increase its exports, mainly petrochemicals produced from the now highly improved coal-to-oil process. Sasol has also gained international recognition for developing its proprietary gas-to-liquids (GTL) technology for the production of new generation fuels and chemical feedstocks that can be derived by beneficiating some of the world's vast natural gas reserves. Two of Sasol's most significant advances since 1990 have been the new-generation Fischer-Tropsch technologies: the high-temperature Sasol Advanced Synthol (SAS) process; and the low-temperature Sasol Slurry Phase Distillate process (SPD process). The SPD process is a critical part of Sasol's technology and has led to the development of high-quality, low-emission gas-to-liquid diesel. The company now manages diverse exploration, production, development, marketing and sales operations in more than 30 countries. Sasol is currently developing two joint venture gas-to-liquid (GTL) plants based on its SPD process in Qatar and Nigeria. They are set to become the world's first commercial operator of GTL technology outside South Africa (DST 2004, pp. 10–11).

# 5 Global Innovation in India

India has now gained a reputation as a 'global R&D hub' for MNCs. Based on a global survey, the Economist Intelligence Unit (EIU) termed India an R&D 'hotspot.' EIU defined an R&D hotspot as "a place where companies can tap into existing networks of scientific and technical expertise; which has good links to academic research facilities; and provides an environment where innovation is supported and easy to commercialize" (EIU 2004).

Starting with the establishment of global R&D units by Texas Instruments (TI) and Astra Research Center India in 1985, India has been attracting R&D-related FDI. Companies like Motorola and Hewlett-Packard followed in the early 1990s. By the end of 1999, there were 196 global R&D units, including wholly owned units and technology alliances in India (Reddy 2000, pp. 97–99). A World Bank study estimated that by the end of 2007, there were about 370 R&D units set up by MNCs (World Bank 2008). However, it is not clear how many of these units are involved in global product development and how many focus on an adaptation type of R&D. Nevertheless, the global innovation activities of MNCs are increasing rapidly in India. Among the MNCs that set up global R&D facilities in India are: Caterpillar, Cisco Systems, DaimlerChrysler, DuPont, General Electric, IBM, Intel, Lucent, Microsoft, Oracle, Philips, SAP. GE's John F. Welch Technology Center in India, with an investment of US$80 million and 1,600 researchers, is the company's first and largest R&D center outside the US.

According to TIFAC (2006), between 1998 and 2003, foreign companies have spent US$1.1 billion on R&D in India. Some highlights of MNCs' global innovation activities in India include:

- The German semiconductor firm Infineon's R&D center in Bangalore carried out a significant part of the design and development of the most densely populated processor for mobile phones. The chip, named 'Maple,' is the first chip for mobile applications that has been developed using 65 nanometer technology. It contains 30 million transistors, enabling the mobile phone to perform many more functions than presently possible, without extra battery power.[1]

- The Center for Excellence for Mobile Devices at the Microsoft India Development Center (MIDC) has developed 'Microsoft Office Communicator Mobile,' a unique communications client integrating mobile applications with enterprise-grade, real-time communications tools.[2]
- Intel unveiled its futuristic chip, called 'single-chip cloud computer.' It has 48 cores and has processing power 20 times higher than what is presently available. The chip was developed over a two-year period by a team of 40 engineers located in Intel's global R&D centers in Bangalore, India; Hillsboro, New Jersey, US; and Braunschweig, Germany. All three centers contributed equally to the project. The Indian center has contributed in the areas of circuit and physical design, memory controller logic and the mesh interconnect network.[3]
- China's telecom major, Huawei Technologies, has R&D centers in Bangalore, New Delhi and Chennai in India. Huawei's Indian R&D activities are in high-end telecommunications areas like voiceover Internet protocol (VoIP), 3G and Bluetooth. Its solutions cover areas like core layer, transmission layer and access layer. It develops products for fixed networks, mobile networks and data communications. In terms of software outsourcing, Huawei has several partners in India, including Hughes Software Services, TataElxsi, Silicon Automation Systems, Mphasis-BFL, Encore and FutureSoft.[4]

MNCs conduct R&D in several different forms in India: (1) wholly owned stand-alone R&D units, reporting directly to the MNCs' headquarters; (2) joint venture R&D with Indian companies; (3) technology alliances with Indian companies, including outsourcing of R&D to Indian companies; and (4) research collaboration with Indian universities and national research institutes.

One of the unique features of the R&D environment in India is the emergence of R&D service providers in a range of fields in India. Such service providers include both foreign and local companies. Indian ICT and pharmaceutical R&D service providers have established their reputation as capable companies by mastering the delivery processes and are being assigned more high-end R&D activities by MNCs. In addition, Indian national research institutes are being sought after by MNCs for collaboration in basic science research. While many MNCs collaborate with these institutes on specific short- and long-term projects, some MNCs have set up their own R&D centers within the campuses of these institutes.

Another new development is the innovation activities of large Indian companies, which started developing products for global markets on their own. Until recently, Indian companies performed very little research and depended on technology transfer from abroad or on copying off-patent products. Their turning into innovators for global products has implications for the national systems of innovation (NSI).

The main reasons for location of R&D in India include: availability of a large pool of talented scientists and engineers, entrepreneurial traditions, existence of well-known universities and national research institutes, a large domestic market and substantially lower wages of research personnel compared to the industrialized countries (P. Reddy 1997). India's pool of young university graduates (those with seven years or less of work experience) is estimated to be 14 million (1.5 times the size of China's, almost twice that of the US), with an annual increase of 2.5 million new graduates (Farell et al. 2005). The number of professionals employed in the IT and IT-enabled services industry has increased from 51,000 in 1990 to about 1.3 million in 2006 (NASSCOM 2006).

Through in-depth case studies of the innovation activities of MNCs, Indian companies (including R&D service providers) and Indian universities/research institutes, this chapter analyzes the global innovation activities in India.

## 5.1 MULTINATIONAL CORPORATIONS (MNCs)

## Motorola

The telecom major Motorola (a US-based MNC) is an innovation-driven firm, with US$4.4 billion spent on R&D in 2007. Its worldwide patents granted numbered 22,978 at the end of 2007. At the end of 2004, Motorola had major R&D centers (those with over 100 R&D staff) in 19 countries worldwide, including: two in North America, six in the initial EU-15 countries, one each in Poland, Brazil, China, India, South Korea, Malaysia, Singapore and Russia. The first overseas R&D centers of Motorola were opened in 1950 in Canada and the UK, followed by various other European locations in 1960. Motorola is one of the few MNCs that started conducting R&D in developing countries fairly early, with operations in Singapore and Malaysia as early as in the 1970s. Most R&D centers concentrate on product development, mainly adaptation to local or regional markets, rather than on research. Research activities are mainly concentrated in the US, UK, Israel, India, China and Russia (UNCTAD 2005, p. 143).

### *R&D in India*[5]

Motorola originally entered India in the 1980s to sell different components and radiophones. However, establishment of an R&D center in India by Motorola was unrelated to these marketing operations. In the late 1980s, Motorola had a core corporate group called 'Software Engineering Group' based in Chicago, Illinois, US. This group discussed the possibilities of setting up a panglobal software R&D organization outside the US in order to access global talent. Following this at the end of 1991, a Global Software

R&D Center was established in India and later also in China. From the beginning, the center in Bangalore, India, was treated as a 'High Maturity Software Process Organization,' and was equipped to achieve CMM level five, as per the process/capability maturity model devised by Carnegie Mellon University, which ranks the capabilities of the software companies in terms of levels one to five (five being the highest).

In the beginning, because the center was a new concept within Motorola's global organization, only a few divisions, such as the land mobile and semiconductor product sectors, assigned some software development work to the center. In November 1993, the center decided to apply for a formal CMM assessment, and it was ranked as a level five organization. It was a big achievement to reach that level within two years of its establishment, even before any of Motorola's other R&D centers (including those in the US) achieved it. It became the first commercial software company in the world to achieve this status. Prior to Motorola, other organizations that achieved CMM level five were noncommercial organizations such as NASA, Boeing and Defense Labs in the US. This gave a worldwide visibility to the Indian center and created an interest in the global software industry.

Since then the center has grown from 150 people in 1993 to over 2,000 people at the end of 2005 and 3,500 people at the end of 2007. By 2006 Motorola's R&D investment in India had become US$85 million in technology and R&D, increasing from US$50 million in 2002.[6] Motorola's Global Software Group (GSG) in India actively files for patents. For instance, in 2005 it filed for 50 patents. In 2006, the number was expected to go up to 70 to 80 patent filings.

The complexity of the R&D work undertaken has also increased significantly as time progressed. The center, which began by developing test environments, test cases and test scripts, has moved to carrying out cutting-edge technology software for mobile phones and wireless infrastructure equipment that are the core activities of Motorola. The company identified India as a global technology development (R&D) base, which is reflected in its scope and scale of operations in India. By 2007, its development centers in Bangalore and Hyderabad started working on core technology and software development for the next-generation wireless infrastructure technologies and applications.[7]

### *Driving Forces*

The major reasons for location of R&D in India by Motorola in 1990 included:

- Access to India's proven best-in-class scientific and engineering talent was the primary motive.
- Adequate supply of and access to domain expertise enable ramp-up of the teams more easily and quickly.

- Opportunity to work with internationally reputed research institutes and universities in India.
- Exploiting cost differentials was another factor.
- In recent years, gaining access to local markets through locally suited innovative products has also become an important reason for expansion of R&D as the economies of India and other emerging markets started growing rapidly.

In 2007, Motorola's R&D in India was located in Bangalore (Motorola Labs, Global Software Group, Core Network Division) and Hyderabad (Global Software Group, Embedded Software Solutions), and its operations were divided into three businesses: Enterprise Mobility Solutions, Home & Network Mobility and Mobile Devices. The company's focus areas included: mobile handsets, wireless infrastructure, managed and hosted services, broadband equipment (both wired and wireless), trunking and two-way radios, software development, applied R&D on media mobility/convergence technologies.[8]

- Mobile devices—R&D related to a range of products and services, including wireless handsets, cellular and wireless systems and integrated software applications as well as a large complement of Bluetooth-enabled accessories.
- Networks—R&D performed in two divisions: (1) Core Networks Division (CND); and (2) Embedded Communications Computing (ECC). Focus on new telecom switching technologies and products across CDMA and GSM/UMTS networks as well as driving seamless mobility enabling solutions and embedded computing capabilities for network servers. Motorola acquired the global operations of a company called Winforia and made it a part of its Core Networks Division. The Indian unit predominantly develops software for networks. Motorola's Network R&D centers are located in US (Schaumburg, Illinois), Paris (France), Tokyo (Japan) and Bangalore (India).
- Broadband home solutions—R&D related to products that include digital video system solutions and interactive set-top boxes, voice and data modems for digital subscriber line and cable networks, and broadband access systems for cable and satellite television operators, wireline carriers and wireless service providers.
- Global Software Group (GSG)—the oldest and largest international center for software R&D, the group conducts cutting-edge work for the entire range of Motorola's products, including next-generation wireless and broadband technologies, software platforms and application frameworks. The group's mandate is to find ways to make software an integral part of Motorola's tools or products or to separate unbundled software products. Today, nearly every Motorola GSM set has a GSM/GPRS signaling stack developed in India, and Motorola's

Internet browser and multimedia-messaging system on 3G and GSM phones were conceived, engineered and delivered in India.

- Motorola Laboratories—Motorola Labs (new name), set up in 1998 in the corporate headquarters, is a global team of scientists, researchers and technologists focused on inventing, developing and applying new architectures, technologies and applications to design the future of media mobility. In 2005, Motorola Labs consisted of research 'centers of excellence': Wireless Access; Networks and Systems; Human Interaction Research, Applications, Content and Services; Embedded Systems and Physical Sciences; and Physical Realization Research. The mandate of the lab in India, which was set up in 2005, was to engage in applied research in the areas of converged networks, autonomic networking, enterprise applications and embedded systems and physical sciences (e.g., research on new materials). The R&D supports Motorola's vision of media mobility: easy and uninterrupted access to information, entertainment, communication, monitoring and control.

Indian R&D mainly caters to the global needs of Motorola. For instance, a significant percent of the software used in Motorola's phones worldwide is designed and developed in India by the GSG. In recent years, the Indian R&D also started catering to the local market needs through indigenization of Motorola's products and services. The local market for mobile phones has different segments ranging from the cheapest phones to the most expensive. Motorola started developing products for all segments, particularly the low end, which has market potential in emerging economies. The Indian R&D center contributes significantly in this effort.

### *Corporate Innovation System and Knowledge Flows*

Figure 5.1 depicts the corporate innovation system of Motorola India, both global intracorporate network and local external network, and associated knowledge flow between different actors.

In 2006 Motorola's global software groups were located in 20 different countries, all working as a team, sharing expertise and capacities based on need and requirement. For instance, the Indian group had engineers working in Motorola's R&D centers in China and Singapore. Similarly, Indian expertise was also used by other R&D units of Motorola. Synergy between different centers was achieved through division of work on the basis of availability of competence and market needs.

Motorola's R&D centers actively collaborate with major research institutes and universities in India to develop best-in-class talent and skills. Such collaboration facilitates knowledge flows between the partners and enhances learning opportunities for participants. For instance, Motorola has had research collaboration with the Indian Institutes of Technologies

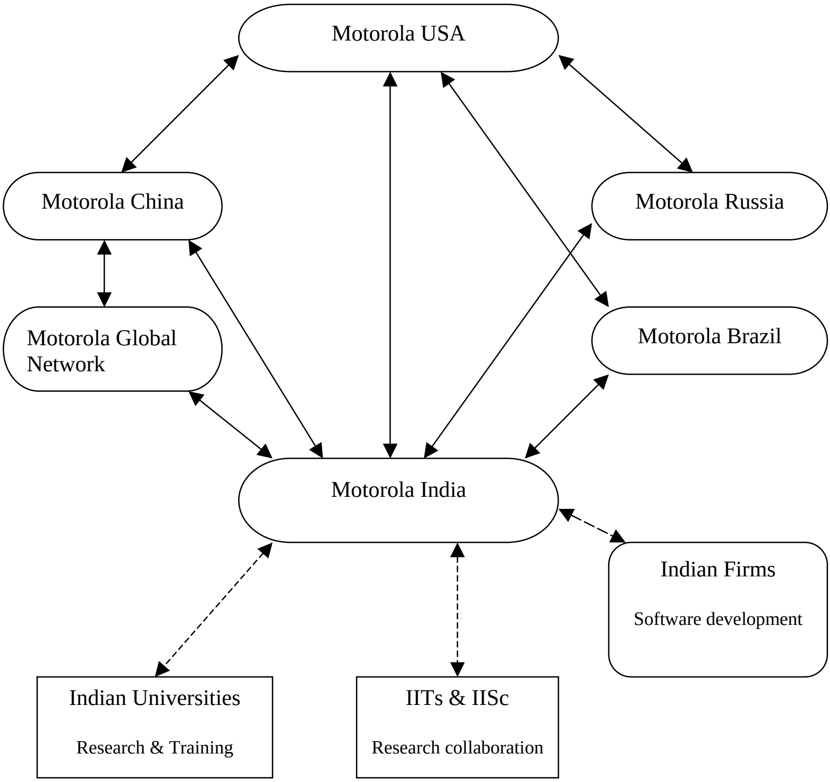


*Figure 5.1* Innovation system of Motorola India.

(IITs) as well as the Indian Institute of Science (IISc) on various topics related to mobile communications. Motorola has a postdoctoral fellowship at IIT-Bombay through the Motorola Foundation, US. In addition, Motorola has joint R&D projects with several other leading academic institutions in India, including the Indian Institutes of Information Technology (IIIT) in Bangalore[9] and Hyderabad, the Jawaharlal Nehru Center for Advanced Scientific Research (JNCASR), the Thyagaraja College of Engineering and the M. S. Ramaiah College of Engineering.

The strength of the relationships with local universities varies among different R&D Groups of Motorola, as the need for such external knowledge differs among different groups. The Global Software Group mainly works on the wireless domain, and Indian universities and research institutes had not done much research in this area in 2006. So the linkages with them did not extend to the entire domain. The wireless protocol R&D was very much carried out in-house. But for some components like digital signal processing (DSP), Motorola collaborated with local universities. In 2006, the global software group had two projects with the Indian Institute of Science

(IISc), Bangalore, for developing new DSP algorithms. There was also collaboration with the Indian Institute of Technology (IIT), Kharagpur.

Motorola India has a special University Relations Program (as part of the Global Corporate Program), for which it has set up laboratories in local universities such as the Indian Institute of Science, Bangalore, and the Regional Engineering College, Trichi. The aim of this program is to diffuse knowledge and expose the students to Motorola's products. It also helps in getting some useful R&D-related work done by the students. For instance, Motorola has had an exchange program with the Birla Institute of Technology and Science (BITS), Pilani. At any given point of time there are about 40 to 50 students from various universities serving as interns at Motorola in Bangalore.

Motorola Laboratories, another division dealing with high-level R&D in applied research, works closely with Indian universities. For instance, it worked closely with the IIT, Bombay, on materials research. It also worked with several other universities through joint research projects and developing joint intellectual property (IP).

Motorola also actively works with local companies in its R&D activities. It has a subcontract program, where it contracts out some R&D activities. Engineers from a variety of Indian companies work on site together with Motorola's teams.

### *Host County Implications*

- Motorola was among the pioneers in setting up global R&D in India. This developed interest among other MNCs to locate their own R&D in India.
- This also brought a lot of expertise into the country and created new knowledge.
- Mobility of people led to diffusion of knowledge into the wider economy in the host country.
- Promotion of entrepreneurship—Motorola opened up new market opportunities locally in terms of servicing local market needs. Several new companies emerged to develop and market add-on products and services based on Motorola technology platforms. Motorola also has a division called Motorola Ventures that invests in technology-based companies.

## QuEST Global—(Formerly Quality Engineering and Software Technology—QuEST)

QuEST Global is a product-engineering design and solutions company incorporated in the US, with operations in the US, Europe, Japan and India. The company was founded in 1997 by two engineers who worked for General Electric (GE) and Ford Motor Company. It started off its business operations in the US by doing finite element analysis (FEA) for turbomachinery (steam turbines, gas turbines, hydro turbines and so on) in the power generation sector. Within a few months after incorporation, it set up an engineering center in India to provide offshore engineering support to the US center, so that it could handle bigger projects and also improve its profit margins by taking advantage of the labor arbitrage between the US and India. QuEST then moved into the domain of aircraft engines, because an aircraft engine is essentially a gas turbine, and from there into the aerospace domain. It also entered the oil and gas domain because of the related technologies.

Today, QuEST is one of the global development centers in mechanical engineering for MNCs like GE, Rolls Royce, United Technologies Corp (UTC), EADS/Airbus, Toshiba, and others. QuEST has a network of sales offices and engineering resources in the US, UK, Italy, France, Germany, Spain, Singapore, Japan and India. It has engineering centers in India (Bangalore and Belgaum), Italy (Florence), France (Toulouse), Germany (Hamburg), the US (East Hartford, Schenectady, Greenville, Houston, Cincinnati and Phoenix) and Japan (Yokohama). As of March 2010, QuEST has a global engineering team of about 1,700 engineers, of whom about 1,100 are based in India, 350 in the US, 250 in Europe and 10 in Japan. Currently, around 50 percent of its revenues come from Europe, 45 percent from North America and the rest from the Asia-Pacific region.

In 2007, QuEST also ventured into manufacturing activities. It does precision machining and sheet-metalworking through QuEST Global Manufacturing, and it has a joint venture with Magellan Aerospace for aerospace special processing. It has thus combined design and manufacturing, mainly for the aerospace sector, but also for the automotive and other industrial sectors. It has even promoted the development of an aerospace supply chain cluster in Belgaum (Karnataka, India) through its 300-acre precision engineering SEZ (special economic zone) there, namely QuEST Global SEZ.

QuEST helps customers in reducing product development costs, shortening product development lead times, extending engineering capacity, increasing product profitability and extending product life, by providing support across the complete product life cycle from concept design and modeling through analyses, manufacturing engineering, prototyping, testing, technical publication, instrumentation and controls, embedded systems development, manufacturing process planning, vendor management, in-house precision machining, sheet metal machining, special processing and supply chain cluster development..

QuEST's capabilities are in the following core industries:

- Aerospace industry—its solutions cover design, development, analysis, technical publications and manufacturing support services for components, subsystems and assemblies for commercial and military aircraft and aero engines. It works in the domains of aero structures (fuselage, wing), aero systems and accessories (landing gear, actuators, avionics and electronics and so on), aero testing and automation (ATEs, test rigs), aeronautics research and technology (flight physics and flight dynamic analyses) and customer services (aircraft interiors, AMM/CMM manuals and so on). QuEST provides complex services like aerospace fluid systems analysis to this sector;

- Automotive industry—it supports product development from concept evaluation and definition through design to complex services like crash analysis, problem resolution in areas like FEA (finite element analysis) and CFD (computational fluid dynamics). In this domain, QuEST works in areas like power-train and engine performance, body in white modeling, next-generation braking systems, process development for complex assembly operations and so on;
- Power generation industry—it provides design and development services of power generation equipment like steam/gas/hydro turbines, generators, balance of plant equipment and related accessories, in addition to high-tech services like CFD analysis (internal flow) for gas turbines, design automation of components and subsystems. It also provides services in instrumentation and controls, substation automation and protection systems design, in related electrical as well as civil structural engineering. Turnkey solutions include project management, vendor development and fabrication in low-cost countries such as China and India;
- Oil and gas industry—it mainly provides services for the downstream part of the industry (and related chemical, petrochemical plants) by providing plant design engineering (PDE) services. Its capabilities include process simulation, piping/3D modeling, mechanical equipment design and engineering, civil structures engineering and so on;
- Industrial products solutions—design and development of high precision engineering systems ranging from fluid control equipment such as valves for heating and ventilation products, hand-held devices, electric motors, industrial-fan industry.

QuEST's customers include global majors such as GE, Rolls Royce, Pratt & Whitney, EADS/Airbus, Toshiba Industrial Power, Hitachi Power Systems, Technicas Reunidas and others.

### *Driving Forces*

- It is important to gain access to India's vast talent pool in the fields of mechanical, embedded systems, electrical and electronics engineering. The size of the individual teams dedicated to customers can be ramped up and ramped down quickly and easily.
- In the area of aerospace, Bangalore (where QuEST has its largest engineering center) is also the home of well-established national research

laboratories (National Aerospace Laboratories) and firms (Hindustan Aeronautics Ltd., Bharat Electronics Ltd.) and is where high-level research is undertaken (Indian Institute of Science). People employed in these organizations are well-trained and form a strong knowledge base in the domain.
- Through ICT industry India has gained significant experience in delivering outsourcing services and established proven outsourcing processes.
- Cost differentials between the US and India are also important.
- Intellectual property protection in India is relatively strong.
- English language abilities are important.

Beginning in 2008, many senior engineers born between 1945 and 1964 (the generation that had the highest proportion of people taking up engineering careers) with high levels of domain experience (e.g., aerospace) and engineering tools knowledge (e.g., computer-aided design (CAD) tools) are expected to retire globally. Subsequent generations took up other vocations (people born between 1965 and 1984 took up careers in service sectors like finance, sales and marketing and law, whereas the generation born between 1985 and 2004 are taking up knowledge- and skills-oriented careers like IT and fashion design.) This is likely to create a shortage of engineering resources globally and hence a substantial increase in the outsourcing of product and process design and engineering activities by companies. MNCs will tend to retain the research and the early stages of product development (conceptualization) in-house, but are likely to outsource the next stages, i.e., detailed engineering, testing and so on. Given its human resources and other advantages, India will likely witness the next wave of outsourcing activities in the area of engineering design and manufacturing solutions. India is also globally competitive in the manufacture of low volume, high precision and complex engineering products (e.g., gear boxes for the aerospace industry).

In India engineering services are provided by three types of organizations:

1. Captive units of product development companies, mainly MNCs—Siemens, Honeywell, GE, and others;
2. Large Indian IT service providers—TCS, HCL, Infosys, Wipro, Satyam Computers (now Mahindra Satyam), and others;
3. Product engineering focused companies—QuEST Global, Infotech Enterprises (more focus on geographical information systems—GIS), and Geometric Software (focus on development of CAD products).

At Aero India 2007, QuEST announced a 50–50 joint venture with Magellan Aerospace Corporation, Canada, to set up India's first independent processing facility for aerospace manufacturing. It will establish a key processing facility for aluminum, titanium and stainless steel alloys to meet the needs of aero structure and aero engine components.

In the projects undertaken for clients by QuEST, the intellectual property (IP) belongs to the client. But for the tools developed by QuEST (at its own cost and time) to conduct projects, the IP belongs to QuEST. For example, QuEST developed AutoDOE, a CAD-CAE tool for automatic design of experiments for analysis, and the IP for this product belongs to QuEST. About three to five percent of QuEST's engineers work on in-house R&D, like developing new tools, building new capabilities and so on.

### *Corporate Innovation System and Knowledge Flows*

In its project work for clients, QuEST does not usually get help from or collaborate with any other organization, except in cases where it does not have in-house capacity, e.g., electronics manufacturing of PCBs. In such cases QuEST works with local companies. Local companies gain from such work, as QuEST provides them with the domain knowledge and other product-related knowledge. QuEST also hires consultants who have retired from other organizations/companies and who bring with them very high domain knowledge and experience. QuEST has an in-house Technology Excellence Group (TEG), led by Ph.D.s, who come up with technology innovations, high-level capability and domain building initiatives, processes and tools and innovation activities.

QuEST, however, has other forms of collaboration with local universities. It has a CADAM (Center for Advanced Design and Manufacturing) program, under which it has developed courses in computer-aided design (CAD) and computer-aided engineering (CAE) tools, which are offered to students on a payment basis in six Indian universities. QuEST has developed the course content and provided the faculty. It helps engineering students in getting trained in these tools and becoming productive immediately after they graduate and take up jobs in the industry. QuEST also recruits the top 15 to 25 percent of these students. The CADAM program helps QuEST ramp up engineering teams for customers rapidly.

As clients' requirements, particularly in aerospace, are increasing, QuEST also collaborates with institutes like the Indian Institute of Science (IISc) and the Indian Institute of Technology (IIT) Madras (Chennai). QuEST is now being asked by clients to develop complete subsystems, pushing the company up the value chain, which could require collaborating with Indian research institutes and sophisticated test facilities in the future.

In terms of knowledge flows between the clients and QuEST, whereas QuEST gains domain and product knowledge, the client also gains knowledge relating to product development processes and gains from the codification of knowledge by QuEST. QuEST engineers interact with the client's senior engineers who have a very high level of domain knowledge gained over many years of experience, and they codify what they learn from the client's senior engineers. This documentation of knowledge is valuable to the client, as it would otherwise go out of the organization when the senior engineers retire.

By working on various projects for clients, the expertise of QuEST's personnel increases, which will enable QuEST to go up the value chain and undertake higher-end work. There is also an exchange of engineers between QuEST and the clients; for example, engineers from clients such as Rolls Royce spend some time at QuEST, and QuEST's own engineers also spend time at clients' premises. This helps in scoping a project, setting standards and protocol. It also helps in better understanding each other's organizational environment and requirements, leading to building of confidence and trust.

QuEST also helps in standardization of engineering processes in organizations where different standards, tools and processes are used in product development, as is usually found in conglomerates.

Because of QuEST Global's manufacturing operations, there is an exchange of knowledge between the engineering and manufacturing teams, and QuEST Global's engineers also take into account manufacturability when they do their design work. This helps in improving the product and reducing the costs of manufacturing.

### *Implications for Contractor's Competitiveness*

- Through outsourcing a client gets cost-effective solutions and access to domain expertise;
- Contracting firm gains access to talented human resources; this is particularly important because of the shortage of product development engineers in home countries;
- Productivity enhancement—in-house personnel of the outsourcing company are domain experts, but not necessarily in applying CAD-CAE tools, whereas QuEST's engineers gain expertise through their work on various products. So they gain better understanding of the tools and tool vendors. This also helps QuEST to come up with design automation solutions in some cases that lead to large productivity gains: reduced time frames—for instance, for a client QuEST reduced the design time of a turbine impeller from 96 hours to 15 hours, after developing a design automation tool for doing the task; reduced team size—in another case, the team size was reduced from 11 people to one person to achieve the same results, using a tool developed for the purpose.

### *Host Country Implications*

- The outsourcing services industry helps in broadening the skills base in the host country, in addition to providing employment to its engineers.

- Realizing the potential of market for product development services, several new companies are emerging in India, developing expertise in this area (i.e., demonstration effect on entrepreneurs).
- In order to cater to these service providers, new vendors are also emerging, supplying CAD-CAE tools.
- Product design and development contracts usually lead to manufacturing, opening up opportunities for new precision engineering companies.

***Home Country Implications***

- Cheaper cost of production through outsourcing helps in enhancing the competitiveness and helps in increasing the market size for the contracting MNCs, resulting in higher revenues for the home countries.
- Offshore outsourcing may also help in realizing the market potential abroad. For instance, an industrial equipment company from the US used QuEST's services in India for developing a product for the Western market, and later it realized that India itself is a large market for such products, but for lower-cost equipment. So this company started developing low-cost equipment for India and other emerging markets by using the same team from QuEST.
- Outsourcing helps in redeploying engineers in the home country into developing new and more advanced products and higher value-added activities, and thus enhances productivity in the home countries.

## 5.2 INDIAN COMPANIES

## Natco Pharma Limited

Natco pharma was established in 1984. The entrepreneur is a scientist with a Ph.D. in pharmacy and several years of work experience as a pharmacist in the US. The company started with the manufacture of injectables and dosage formulations (capsules), and in 1989 it also added the manufacture of active pharmaceutical ingredients (APIs) to its portfolio by acquiring Dr. Karanth Pharma Labs in Hyderabad. Since then it has systematically carried out backward integration.

Natco has an employee strength of 1,500 people, two formulations units, one API unit (USFDA approved in 2004), one R&D unit and one corporate office. Since 2003, Natco went for branded marketing of its products, particularly in the case of its oncology products, and within a span of five years it has achieved a significant reputation in the market. Natco was one the pioneers in the country to introduce 'timed release formulations' (i.e., extended/controlled release mechanisms).

### *Research and Development*

Natco's R&D focus is in the area of chemistry. Natco's R&D center has 100 scientists, with 12 Ph.D.s and the rest with M.Sc. qualification. By the beginning of 2006, it had filed about 100 patents under the PCT. Most of them are for process and formulation innovations, with nine filed for new chemical entities (NCEs).

Prior to the WTO agreement in 1995, the R&D focus of Indian pharmaceutical companies was on process development. Few companies carried out drug discovery research. With the impending implementation of the TRIPS Agreement that provided product patents for drugs in India since 2005, companies started shifting their R&D focus. Some companies have been more proactive in conducting drug discovery research and have developed NCEs.

Natco started drug discovery research in 2000, having had a long experience in process development research, with special strengths in oncology and antidepressants. This development work provided a better understanding of the chemistry involved in these drugs, and Natco's researchers developed strong competencies in these areas. As a consequence, when Natco embarked on discovery research it decided to focus on products in which it is relatively strong (e.g., oncology, five types of anticancer drugs). The research teams developed ideas on how to improve the molecules, how to circumvent biological side effects, how to develop NCEs using the old chemical entities as a base. In other words, Natco adopted an evolutionary path rather than going for a discontinuous model.

Earlier Natco received the National Technology Award for its process innovation for the chronic myeloid leukemia—CMC drug, which reduced the price of this drug from INR 1,000 to INR 90. This was a totally new process for a compound whose patent belonged to an MNC. But because this was a pre-1995 compound, it did not enjoy product patent protection in India. To start with, Natco's discovery research focused on developing a similar compound through what is called 'molecular modification' or 'rational drug design.' This method has been one of the pioneering innovations in recent times in drug discovery process. Through this process, the molecular reactions on the target can be simulated on the computer, and this simulation helps in generating ideas about how to improve the compound. Within two years, Natco developed two NCEs through molecular modifications, which showed greater potency than the existing drugs for leukemia. Some of the parameters for assessing an NCE are that it should lead to lesser dosage intake by the patient or reduce the cost of the compound, or the bioavailability should be more or toxicity should be less.

Once the NCE is developed, it goes for screening in a test tube with living cells (in-vitro screening), followed by animal testing (in-vivo testing). At the latter stage, companies usually require collaboration either because the company has no expertise in animal testing or because such facilities are not available in-house. Such facilities may be available in the country, but may not be accessible due to their proprietary nature (e.g., in-house facilities of large competing companies). Moreover, there are strict regulations regarding animal testing due to animal rights, and the tests should be certified formally by the authorized agency that the animals are budgeted for, the toxicity of the compound must be reduced before introducing it into the animal, a minimal number of animals must be used and so on. The USFDA takes these into consideration before evaluating the investigational new drug (IND) and giving approval for proceeding to the next phase of drug discovery, i.e., clinical trials. Natco signed an agreement with Temple University, Philadelphia, Pennsylvania, US, to test its NCEs. It is a one-time agreement to test 26 NCEs for Natco. The intellectual property rights (IPRs) belong to Natco, and Temple University provided only a fee-based service.

In addition to Temple University, Natco also has had collaborations with some contract research organizations (CROs) in the US in the area of biology (early to final stages). Natco's strategy is to develop the NCEs in-house and outsource the rest of the stages up to IND filing.

Natco also has R&D collaborations with several Indian research institutes. They include:

- Indian Institute of Chemical Technology (IICT), Hyderabad (which has animal house and toxicology divisions);
- Nizam's Institute of Medical Science (NIMS), Hyderabad (for clinical trials);
- National Institute of Pharmaceutical Education and Research (NIPER), Chandigarh (need- and fee-based service);
- National Institute of Toxicology, Pune (need- and fee-based service);
- University of Hyderabad (biology).

Many companies start as chemistry-based companies and move on to biology. Natco carried out a SWOT analysis of the company and decided that its strength lies in chemical synthesis and not in biology. At this stage Natco does not want to invest in creating bio facilities or in recruiting biologists. So it collaborates with local universities in this area, especially the University of Hyderabad.

Natco's synthetic chemistry strengths include: heterocyclic chemistry; metal hydride reagents—handling on commercial scale; organo metallic reagents—handling on commercial scale; catalytic hydrogenations; chiral synthesis; optical resolutions; commercial column and flash chromatography. It is also exploring new fields like custom synthesis of protected amino acids, unnatural amino acids and peptides.

### *Contract R&D (Outsource) Service for MNCs*

Natco also carries out contract R&D for MNCs. By 2006 six MNCs had outsourced some of their R&D work to Natco. The R&D carried out for MNCs is in the area of custom synthesis and manufacturing, but not in the discovery area. Custom synthesis involves developing a molecule (intermediates) and a process to manufacture it in small volumes. As the drug development moves to the next stage, the volumes change, requiring changes in processes. Some of the molecules may be dropped completely, if the compound under development fails to act on the target.

Product development involves a number of steps, and some these steps are outsourced by MNCs. Through such outsourcing MNCs gain access to specialized knowledge in a cost-effective manner. The service provider's strength may not be the focus of the MNC, so it is worthwhile to outsource such activities.

For reasons of confidentiality, Natco does collaborate with other organizations in carrying out the subcontract R&D. Outsource R&D services account for about 15 percent of Natco's total R&D activities.

### *Driving Forces for MNCs to Outsource R&D to India*

- To gain access to talent and human resources;
- To gain access to specialized knowledge;
- To take advantage of the cost differentials;
- Favorable government policies, including the IPRs regime in India.

In terms of knowledge flows in outsourced R&D activities, there are basically two different types of contracts:

1. The MNC provides the laboratory knowledge as it has already developed the molecule and requires R&D help in scaling up or further good manufacturing practice (GMP) validation. In such cases, some synthesis knowledge is passed on to the service provider. IPR belongs to the MNC. The knowledge flow from the service provider to the MNC is limited to scale-up processes and methodologies to do so;
2. The MNC just indicates the type of molecule (structure) it requires and asks the service provider to develop it completely. In such cases the knowledge flow from the MNC is limited to certain standardization issues. Knowledge flow from the service provider is more substantial, in terms of the structure of the molecule, ways to achieve it and processes to manufacture such molecule.

As they gain confidence, MNCs are increasingly seeking to outsource more core activities such as early phase development and in some cases even the entire compound. In such cases, the knowledge flows will be much more substantial.

### *Host Country Implications*

- R&D outsourcing by MNCs to Indian companies/institutes is beneficial to the country. R&D by MNCs creates competitive threats to local companies, compelling them to perform R&D, and as a consequence they foster an R&D culture in the host country.

- The fear of MNCs' R&D centers recruiting the cream of the local talent depriving the local companies of such talent is not such a big issue. Such things could happen even among Indian companies due to differences in salary and career growth opportunities.

#### *Implications for Contractors' Home Countries*

- In terms of home country effects, the implications are mixed. In drug discovery more than 20 activities need to be performed. It is difficult to find expertise or some times it is not cost-effective to locate all activities in one country. So MNCs will continue to globalize R&D. However, some R&D activities have 'stickiness' and thus may not be easy to globalize (e.g., availability of sophisticated and costly equipment and instrumentation). Such activities will become the core activities of the company that will be performed in the home country. However, given techno-economic factors, the competitiveness of the MNCs will improve with outsourcing of some R&D activities.

## Sai Life Sciences

Sai Life Sciences was established in 1999, as an R&D outsource service providing company. The entrepreneur did his Ph.D. in pharmacy (pharmaco kinetics) in the US and later on did clinical work in a hospital in the US for several years. He returned to India in 1979 and until 1997 worked with an Indian pharmaceutical company, which manufactured active pharmaceutical ingredients (APIs). In 1997, he started a marketing company called Sai Quest to source intermediates and APIs for pharmaceutical companies. In 1998, a contract research organization (CRO) based in Chicago, Illinois, US, encouraged him to set up a laboratory to develop some chemicals in India by promising to outsource R&D work to the laboratory. At the time, the concept of setting up a research laboratory as a business venture was new in India. So obtaining financing from financial institutions, which were not convinced of the business plan, was very difficult. However, with an initial investment of US$30,000 the laboratory was set up.

The first project was a process development research work for a US-based biotech company, obtained through the CRO based in Chicago on a subcontract basis. The value of the contract was US$60,000. A team of four scientists (one Ph.D. and three M.Sc. graduates), with an external consultant from a national research institute located in Hyderabad worked on the project successfully. The company made its first profit, which was reinvested. Since then the company has started growing rapidly.

By 2006, Sai Life Sciences had grown to a staff strength of 300 people, with 225 scientific and technical staff (30 Ph.D.s, 180 M.Sc. degree holders). It has two R&D centers and two pilot plants. A number of eminent and experienced scientists who previously worked in the national research institutes joined the company or helped as external consultants. The company focuses exclusively on chemistry research.

Sai Life Sciences provides R&D services for foreign pharma MNCs and small biotech companies in the following areas:

- Medicinal chemistry—preparation of building blocks/scaffolds in gram to kilogram quantity; developing new synthetic methods for novel scaffolds; focuses on libraries (typically 50 to 200 members); synthesis of standard reference compounds, intermediates and so on.
- Process development—process/technology development for IND track and clinical compounds; route selection and optimization; analytical method development and validation; impurity profiling and structure elucidation; stability studies; technology transfer to commercial manufacturing; C-GMP manufacturing from gram to kilogram to hundreds of kilograms levels; complete process documentation with batch-wise consistency.

Its services range from the early-stage research to process development (up to commercial) in chemistry. Sai Life Science plans to add radioactive chemistry (ADM spike) soon to its capabilities. The company also manufactures (cGMP) niche APIs in small volumes in its pilot plants. These APIs are difficult to manufacture in small volumes. MNCs usually assign such manufacturing as part of the contract for process development. Sai Life Sciences can manufacture such APIs in the fields of oncology, ophthalmology and injectables.

Sai Life Sciences has a customer base of about 40 foreign companies, with 80 percent of them based in the US and the rest in Europe and Japan. It has executed over 200 projects by 2006. Its customers now feel confident in the company and are assigning it development projects even in their core areas.

### *Driving Forces*

- Lower cost is the primary reason for outsourcing of R&D to India;
- Access to specialized skills and expertise is another important reason;
- Improvement in efficiency (time to market) is another important reason; Outsourcing enables more efficient utilization of resources in customer's laboratories by freeing them from some non-core activities.

### *Knowledge Flows and Learning*

Outsourcing contracts facilitate two-way flow of knowledge between the service provider and the customers. In a typical contract, the customer provides the knowledge relating to the compound that the customer already possesses or the research results it obtained or the chemistry relating to the compound. The service provider further builds on this knowledge from the customer and transfers the added knowledge to the customer.

According to Sai Life Sciences, the most important thing in the business of R&D services is to gain the confidence and trust of the customer. For this reason, the company feels that R&D service providers cannot be both product innovators on their own and R&D service providers at the same time. The customers do not feel comfortable with an R&D service provider who could become a potential competitor. Sai focuses only on R&D services and does not intend to make its own products. It is a service-for-fee business model. The customer specifies a compound to be developed, including the process innovation to produce that compound. Although the intellectual property (IP) for such process innovation rests with the service provider, the customer does not pay any royalties or licensing fee for using that process. In effect all IP belongs to the customer.

Protection of the data is to a large extent built into the nature of the outsourcing contract and relationship. MNCs only specify the structure of the molecule/compound to be developed and do not disclose the details of the target or the disease against which it will be used. Therefore, the possibility of the service provider using such a compound to compete with the MNC is remote.

When executing an R&D project for a customer, almost all the work is carried out in-house by the service provider. There are practically no linkages with local organizations. This prevents leakage of information to third parties. Any such linkage with the local research institutes, if required, is formed only with the permission of the customer. Each project will have an advisory committee formed with the in-house researchers.

### *Host Country Implications*

MNCs' outsourced R&D brings in a lot of benefits to the country, apart from the creation of jobs for scientists and engineers. Such R&D activities result in the inflow of new techniques and managerial processes into the country. Knowledge accumulation and training that accrue to the scientists during the process of executing the project are very important not only from the point of view of the R&D service provider, but also from the perspective of the larger NSI.

In order for this R&D service industry to thrive, the Indian government policies need to be changed in some respects. For instance, one of the major problems faced by the R&D laboratories in India is to get chemicals on time from abroad for medicinal chemistry work. Government policy should facilitate storage of such chemicals in bonded warehouses by chemical suppliers and allow them to send the unused chemicals back without paying the duty. As per the present policy the duty needs to be paid within six months of import, irrespective of the usage of such chemicals.

In the medium- to -long-term, this industry may witness a shortage of well-trained human resources. The growing R&D operations of MNCs and the local companies in India are increasing the demand for research personnel. This is likely to wipe out the cost advantage. In order to prosper, service providers must focus on quality and higher value-added activities. The government must focus on increasing and improving the S&T education in India.

## Avra Laboratories Private Limited

Avra Laboratories was established in 1995 by an academic scientist turned entrepreneur, who is a former director of the Indian Institute of Chemical Technologies (IICT), to cater to the process and product needs of pharmaceutical companies. The entrepreneur is an internationally well-known scientist with a Ph.D. in medical chemistry. He did his postdoctoral in Harvard University, Cambridge, Massachusetts, US, under the supervision of a Nobel laureate in chemistry. The entrepreneur's work on the isolation, structure elucidation of natural products and synthesis of complex natural products is reflected in 262 research papers and 30 patents and 109 students who have obtained their Ph.D. degrees in chemistry under the supervision of this scientist. The entrepreneur's scientific achievements are several. The following story of Vinca rosea reflects his achievements:

### *Vinca rosea—The Anti-tumor Agent*

In the early 1970s, India was the largest exporter of dried leaves of Vinca rosea to the US. The US-based pharma MNC, Eli Lilly, had a virtual monopoly at the time in isolating vinblastine and vincristine, the two dimeric alkaloids widely used as anti-tumor agents. Even today, vincristine is the only drug for pediatric leukemia. Due to the poor quality of supplies from India, Eli Lilly started its own plantation in Houston, Texas, US, and encouraged cultivation of Vinca rosea in parts of Africa. As a result stocks of this plant piled up in India. Maharastra state was one of the largest producers of the plant, and its government was keenly interested in the isolation and export of vinblastine and vincristine, but considered it as an insurmountable problem.

The founder of Avra, Dr. Rama Rao, who was a scientist at the National Chemical Laboratories (NCL) at the time, took up the challenge. He had just then returned from the US after spending two years as a postdoctoral associate in Prof. E. J. Corey's group. With financial support from the government of Maharastra, he began this work, which was at the time innovative to India. Eli Lilly's processes depended on tedious chromatography and therefore required huge investments and large teams. Alternative processes were considered as not feasible. The research program was initiated in 1979, and within a year Dr. Rao and his small team came out with a simple approach to isolating vinblastine from Vinca rosea completely unaided by chromatography. Using what could be described as 'bare-foot technologies,' the team optimized the process in the laboratory by extracting 10 grams of vinblastineBP from 40 kilograms of dried Vinca rosea, which was converted to vincristine by oxidation with potassium permanganate. Finding a superior process for the isolation of vinblastine and its conversion to vincristine was successfully accomplished within a year.

However, no Indian company came forward to undertake the commercial production of vincristine, as the Indian market was not considered large enough to support its commercial production. Dr. Rao persuaded a forward-looking Indian company, Cipla, to commercialize the innovation, not only for the domestic market, but also for the export markets (the first time for an Indian pharma company to export its product). In 1983, Cipla successfully produced the first batch of vincristine vials and sold them at a quarter of the price of imported vials. This project also became one of the important contributors to the entry of Indian pharma companies into international markets.

In 1995, Dr. Rao retired as the director of the Indian Institute of Chemical Technologies (IICT) and established his own company, Avra Laboratories Pvt. Ltd., which provides R&D outsourcing services to foreign and local biopharma companies. As the director of IICT, the entrepreneur had the opportunity to deliver lectures in many pharmaceutical companies in India and abroad, including the MNCs. This provided contact with potential customers. This was a time when contract R&D performance (outsource service) by private companies was still new to India.

G. D. Searle and Company, a US-based company (now part of Pfizer) gave the first contract to develop a process for manufacturing a drug that was in Phase III development. Searle had also developed its own process for it, but wanted Avra to develop an independent alternative process. The advance of US$100,000 paid to Avra out of the total contract value of US$200,000 became the seed money for the company. Avra's process proved to be more efficient than the one developed by Searle in-house. So Searle adopted this process and wanted Avra to build a pilot plant to produce 100 kilograms of this compound. The profits from this contract became the investment for setting up the laboratory and other infrastructure.

At the end of 2006, Avra's infrastructure included: two R&D units, one pilot plant, one steroid plant and one production plant.

Avra's R&D services include:

- Research and development—early stage development of new compounds, where the focus is more on research than development. In some cases, Avra also developed its own products and licensed them to pharmaceutical companies (e.g., an antipregnancy drug);
- Screening of compounds;
- Process development—the customer has a new molecule developed through medical chemistry and wants to procure this molecule in

small volumes. Avra takes up the molecule and develops a new process for manufacturing it. As the drug under development by the customer goes through different phases, the process also changes. Avra supports the customer through various phases of drug development.

*Driving Forces*

- Access to talent is the primary motive for outsourcing R&D to India. India has established an international reputation for its capabilities in chemistry. MNCs and other foreign companies would like to gain access to such expertise and talent;
- Cost of doing research in India is much lower than in the industrialized countries. In a period when drug discovery costs are soaring, it becomes cost effective to carry out R&D, at least some of it, in locations where the talent is available;
- The Indian IT industry has already established a trust among international clients in the ability of Indian companies to deliver R&D outsourcing services;
- The changes in the Indian IP law in accordance with the WTO Agreement also provided confidence among international customers on the issue of protection of data.

*Host Country Implications*

R&D outsourcing by MNCs exposes the scientists to new project management skills, technologies and equipment. Furthermore, contact with foreign companies is also opening up new opportunities and is promoting more scientists to become entrepreneurs by themselves.

## 5.4 INDIAN NATIONAL RESEARCH INSTITUTES

### Indian Institute of Chemical Technology (IICT)

The Council for Scientific and Industrial Research (CSIR) is the largest national research organization, which carries out research with a network of over 38 laboratories. CSIR has a workforce of over 25,000, including 6,000 scientists and 2,500 Ph.D.s. It files over 250 patents applications and publishes more than 2,000 scientific papers annually. The CSIR network of laboratories undertakes basic as well as applied research and earns about 20 percent of its revenues through contract research. The R&D services of CSIR laboratories are being utilized by several MNCs, including GE, Boeing, DuPont, Akzo Chemicals and Novo Nordisk.[10] The Indian Institute of Chemical Technology (IICT) belongs to the CSIR group.

The Indian Institute of Chemical Technology (IICT) located in Hyderabad originated as the Central Laboratories for Scientific and Industrial Research (CLSIR), established in 1944 by the then government of Hyderabad state. In 1956, the Central Laboratories came under the aegis of CSIR and was renamed Regional Research Laboratory, Hyderabad (RRL-H). In 1989, the RRL-H was rechristened the Indian Institute of Chemical Technology (IICT), recognizing the multidisciplinary activities and the expertise developed by the institute in the field of chemical technology.

Major areas of research at IICT are: natural products chemistry; drugs and intermediates; specialty and fine chemicals; fluoro-organics; inorganic and physical chemistry (catalysis and material science); lipid sciences and technology; coal, gas and energy; chemical engineering; and mechanical design and engineering.

### *Vision*

- To become an innovative global R&D provider in the field of chemical sciences and technology with reference to industrial and specialty chemicals.
- To be an institution of international excellence in basic research in organic chemistry and adjacent chemical and engineering sciences.
- To establish balance between innovation and drug research in the institute's thrust areas.

IICT houses the following centers of excellence—National Center for Mass Spectrometry; Nuclear Magnetic Resonance; X-Ray Diffraction; Molecular Modeling; Process Safety; Pharmacology; Bioengineering and Environmental Center; National Facility for Pheromone Research and Envis Center on Bioinformatics.

### *Selected R&D Capabilities of IICT*

- Natural products—expertise in the isolation and synthesis of bioactives especially in the pharma sector, natural products research with special emphasis on developing investigational new drugs (INDS) from herbal formulations. It activities include: development of new synthetic methodologies for novel scaffolds, hybrid natural products and combinatorial chemistry; phytochemistry; and new bioactive molecules, herbal drugs and standardization. Its clients in this area include: Glaxo SmithKline (UK), G. D. Searle (US), DuPont (US) and Arqule (US).
- Agrochemicals—development of commercially viable and green technologies for market-driven products and organic intermediates. Its activities include: development of novel processes for com-

mercially important pesticides; synthesis of new chemical entities; and isolation, characterization and activity profiling of natural products.

Drugs and intermediates—development of new drugs for various diseases, with special emphasis on asthma, HIV, tuberculosis, cancer and tropical diseases like malaria; basic research in the area of synthetic organic chemistry, especially asymmetric synthesis, and total synthesis of natural products; and development of new designer molecules to supplement the traditional methods of finding bioactive molecules from nature. Competencies in the area include: synthesis of non-natural peptides, non-natural saccharides and other designer molecules; solid/solution phase organic synthesis useful to make combinatorial libraries; synthetic route identification/process development of lead molecules; and synthesis of NCEs for their biological evaluation for lead generation. Foreign firms among its clients in this area include: Civenti (US), Smith Kline Beecham (UK), Cytomed/Leukosite (US), Arqule (US) and DuPont (US).

- Specialty and fine chemicals—IICT's core competencies in this area include: industrial research leading to technology development and its transfer to sponsors; basic research in organic chemistry; development of processes and technologies for drugs and pharmaceuticals, organic intermediates, specialty chemicals and value added chemicals, drug discovery; biophotonics, supramolecular chemistry and molecular recognition; carbohydrate chemistry leading to synthesis of natural products, oligosaccharides and glycoconjugates.
- Coal, gas and energy—value addition and better utilization of coal and gas; hydrogen energy technologies for fuel cell applications; energy-efficient gas separation processes and gas purification.

IICT employs over 200 scientists, 300 technical staff and 100 administrative staff. IICT's scientists get an incentive in the form of 40 percent of the earnings from the IP when it is commercialized. IICT can carry out complete drug development, as well as process development methodology (e.g., automated synthesis). IICT develops the methodology on a laboratory scale, which customers scale up later.

The industry knows about the capabilities of IICT through its publications of about 400 papers per year and 40 to 50 patent filings a year. Furthermore former students of IICT are spread around the world, with many of them working for MNCs. Companies themselves approach IICT for their R&D requirements. Based on the performance of IICT, clients also refer its services to other companies. IICT has a continuous long-term relationship with four foreign pharma MNCs (i.e., whose project value is more than US$100,000/year/client). In any given year there are about 20 foreign companies with R&D projects at IICT. Among the Indian firms 270 private sector firms and 23 government-owned companies have contracts with IICT. The total annual turnover of IICT is about US$250 million.

### *Driving Forces*

- The expertise and the facilities (instrumentation) available in IICT are the major reason for companies to outsource R&D to IICT.
- Developing and screening a greater number and wider variety of compounds cost-effectively enhances the chances of success in drug development.
- Cost differentials are not considered as a driving force, as IICT is not a low-cost service provider.

IICT differentiates its services from those provided by the private R&D service organizations in the following respects:

- Generates new chemistry—projects with IICT involve generation of new chemistry (not well-known routes). The customer only provides a target and IICT develops cost-effective solutions. Projects with private R&D service providers mainly involve only conversion process, where often the customer provides the procedure and raw materials;
- No commercial interest—IICT being an academic research institute, there is no threat of competing with the customer by copying its technologies. So customers feel more confident with IICT;
- No small volume manufacturing—IICT does not take up projects involving small volume manufacturing, which are mainly cost-saving projects.

In order to protect the confidentiality in its projects for the industry, IICT does not collaborate with other organizations. IICT also does not accept two customers for the same kind of R&D.

R&D projects for MNCs often generate new knowledge. When new chemistry is developed, the MNCs usually approve its publication by the IICT research team, without mentioning the sponsoring company's name. Such projects have not resulted in any patents for IICT so far.

### *Knowledge Flows and Learning*

- Contract R&D projects for MNCs result in two-way knowledge flows. While the MNC customers get the knowledge relating to the new product or process, IICT also gains knowledge from MNCs. Until recently, India did not have much experience in developing new molecules. Working for MNCs helps in understanding the finer things of

R&D, e.g., how to look for a new molecule, why change a particular molecular structure and so on.

- Scientists who are well equipped with basic science knowledge acquire knowledge relating to methodologies and techniques that transform scientific knowledge into a product or process development. IICT scientists also get exposed to sophisticated and advanced equipment and facilities of MNCs, e.g., automation synthesis, HTPS and so on, an opportunity that might not have opened up otherwise.
- There is an exchange of research personnel with MNCs' customers. Teams from customers spend some time at IICT, and IICT's scientists spend some time at customer's R&D laboratories abroad. For instance, in a project for a Swiss company, the customer has strong specialization in the field of biology relating to diabetes and IICT is strong in chemistry. Through joint work, the Swiss team is gaining chemistry knowledge and IICT's scientists are getting exposure to the Swiss company's methodologies in biology.

IICT has international institutional R&D collaboration with France, Germany and Japan. These projects are funded through bilateral agreements. The Department of Science and Technology, Government of India, and CSIR also have funds for collaborative projects with institutions abroad.

### *Host Country Implications*

- The location of R&D by MNCs is increasing the employment opportunities for scientists. More important, through such R&D, Indian scientists are getting trained in product development methodologies and processes. Such knowledge, which is vital for economic development, gets diffused through the mobility of scientists.
- Outsourcing of R&D by MNCs is turning many scientists into entrepreneurs. As the number of compounds screened by the MNCs increases, the business opportunities for R&D service providers are increasingly motivating scientists to set up their own laboratories.

## Indian Institute of Science (IISc)

The Indian Institute of Science (IISc) originated with the efforts of J. N. Tata (1839–1904), a pioneer industrialist, who planned to set up an institute to promote original investigations in all branches of learning and to utilize the research for the benefit of India. The institute came into existence in 1911, with the first batch of students admitted into the Departments of General and Applied Chemistry and Electrotechnology. The institute acquired a deemed university status in 1956.

In the Indian context, the institute is unique in character, as it is neither a national laboratory, which concentrates solely on research and applied work, nor a conventional university, which concerns itself mainly with teaching. IISc is concerned both with research in frontier areas and education in current technologically important areas. This is also the first institute in the country to introduce innovative integrated Ph.D. programs in biological, chemical and physical sciences for science graduates.

In addition to engagements in formal education and research, the institute has been playing an active part in offering short-term courses to scientists and technologists in service. The Continuing Education Program covers a wide range of topics, and over 1,500 working scientists and engineers go through such courses every year. IISc also provides consultancy services, through its Center for Scientific and Industrial Consultancy, so that the know-how generated in the institute percolates to industries via industry-sponsored projects.

IISC has six divisions: Biological Sciences, Chemical Sciences, Electrical Sciences, Information Sciences, Mechanical Sciences, and Physical and Mathematical Sciences. Outside the framework of divisions, it has the Center for Application of Science and Technology to Rural Areas, Center for Continuing Education, and Center for Scientific and Industrial Consultancy.

Some of the R&D areas in which IISc is active include: aerodynamics; artificial intelligence; atmospheric sciences; biological chemistry; biomedical signal processing; biotechnology; combustion chemistry; combustion and propulsion; composite structures; computational science; electrochemistry; electronic devices circuits and technology; fluid dynamics; genetics; i. c. engines; mechatronics ergonomics; molecular cell biology; neural networks; protein engineering; signal processing; software architecture.

Since its inception, IISc has been actively interacting with the industry through individual contacts of its faculty members. This became formalized with the establishment of the Center for Scientific and Industrial Consultancy in 1975. The Society for Innovation and Discovery (SID), which is a part of IISc, actively promotes such collaboration. Through SID, several MNCs as well as Indian companies have located their corporate laboratories within the IISc campus to closely interact with the IISc faculty and researchers. SID, founded in 1991 and registered under the Society's Act, has the mission to enable industries and business establishments to compete and prosper in the face of global competition by utilizing Indian innovations in S&T. SID undertakes R&D projects based on individual and/or joint proposals from the faculty and scientists of IISc in collaboration with industries, business establishments, national and international organizations.

SID's contact with the industry is established in the following ways:

- A faculty member has some contact (e.g., a consultancy) with the company and it subsequently leads to a larger project at IISc, sponsored by that company;

- SID presents itself to companies by making presentations of IISc's capabilities;
- Industry itself is aware of IISc's capabilities through its publications and what it is doing with the industry;
- IISc's former students (alumni) have also been good ambassadors in spreading its reputation and its capabilities worldwide.

### *Driving Forces*

- Availability of expertise and talent is the reason for the industry (particularly foreign firms) to approach IISc for R&D collaboration.
- Cost is not a determining factor, as IISc does not accept projects that do not involve cutting-edge research and innovation. For instance, in 2005, IISc turned down about US$20 million worth of projects, as they did not have a sufficient research component.
- SID focuses only on areas in which only IISc has the expertise. Otherwise, it will advise the client to approach another organization, which does that particular type of work.

SID started with individual consultancy work for companies. But the real interdisciplinary collaborative work in projects began in 1991, and actual projects started coming in since 1994. Faculty members, as in any other academic institution, are more interested in publications as they determine their career growth. So collaboration with industry has been evolving gradually. It takes time to understand an industry's requirements and for industry itself to get convinced of IISc's capabilities. Since 2003, there has been an explosive growth in collaborative projects with industry.

IISc, however, does not want too much industry-related work. Education and advanced research are its priority activities. A balance in activities is very important from IISc's perspective. If a faculty member's research and publications are relevant to an industry, but he is not aware of it, SID helps him in getting some monetary reward by linking up with the industry.

As a normal practice, a company wanting to engage the services of IISc approaches the SID, which in turn identifies and allocates the work between relevant departments of IISc. When a client approaches SID, it makes a presentation of IISc and its capabilities. The company is also requested to make a presentation and identify the departments of IISc that the company would like to collaborate with and identify the faculty from the database of competencies provided by SID. The selected faculty starts understanding the needs of the company in one-on-one meetings, and the sponsoring company visits the laboratories of IISc to see what is going on there and to identify a program. SID takes the responsibility for implementing the program by providing the budget, receiving the money from the company, buying the necessary equipment and monitoring the progress of the program.

Among the clients with whom IISc has R&D collaboration are: Microsoft, Motorola, Intel, Texas Instruments, Boeing, General Motors, DuPont, and Alcoa.

For instance, researchers at the IISc are collaborating with Boeing in nine projects that will contribute to building next-generation flights. To build these new flights, the IISc faculty has proposed the use of smart structures, application of lightweight materials such as nano materials, alloys and their composites. The designs will be tested in a virtual environment that is being developed at IISc. Over 30 faculty members from various departments including aerospace, metallurgy, the Center for Product Design and Manufacturing and civil engineering are involved in these projects. The areas of focus include developing flaps for the aircraft that are fitted with smart sensors so that they can direct wind currents better and use of aluminum alloys in high temperature areas as well as in landing gear boxes. In 2005, Boeing signed a memorandum of understanding with IISc to collaborate in these projects. IISc is the only Asian institution that Boeing has tied up with for research and transfer of technology. Boeing's other partners include Carnegie Mellon, Stanford Engineering, MIT, Caltech, University of Illinois at Urbana Champaign, and University of Cambridge. Boeing is investing US$5 million a year on research at IISc for five years.[11]

IISc also allows companies to set up their own R&D laboratories inside its premises by providing 2,000 to 4,000 square feet of space to each company. This is a unique concept not practiced by many universities or national research institutes in India. The company creates its own infrastructure and plans its own research. The stipulation is that the research conducted by the company in this R&D lab should be relevant to IISc's research, and it should contract out some projects to IISc's faculty. Research team of the company and IISc's faculty spend time and use each other's laboratories. In this way, IISc's students also get to do projects in the company's R&D lab, and many of them subsequently tend to be recruited by the company. Through this model, IISc feels that the talent available in pure sciences can join with industry to develop cutting-edge and complex technologies.

Among the companies that presently have R&D laboratories on IISc's campus are: Cookson Electronics, US (research on nano technology); ViZiPhar Biosciences, Belgium; IMI, US (electronics); Tata Motors (automotive), India; Cadila Pharmaceuticals Limited, India (biopharma); and Unichem Laboratories, India (Biosciences R&D Lab).

According to SID, the faculty of IISc cannot be expected to be better than the company's own R&D team in actual product development. But it has strength in certain areas of S&T that even the best of the companies may not have, e.g., research on advanced materials. The research facilities (equipment and instrumentation) available at IISc are of world class, and companies may not be in a position to invest in creating such facilities on their own. The research environment at IISc is also completely different from that of the environment in industry. IISc's environment enables companies to approach the problem from different perspectives, other than the approach that a company had taken until then, which might lead to innovative solutions. It is an ideal environment for discontinuous innovations.

IISc's research teams working with industry get incentives in the form of monetary benefits, participation in conferences, travel grants, training abroad, equipment and operating costs, and so on.

### *Knowledge Flows and Learning*

In collaborative work there is substantial knowledge flow both ways. The company gets access to the talent and knowledge available at IISc, and the scientists at IISc get exposed to the industrial requirement; this helps in changing the perspective with which scientists pursue their own research. Scientists get exposed to management techniques in project management. There is also an exchange program between the collaborating partners. IISc's scientists visit and spend time at the client's R&D centers abroad, and the client's own teams come from abroad and spend time at IISc. For instance, this exchange is well established with General Motors. Scientists as well as students from IISc spend three months at GM's R&D facilities in the US, and GM's research teams from around the world spend some time at IISc.

Issues relating to intellectual property rights (IPRs) are gradually evolving at IISc. Initially there was no insistence on sharing of IPRs, but now IISc insists on sharing IPRs with the collaborating/sponsoring company getting the first priority to use the IP. The company has to file for the patents and maintain them.

### *Host Country Implications*

When research is done at the cutting-edge level and creates new IP, the scientists in the country get exposed to doing such advanced research, which not only provides training opportunities, but also motivates them to do such advanced work on their own on other problems that would be beneficial to the country.

R&D by MNCs also motivates and compels local companies to perform and enhance their own R&D activities. For instance, when General Motors set up its R&D center at IISc, the Indian automotive companies, such as Tata Motors, Mahindra & Mahindra, Ashok Leyland and TVS, started looking at IISc with special interest. Until foreign companies started working with IISc, local companies were not aware of the capabilities available at IISc, but now the Indian companies want to collaborate with IISc, either by locating their own R&D laboratories on the campus or through sponsorship of research projects.

## 5.5 QUESTIONNAIRE SURVEY[12]

A questionnaire survey was carried out in India by the author of this book in 1995 (P. Reddy 1997). Although the survey was carried out more than a decade ago, as the case studies in the present study reveal, the determining factors for location of global innovation in emerging economies remain the same. The survey was conducted among MNCs involved with new technologies as well as conventional technologies. The conventional industries category included: chemicals, pesticides, fertilizers, pharmaceuticals, engineering, hygiene and health care products and branded consumer goods. The new technologies category included: electronics (including ICT and software), biotechnology and solar energy companies.

The survey showed that the majority of R&D units performed technology transfer unit (TTU) and indigenous technology unit (ITU) types of R&D, i.e., adaptation of products and processes to local conditions and product development for the local market. This is more so in the case of conventional industries, where about 87.5 percent of the firms were involved in these two types of activities. On the other hand, only 25 percent of the new technologies firms reported carrying out TTU and ITU types of R&D. All the global technology unit (GTU) and corporate technology unit (CTU) types of R&D units belonged to new technologies firms, with 50 percent of new technologies firms carrying out GTU and 12.5 percent performing CTU types of R&D. This suggests that in new technologies there is less need for product or process adaptation to the local market. Similarly, the development of products exclusively for the local market (ITU type) by new technologies firms is also less, except in the case of biotechnology companies developing new plant varieties based on the local soil and weather conditions.

In terms of the driving forces for the establishment of R&D units in India, the availability of personnel was the main factor across all types of R&D and industries. As the data in Table 5.1 show, the weighted average rank of this motive was 4.12 across the industries and different types of R&D units. However, this factor was relatively more important in the case of new technologies (4.31) than in the case of the conventional technologies (3.93). The next most important motive for the new technologies units was the low costs of R&D, with a weightage of 3.25. On the other hand, the two most important motives for conventional industries were: to be in proximity to manufacturing facilities (4.56) and to be in proximity to the Indian market (4.06). The corresponding figures for these two factors in the case of new technology firms were 2.13 and 2.81, respectively, suggesting that R&D in new technologies could be geographically delinked from manufacturing facilities. The shortages of S&T personnel in industrialized countries as a driving force for location of R&D in India did not seem to be an important factor, with a weightage of only 1.69 across all industries. However, it assumed relatively greater importance in the case of new technologies firms with a weightage of 2.38.

*Table 5.1* Questionnaire Survey—The Driving Forces for Location of R&D in India (ascending order of weightage 0–5)

| *Driving force* | *conventional technologies* | *new technologies* | *total* |
|---|---|---|---|
| Availability of S&T personnel | 3.93 | 4.31 | 4.12 |
| Low-costs of R&D | 2.88 | 3.25 | 3.06 |
| Shortages of S&T personnel inhome countries | 1.00 | 2.38 | 1.69 |
| Proximity to manufacturing | 4.56 | 2.13 | 3.34 |
| Proximity to Indian market | 4.06 | 2.81 | 3.44 |
| Proximity to Asian market | 2.06 | 2.38 | 2.22 |
| Availability of raw materials | 2.81 | 2.06 | 2.44 |
| Government incentives | 1.94 | 1.63 | 1.78 |
| Corporate image building | 2.94 | 1.89 | 2.41 |
| Technology monitoring | 3.06 | 2.44 | 2.75 |

*Note*: The respondents were asked to rank the motives for locating R&D in India as they perceive on a scale of 0 to 5, with 0 as not a motive at all and 5 as the most important motive. Since there may be more than one equally important motive, the respondents were given the freedom to assign the same value to more than one motive.

*Source*: Adapted from P. Reddy (1997, p. 1828).

Table 5.2 presents the type of R&D units and the main motives for their location in India. For TTUs, being in proximity to manufacturing facilities had been the main driving force with a weightage of 4.78, followed by the motive to be in proximity to the Indian market, with a weightage of 4.33. For RTUs, the low-costs of R&D and proximity to the Indian market showed equal weightage of 4.50, closely followed by the proximity to manufacturing with 4.25. On the other hand, proximity to the Asian market as a motive had a weightage of only 3.25. This discrepancy might have been due to their reliance on the Indian market as the main base and then venturing into the regional market through adaptations.

The main driving force for establishing GTUs has been the availability of R&D personnel, with a weightage of 4.75. The next most important motive was the low costs of conducting R&D, mainly due to the lower-wages of personnel, with a weightage of 3.25. Being in proximity to the market or manufacturing did not seem to be important for locations of GTUs. For CTUs also, the availability of personnel was the most important motive for location, with a weightage of 4.00. The next most important motive was stated to be the proximity to the region's market, with a weightage of 3.00. This might have been due to the fact that some of the R&D being carried out by the CTUs in the survey involved developing potential biotechnology-based

*Table 5.2* Questionnaire Survey—Type of R&D Unit and Driving Forces for Its Location (ascending order of weightage 0–5)

| *Driving force* | *TTU* | *ITU* | *RTU* | *GTU* | *CTU* |
|---|---|---|---|---|---|
| Availability of S&T personnel | 4.00 | 3.78 | 4.00 | 4.75 | 4.00 |
| Low-costs of R&D | 2.78 | 2.67 | 4.50 | 3.25 | 2.50 |
| Shortages of S&T personnel in home countries | 1.33 | 1.11 | 2.25 | 2.25 | 2.50 |
| Proximity to manufacturing | 4.78 | 4.33 | 4.25 | 0.75 | 1.00 |
| Proximity to Indian market | 4.33 | 4.22 | 4.50 | 1.25 | 2.50 |
| Proximity to Asian market | 2.56 | 1.67 | 3.25 | 1.75 | 3.00 |
| Availability of raw materials | 2.33 | 3.44 | 3.50 | 0.88 | 2.50 |
| Government incentives | 2.00 | 2.33 | 1.50 | 1.13 | 2.00 |
| Corporate image building | 2.56 | 3.56 | 3.25 | 0.88 | 1.00 |
| Technology monitoring | 3.00 | 3.22 | 3.75 | 1.75 | 2.50 |

*Note*: The respondents were asked to rank the motives for locating R&D in India as they perceive on a scale of 0 to 5, with 0 as not a motive at all and 5 as the most important motive. Since there may be more than one equally important motive, the respondents were given the freedom to assign the same value to more than one motive.

*Source*: Adapted from P. Reddy (1997, p. 1829).

drugs and diagnostics for tropical or infectious diseases prevalent in the region. Therefore, proximity to the regional market might have been assigned a higher weightage.

The survey also revealed the linkages of different types of R&D units both within the corporate structure and external organizations. All the units were linked to the MNCs' corporate R&D in their respective home countries. More than 80 percent of R&D units of the new technologies firms were also linked to the parent's R&D units worldwide, whereas the figure was only 50 percent for the R&D units in conventional technologies. The CTUs were the most integrated into the global corporate R&D network of the MNCs, with 100 percent of them linked to parents' R&D units worldwide. The corresponding figures for other types of units are: GTUs (87.5 percent), RTUs (75.0 percent), ITUs (55.6 percent) and TTUs (44.4 percent), indicating the relative integration of these different functions within the corporate R&D structure. However, when viewed from the perspective of commercialization of R&D results within the host country, all the conventional industries were linked to manufacturing facilities in the host country, whereas only 50 percent of the new technologies units were (Reddy 1997, p. 1830).

In terms of external linkages, across all types of R&D units and technologies, only a few linkages with the local industry were reported. A partial explanation of this might be that MNCs' R&D activities tend to be in high-tech areas in which it might have been difficult to find domestic firms that could complement those activities in a developing host country, particularly in the 1990s.

On the other hand, linkages with the local university system were reported to have been stronger. The conventional industries tended to rely more on the local academic system than did the new technologies firms. 62.5 percent of the conventional industries reported having linkages with the local universities, whereas this only applied to 43.8 percent of the new technologies firms. 44.4 percent of the TTUs and ITUs also established linkages with local universities, a figure almost equivalent to 50 percent of the GTUs. This appears contradictory to conventional views. Part of the explanation for this may lie in the fact that TTUs and ITUs are not confined to their specific activities alone. It is possible that they had these linkages in the course of performing other types of R&D activities. Another explanation could be that TTUs and ITUs, which were mostly in the conventional technologies, were established several years ago, prior to the liberalization of the Indian economy. At the time, due to import restrictions, these units had to carry out material substitution in products and therefore new processes as well. These activities perhaps involved more than just tinkering with the parent's technologies and had to rely on the local university system for support (Reddy 1997, pp. 1830–1831).

# 6 Global Innovation in China

R&D-related FDI inflows into China have surged in recent years, accumulating to about US$4 billion, and the number of registered R&D centers of foreign companies reached 700 by 2004. Although the first R&D center of an MNC was set up in 1993, most of the known projects are of recent origin (established after China's accession to the WTO in December 2001). While the majority of these centers focus on adaptation types of innovations, some perform innovative R&D that is closely integrated with MNCs' global innovation networks, targeting global markets (UNCTAD 2005, p. 141).

According to some scholars (Schwaag-Serger 2006; Walsh, 2003), it is difficult to accurately estimate R&D activities by foreign companies in China. The R&D staff strength of foreign companies in China only partially reflects the actual R&D activity, as many of them conduct R&D through cooperation with Chinese organizations, and this is not reflected in the data. Moreover, foreign companies are offered significant incentives (financial and otherwise) to establish R&D units, sometimes making location of a R&D unit a performance requirement for being allowed to manufacture or sell in China. One foreign company as quoted by Schwaag-Serger (2006, p. 244) said, "[T]he Chinese demanded [that we carry out R&D in China], so we hired a few engineers." As a result, although some R&D units exist on paper, they do very little R&D.

According to Walsh (2003), the Chinese government encourages R&D-related FDI, particularly in ICT-related industries, by offering a range of preferential policies that include tax rebates, loans and other incentives. As a result in this sector, foreign MNCs have established over 200 R&D centers, programs or labs in China between 1990 and 2002 (p. xiii). The preferential treatment and government incentives extended to foreign companies for locating R&D may induce some of them to register their activities as R&D even though these activities may not otherwise be classified as such. Companies may also establish R&D units to earn goodwill with Chinese authorities, as location of R&D is seen as evidence of a company's long-term commitment to China (Gassman & Han 2004).

Although the Chinese Ministry of Commerce claimed that by late 2005 there were more than 750 foreign-established or foreign-invested R&D

centers in China (MoC 2005), for the reasons mentioned above, the number of centers actually carrying out R&D of relevance to the company's China or global operations is likely to be considerably smaller. According to von Zedtwitz's (2004) estimation, there were 199 foreign R&D facilities in China at the beginning of 2004. Since then the number has increased rapidly, but there may not be more than 250 to 300 foreign R&D units currently. Almost all foreign companies that have R&D activities in China also have production and/or distribution facilities there. So it becomes even more difficult to assess how many of these companies are carrying out innovative global R&D. Schwaag-Serger (2006 pp. 244–245) examined and cross-referenced annual reports, company websites and news clippings and found a discrepancy. The R&D units declared as strategic by a company or by the Chinese press were not represented in that company's list of global R&D centers, either on its home page or in its annual reports. After correcting for this discrepancy, she found approximately 30 MNCs that currently have up to 60 facilities performing global R&D in China.

Sun (2003 p. 150) classifies the foreign R&D centers in China into two categories: (i) strategic; and (ii) tactical. Apart from the market potential, strategic R&D differs from tactical R&D in many aspects, such as the nature and scope of activity, requirements for the type of S&T personnel, communication patterns and even locations in the host country. For instance, strategic R&D focuses on global markets, with a time horizon of mid- and long-term and the type of R&D conducted being basic research. On the other hand, tactical R&D's focus is on local and/or regional markets, with a short-term time horizon and the type of R&D being more development-oriented. In a later study, Sun et al. (2006) examined foreign R&D units located in Shanghai. Through interviews at 18 foreign R&D units, the study found that the majority of foreign R&D activities in China are of adaptive and tactical nature carried out to cater to the local market. However, there are also several strategic foreign R&D units engaged in projects for the global markets. The size of these strategic foreign R&D units varies significantly, with the smallest one having only four employees and the largest one several hundreds. The sectors covered range from chemistry, electronics, life sciences and materials to ICT.

Companies that perform innovative R&D in China include Nokia, Microsoft, Ericsson, Intel and Motorola. For instance, Nokia relocated a substantial portion of its third-generation software development to Hangzhou, transferring technologies and people from the former competence center in Finland (von Zedtwitz 2004). Similarly, Microsoft China's R&D activities form an important part in its global value chain. One of Microsoft's six research labs worldwide, Microsoft Research Asia (MSR Asia), was established in 1998 in Beijing, with 170 researchers, and in late 2003, Microsoft opened its Advanced Technology Center (ATC) in the same location (Buderi 2005). "The lab and the technology centre are not only researching and developing products aimed at the Chinese market, but also expect to be key technology transfer point for a host of new Microsoft's products worldwide, such as web search and mobile technologies" (Schwaag-Serger 2006, p.243).

There are several different forms in which foreign companies conduct R&D in China: (1) wholly owned stand-alone R&D units; (2) R&D activities in the company's production units; (3) joint venture R&D with Chinese partners/organizations; and (4) collaborative research with Chinese research institutes and universities or institutes.

The driving forces for location of R&D in China are several (Schwaag-Serger 2006; Sigurdson, 2005; von Zedtwitz 2004; Walsh, 2003). They include:

- Availability of a large pool of talented human resources.
- Lower wages of research personnel compared to those in industrialized countries.
- Gaining access to a large and rapidly growing domestic market. The desire to be close to the strategically important Chinese telecom market motivated foreign telecom companies to locate R&D in China.
- Supporting the local manufacturing activities through product and process development.
- Capturing new technological opportunities through contact with China's research programs.
- As a response to political or institutional requirements such as incentives and location of R&D and technology transfer as a performance requirement. For instance, some national regulations may require foreign companies to set up R&D along with production facilities.
- Domestic technical requirements and new standards set by the Chinese government are another important driving force for foreign companies to locate R&D in China.

As Gassman & Han (2004) point out, perhaps the most important driving force for location of R&D in China by MNCs has been the perceived compulsion. Since China became open to FDI, it has pursued a policy that required foreign companies manufacturing or selling goods and services in China to transfer technology. Even though the Decision on Amendments to the Implementation Rules of the Law on Wholly Foreign-Owned Enterprises issued by the State Council in 2001 removed these requirements on foreign companies, in practice many of them feel pressured to locate R&D in China (Walsh 2003; Long 2005; Schwaag-Serger 2006).

Another important driving force for foreign companies to locate R&D in China has been the perceived need to tap the informal networks and information sources for business success (the frequently mentioned 'GuanXi'). Local R&D activities facilitate a company's gaining access to and maintaining informal networks with local universities and scientific communities, which play an important role in the policy arena. The Chinese economy is undergoing a transition from a planned to a market-based system, which makes the changes in industrial regulations, legislation and policies very dynamic. Local R&D activities and proximity to the government would help MNCs to keep pace with changes in this dynamic policy environment (Schwaag-Serger 2006, p. 252).

In a research survey study, Ke Wen (2005) found three types of barriers for foreign R&D in China:

- Barriers from policy environment—strong and bureaucratic government; import limitations; weak IPRs protection system; and difficulties in traveling to Taiwan.
- Barriers from local market—increasing operational costs; and imperfect infrastructure.
- Barriers relating to human resources—lack of innovative and experienced labor force; high employee mobility; and difficulties in managing diversified staff.

According to Walsh (2003, 2005), there have been several distinct stages of the evolution of foreign R&D in China: Phase 1 (late 1980s-mid-1990s), foreign R&D in China started with exploratory activities and forming of strategic partners with local research institutes/universities or joint venture partners in local manufacturing and marketing; Phase 2 (mid- to late 1990s), the expansion phase of R&D activities took place. The activities/forms included: contract R&D/outsourcing to local universities or firms, training centers and product development through localization and systems and standards integration; Phase 3 (late 1990s to early 2000s), the consolidation of the R&D activities through establishment of more centralized facilities, more advanced R&D objectives and closer relations with the parent company; Phase 4 (2003 to 2005+), a phase of explosive growth of foreign R&D in China, increasing inflow of R&D-related investments, China and MNCs seeking new ways to exploit commercial R&D in China, cross-regional collaboration in R&D, with China serving as hub.

Taiwan is one of the largest sources of FDI for China. China is also a large manufacturing base for Taiwanese electronics firms. About two-thirds of China's electronics exports are attributable to Taiwanese firms. Chen (2004) conducted a study among Taiwanese firms about their global R&D activities, through a questionnaire survey in July 2000 that received 82 USble responses (a response rate of 13.67 percent), followed by detailed interviews with 21 of these firms or their Chinese subsidiaries. The survey revealed that 39 out of the 82 respondents (47.56 percent) had located R&D in China, followed by 22 in the US, 13 in Japan, seven in Europe, three in South Korea, three in Singapore, three in India, and one in Israel. If only the respondents engaged in R&D are considered, the proportion of R&D units located in China rises to 67.24 percent, suggesting that China had become the major offshore R&D location for these Taiwanese firms (p. 343).

Based on the firm-level interviews, Chen (2004, pp. 345–346) identified five types of R&D units of Taiwanese firms in China. First, the product development is undertaken in Taiwan, while engineering support and manufacturing-related R&D are conducted in China; second, some Taiwanese firms outsource their software development activities to Chinese firms; third, Taiwanese firms have research collaboration with Chinese universities and/or research institutes; fourth, some Taiwanese firms conduct their upstream (core) R&D (or R&D for products at the developmental stage) in Taiwan, while their subsidiaries in China are assigned the downstream (non-core) R&D (or R&D for products at the mature stage); and finally, some Taiwanese firms carry out R&D in China for systems-related products, often modular products for the local market, such as handset motherboards for communication systems, but carry out R&D for peripherals, such as handset motherboards, in Taiwan.

## 6.1 ILLUSTRATIVE EXAMPLES OF FOREIGN CORPORATE R&D IN CHINA

### Nokia's R&D in China[1]

Much of Nokia's R&D work is closely linked to technologies, business or products in China. A sufficient proportion of work, however, focuses on global projects to ensure competence creation and also to utilize created competencies to contribute to local activities and utilize local researchers to study China-related topics, which are natural to do in China and difficult to do at other global facilities.

#### *Driving Forces*

- China is the world's largest mobile market as far as having the most subscribers and being the most dynamic;
- China is a strategic country market for Nokia. China was Nokia's second-largest market by 2004 and became the largest market by 2005. Nokia is the number one supplier of handsets in China and the leading supplier of 3G systems in the greater China area.

China is one of the 12 global R&D bases of Nokia in the world. Chinese R&D operations support both local and global markets. Nokia Research Center, Beijing, was established in 1998. It carries out long-term research projects and contributes to local business through accumulated expertise. About 30 percent of its staff hold Ph.D.s and 60 percent master's degrees, and 90 percent of the staff are Chinese nationals. It carries out research on: beyond 3G radio, core and IP networks and their performance; multimedia technologies and applications (research on Asian user interfaces), Chinese mobile applications and services; and technology exploration in China and other countries in the region. Researchers are encouraged to prepare inventions and scientific publications. On average, one patent application is filed per researcher annually. Some of its achievements include the world's first WCDMA high speed uplink packet access (HSUPA) demonstration system. Beijing Product Creation (Beijing PC) was established in September 1999. The initial purpose was to expand Nokia's capabilities to develop and localize terminal products for Nokia in China and Asia. Now it is a key R&D center in the global mobile phone business group. It designs, develops and delivers mobile devices for the global market as well as China-specific products. More than 40 percent of the globally shipped volume in the Mobile Phones Business Group comes from products designed and developed by Beijing PC.

Nokia has research cooperation with top-level Chinese universities. The cooperation takes various forms, including: funding for university research; research subcontracting; scholarships, fellowships, innovation funds, equipment, sponsoring of conference participation and so on; joint national or European Union (EU) projects; academic information exchange; internship positions for Chinese students; and joint postdoctoral programs.

## France Telecom's R&D in China[2]

China is one of 16 locations of France Telecom's R&D centers throughout the world. It is a wholly owned subsidiary. The main focus is on research and innovation in telecom-related areas that are most dynamic and advanced in China. The center contributes to France Telecom's global operations through innovative applications and services. The center has 70 scientists and engineers.

### *Driving Forces*

- To gain access to the dynamic telecom market in China.
- To gain access to the large pool of human resources in China.

France Telecom's R&D in China is organized into six laboratories that work on: open source technology; IP network and services; wireless systems; multimedia and visual and audio systems; speech and language processing; and innovative terminals. It has academic partnerships with local universities and research institutes as well as local companies. France Telecom also participates in European Union projects.

## Lucent Bell Labs in China[3]

Lucent Technologies (China) is the holding company handling all Lucent's businesses in China. In March 2000, Bell Labs Research was established in Beijing, followed by Bell Labs China's Wireless Laboratory in Beijing. In April 2002, the Lucent Mobility R&D Center was established in Beijing, followed by another center in Nanjing for 3G projects. The Lucent Mobility R&D Nanjing works on: 3G technology and product development; mobile switching (MSC, ECP, BSC) software development for Lucent's global 3G products; and technical support for Lucent's customers and business teams in China. The center has 300 in staff.

***Driving Forces***

- China's market potential—to be close to customers;
- Large supply of talented human resources available at a low cost;
- Manufacturing and sourcing activity in China—to be close to production facilities as R&D is complementary to it;
- Government support.

## 6.2 MULTINATIONAL CORPORATIONS

### Intel Corporation

Intel, a US-based MNC in the semiconductor business, has over 20,000 R&D employees located in more than 30 countries. Intel's R&D operations cover wholly owned R&D units, collaborations with universities/research institutes, joint venture R&D with other firms and venture-capital investments in technology-intensive companies. Intel's R&D investments in China, India and Russia are growing faster than elsewhere. These R&D investments are driven by the availability of an educated and skilled workforce with specific competencies in relevant areas in these countries to conduct key research in a variety of fields (UNCTAD 2005, p. 132).

Intel China Research Center (ICRC) in Beijing was established in 1998 to conduct applied research in the areas of human computer interface, computer architecture, future workloads and compilers and runtime. In early 2005, it had a staff of 75 researchers, most of whom hold a Ph.D. or an M.Sc., mainly from Chinese universities. The center's innovations include: the open research compiler, developed jointly with the Chinese Academy of Sciences; audio visual speech recognition, a system using computer vision to assist speech recognition; and microphone array and audio signal processing technology. The Intel Design Center in Bangalore employs more than 800 employees for chip design and development of software solutions for the company. The Nizhniy Novgorod (Russia) Software Development Center employs around 340 scientists and engineers for developing software tools and applications for Intel (UNCTAD 2005, p. 132).

### *Intel's R&D in China*

In 1985 Intel established a representative office in China. But in terms of business operations, Intel established IADL in Shanghai in January 1994, and the Intel China Research Center in Beijing was announced in May 1998. In January 2001, Intel established IXA Development Center in Beijing. Intel now has more than 4,000 employees in total in China and sales offices in 14 cities in China.

The Mission of Intel's R&D in China is 'to establish world-class technology research & development and build ecosystem support for key technology initiatives to ensure Intel's technology leadership position in PRC.'

Globally, Intel operates in five business areas: Intel Capital Investments; Government Standards and Regulatory; Research and Technology Development; Industry R&D Engagements; and Academic R&D Engagements. All five areas have R&D presence in China. In addition, China is also host to a Corporate R&D Center (which does more research than development work) and a Manufacturing Technology R&D Center of Intel. All the R&D centers report to the headquarters of Intel and not to Intel China's management.

Intel has an evolutionary framework for growth of R&D in China in a substantial and yet manageable way. This framework spanning 10 years envisages: 'As R&D continues to grow & mature in PRC, it will develop deeper competencies and take on more local market influence.' The Intel R&D Phased Development Model is based on competency/maturity and organization impact. Intel classifies its R&D centers into a hierarchy that begins with lab extension (Level 1), progressing to competence center (Level 2), progressing to finally reach the category of influential R&D center and technology leader (Level 3).

The salient features of lab extension (Level 1) and competency center (Level 2) are summarized in Table 6.1:

*Table 6.1* Intel's R&D Laboratories and Their Features

| *Lab Extension (Level 1)* | *Competence Center (Level 2)* |
|---|---|
| Core competencies under development | Core competencies clearly established |
| Projects defined and led by US Labs | Projects in core technology areas aligned with US Labs and locally led |
| Developing local strategy and technology focus | Labs agenda influenced by local strategy and focus |
| Limited local influence/R&D engagement | Coherent strategy for local influence/ R&D engagement |

*Source*: Intel China Research Center (2005).

R&D centers in China work on products for worldwide markets. It is important to note that all Intel products (semiconductors and other silicon products) are global products, with little or no localization requirements. Moreover, most of the manufacturers (local as well as MNCs) of the products that use Intel's products as core components in their products (e.g., computers, consumer electronics and so on) are based in China, and these final products are marketed both locally and globally. Therefore, the R&D work carried out in China can be considered as being related to worldwide products.

Nevertheless, different products will have different emphasis. For instance, in the Enterprise Group the work is more on systems and hardware (large server systems), whereas in the Consumer Electronics Group the focus is more on software. In both cases, there may be local variations, and these need to be addressed locally in China. Sometimes, the work assigned to an affiliate differs from generally held views. For instance, India as a country is well-known for software development and China for hardware, but, Intel's R&D in India carries out a lot of hardware development (including IC design), and its R&D in China carries out substantial software development work (particularly for local applications and Chinese-language-related developments).

Different business units of Intel in China leverage different skill sets that are available locally. For instance, the focus of the Consumer Electronics Group is software development. In many consumer electronic products, the hardware element is fairly simple and standardized when compared to large servers. So Intel has a core hardware product developed in the US, but in consumer electronics, the software that runs these products requires a lot of localization, as there are large differences in the application USge models, interface language and so on. In the consumer electronics business, Intel's R&D in China addresses these market-specific needs and requirements by focusing on software development, but not on hardware development. In addition to its in-house software team in China, Intel also works together with local independent software vendors (ISV) in China.

In the servers business, there is a requirement for large hardware as well as large software components. Hardware is global and does not involve localization. Even with respect to software, enterprises that use the servers tend to use almost the same software packages, e.g., enterprise solutions such as those sold by IBM, Oracle and SAP around the world. There is not much localization involved in these software packages. However, the large servers are used for different applications in different businesses, and this usually requires different configurations. So there is a lot more differentiation in the hardware required locally (different from localization), and such solutions could also be used worldwide if the configuration suits the needs. China is a very big market with a complex system, and R&D to develop such solutions needs to be carried out in China.

R&D teams in China predominantly work on worldwide products (70 to 80 percent). This is the same with the hardware team in the Enterprise Group as well as the software team in the Consumer Electronics Group. Intel does not conduct any chip design activities in China.

### *Driving Forces*

- Local differentiation is the major driving force for location of R&D in China, but in practice such work constitutes only a part of the R&D work done in China. It is difficult for R&D teams in the US and other countries to understand the unique characteristics of the Chinese market. Therefore, local R&D is required to respond to local needs. Intel also keeps a close watch on the skills available in China to leverage them for global use. So location of R&D is not just driven by market considerations alone.
- China is the second-largest market for Intel, after the US. Most of Intel's customers, both local companies as well as MNCs, have manufacturing facilities in China. China and Taiwan together account for almost 70 percent of Intel's global business.
- Availability of the vast talent pool in China is another important consideration. China and other emerging economies such as Brazil, India and Russia have talented and well-educated scientists and engineers, whose skills are on a par with those in the industrialized world and could be utilized for corporate growth.
- Cost differentials between China and other locations are also important, but not the most important factor.
- Government relationship is another important factor. In China, as in most emerging economies, the government plays a large role in business/industry both directly through state-owned enterprises and indirectly through policies. In order to do business in such economies, it is important to understand the government perspective and to show a long-term commitment to the local economy by not just selling, but also by investing, transferring technology and leveraging local talent and so on.

Presently there are 1,200 engineers employed in R&D functions in China. Intel feels that it has reached the critical mass to carry out its planned growth in activities.

### *Corporate Innovation System and Knowledge Flows*

Figure 6.1 depicts the corporate innovation system of Intel China Research Center and the associated knowledge flows among different actors. Intel R&D Center in China is strongly embedded into the global intracorporate R&D network of Intel as well as into a network of local external organizations in China.

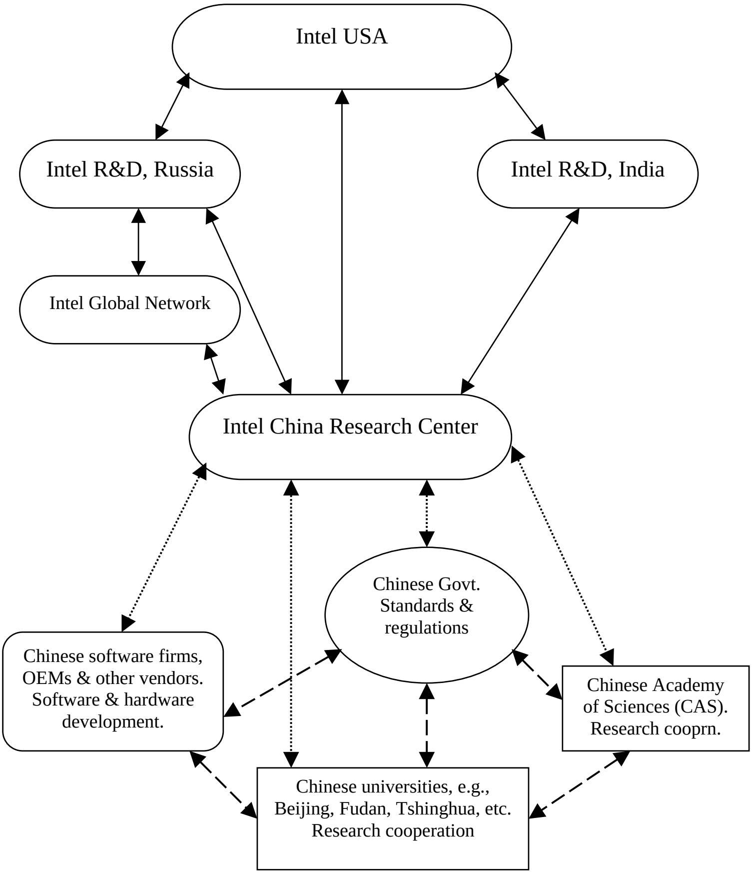


*Figure 6.1* Innovation system of Intel China Research Center.

R&D centers in China work closely with the R&D units of Intel's headquarters in the US by carrying out projects planned and assigned by the headquarters. R&D centers in China also collaborate with Intel's global R&D centers located in other countries, such as India and Russia, depending on the needs of the product groups. There is a continuous flow of people between Intel's headquarters and the centers in China, resulting in a continuous flow of knowledge among the centers in Intel's global intracorporate R&D network.

Intel works closely with local firms, exchanging knowledge with them. For instance, Intel's Consumer Electronics Group works with local software vendors, whose software works on Intel's hardware (e.g., Hanwang Technologies). In order to make sure that such software works perfectly, Intel passes on the knowledge relating to the hardware and also advises the local vendors on software development processes. Similarly, Intel works with original equipment manufacturing (OEM) customers, who manufacture PCs and servers, on how to differentiate their products from their competitors' products. A lot of technical knowledge relating to processes, configuration and product design is exchanged.

Intel has a strategic program to collaborate with the local universities in the countries in which it operates. Intel collaborates with local universities in China from a long-term perspective. Much of such collaboration is of an enabling nature, in the sense that it mainly sponsors research programs in the universities and the Chinese Academy of Sciences (CAS). Among the 30 or so Chinese universities with whom Intel has collaborative linkages are: Tsinghua University, Beijing University, Shanghai Jao Tong University and Fudan Science and Technology University. By collaborating with universities, Intel gains access to the results of research in areas of its long-term interests. Collaboration also facilitates recruitment of talented new graduates.

Intel collaborates with the government as well. Standard setting by the Chinese government affects Intel, just as it affects many other MNCs, as all Intel's products fall under the purview of standards and regulations. Most of Intel's products are based on international standards, and the Chinese standards under development are somewhat different from those that are followed globally. China, being new to the task of setting standards, requires international cooperation, and Intel sees itself as becoming a trusted adviser to the government in framing Chinese standards. It assists the government on various issues such as cellular communication, security and so on, even at the level of technical details. Through this process Intel encourages China to participate in the process of setting international standards, as too many standards around the world are not good for the industry.

In terms of promoting 'intrapreneurship' (and also entrepreneurship) Intel has an internal initiation to assess proposals submitted by its staff. After assessment, selected projects are provided with seed funding and even incubation for up to two years. Basically the project becomes an Intel spin-off. But such spin-offs have not emerged in China so far.

### *Strengths of China in R&D Activities*

- The sheer intelligence of the engineers and scientists in China; the top one percent of talented people in China are interested in working for Intel given its global reputation;
- Chinese students have a very strong foundation in basic education;
- Local innovations—some Chinese innovations have been very useful and technologically advanced, and these could be leveraged for local and global applications.
- Until recently the Chinese people were bound by tradition. Presently technological change is taking place at an unexpectedly fast pace in China. So people are very excited about emerging technologies and their applications, e.g., mobile phone usage models in China. On

the other hand, in the industrialized world people have always been exposed to advanced technologies, and emerging technologies are not so exciting for them.

### *Weaknesses of China in R&D Activities*

- The education system is top-down driven. Students do not chose their topics for research, but work in projects directed by the professors. This dampens independent thinking and conceptualization.
- At the individual level, there is a gap when compared to researchers in the industrialized world, in terms of understanding of the domain knowledge.

### *Host Country Implications*

- Intel has contributed substantially to the building up of PC industry in China by transferring technologies to Chinese companies such as Lenovo. Intel now has a joint venture R&D Center with Lenovo. PC industry is now a dominant sector in the Chinese economy.
- Intel Capital, which invests in high-tech start-up companies, has a large presence in China. It invests several hundreds of million dollars every year in Chinese companies, not only nurturing the companies, but also creating an ecosystem.
- Similarly, Intel also nurtures local talent. Working for Intel is a valued experience for many. Many former employees of Intel have now set up their own companies, and some have become professors in local universities. Through such mobility of its people, Intel is contributing to the diffusion of knowledge to the wider society.

### *Home Country Implications*

- The emerging economies are quickly catching up with the industrialized countries in technological capabilities and have even surpassed them in market potential. Like emerging economies, the industrialized countries should now put more efforts into fundamentals, such as strong basic education (not just in highly advanced research only) and infrastructure.
- There are still a lot of skills available in a home country like the US, which are not available in a host country like China. So home countries still get the benefit of accessing cheaper complementary skills, as well as increased demand for home country-based skills as the demand in the emerging countries increases for Intel's products.

## Hitachi (China) Research & Development Corporation

Hitachi, a Japan-based MNC, has its main R&D located in Japan. In addition, Hitachi has R&D centers in five countries globally: the US, Europe

(France and the UK), Singapore and China. Among them the R&D center in China is the biggest with 80 engineers, including seven expatriates from Japan employed in R&D (50 in Beijing and 30 in Shanghai).

The Hitachi (China) Research and Development Corporation (HCR&D) was established in April 2005 as the first R&D independent entity set up by Hitachi Ltd. The HCR&D originated from the R&D Center of Hitachi (China), which was founded in 2000 with three people, as the third foreign R&D center after the US and Europe. This R&D unit was operating under the Hitachi (China) Co., which is the business arm of Hitachi. It was felt that it would be easier to manage a central R&D operation as an independent unit to cater to several businesses of Hitachi in China. With the concept of 'Contribution to Society by Technology,' HCR&D's main mission is to support the Hitachi business in China by creating brand new products and technology. Its research fields include: ICT, software engineering technology, digital television, energy-saving air conditioners, functional materials, medical image processing and speech synthesis. R&D conducted by HCR&D also includes products marketed worldwide by Hitachi.

The 11th Five year Plan of China aims to turn China from a country with manufacturing power to R&D power. To achieve this goal it has set up certain tasks that include: bringing up domestic innovative and original technologies; standardization of domestic technologies; and strengthening of competitive power with intellectual and brand power. Hitachi perceives that China needs international cooperation at different technology levels in achieving its goal: (1) standardization level; (2) technology level; and (3) product level. Hitachi would contribute to China and the worldwide market with innovative technologies by locating R&D activities in China. Such an approach would contribute toward China's achieving its goals and also facilitate Hitachi's market entry into China. By locating R&D, Hitachi intends to show its long-term commitment to the Chinese economy.

### *Driving Forces*

- Standardization of technologies/products—Chinese proprietary standards are somewhat different from international standards in most cases and totally different in some cases. This requires location of R&D in China. For instance, the TV broadcasting system in China is different. At present, only Chinese companies can participate in the meetings relating to standardization.
- The Hitachi Group has over 100 companies with operations in China. HCR&D caters to the technological needs of these companies.
- Gaining access to talented human resources. Chinese universities have excellent staff and students, whom Hitachi utilizes for its R&D.
- The cost differentials between Japan and China in terms of salaries of research personnel and other operational costs are also important.

About 80 percent of the software outsourced from Japan is developed in China. China has an advantage over others in relation to the Japanese language because of the similarity of the script (writing characters). HCR&D develops software for local application. An important characteristic feature of HCR&D's R&D in China is the collaboration with local universities.

By 2010, HCR&D aims to have a balance between different market orientations in its activities as follows: local market orientation, global market orientation and service/development centers. Such global market-orientated R&D includes: HD video and blue ray disk, voice recognition and video processing. China's R&D activities are closely linked to the R&D center in Japan, as the latter is also involved with the same work. The work is shared between the R&D units in Japan and China. For instance, in the development of HD video and blue ray disk, HCR&D developed the software package for middleware and rapid prototyping.

### *R&D Field*

- ICT research—toward a ubiquitous network society, Hitachi's research focuses on wireless, mobile and broadband network and its application technologies, covering next-generation mobile communication systems (3G/4G), broadband optical access network, radio and intelligent transportation system technologies;
- Ubiquitous platform R&D—this is aimed at the digital consumer products in the Chinese market through R&D in key technologies and localization of Hitachi's common worldwide platform to adapt to the Chinese technical standard. The technologies are related to digital TV and multimedia appliances;
- Open system software technology R&D—In order to realize a common open standard for the system environment, certain new technologies and solutions are required. The current research topics are mainly related to the worldwide activities of Hitachi, as well as the development of new business opportunities in China. Offshore software development methodology and supporting environment; high reliability of open source software; IT mansion and finger vein authentication; and web USbility research.
- Home appliances development—this department is dedicated to the development of air conditioners for the world market, by focusing mainly on new air-conditioner designs, production of prototypes and performance testing;
- Innovative systems and materials—in order to support the long and stable development of the Chinese economy, Hitachi has research cooperation with some well-known Chinese universities and research institutes in fields such as environment-friendly materials, human interaction (Chinese language processing and speech

synthesis technologies), medical image processing (to achieve high speed and high accuracy); and system management technologies (Fudan-Hitachi Innovative Software Technology Joint Research Laboratory) to make a more secure and comfortable life for Chinese people and people around the world.

### *Corporate Innovation Systems and Knowledge Flows*

Figure 6.2 depicts the corporate innovation system of Hitachi China R&D. As the figure shows, HCR&D is strongly embedded into the Chinese local innovation system through knowledge linkages with the local organizations.

Chinese universities have professors who are internationally well known for their expertise in the domain. Similarly, Chinese students are highly talented, and Hitachi utilizes them to develop new technologies. It is because of its collaboration with the local universities that HCR&D, with only 80 in-house researchers, is able to conduct R&D in several fields. Whenever other business units of Hitachi would like to gain access to certain expertise available in the local universities in China, HCR&D facilitates such collaboration.

Hitachi's collaboration with Tsinghua University is the oldest, established since 2001. HCR&D and Tsinghua University have established the Tsinghua-Hitachi Ubiquitous IT Joint Research Laboratory to conduct research on 3G/4G, wireless and broadcast communication convergence. Furthermore, the two partners also collaborate in many other research

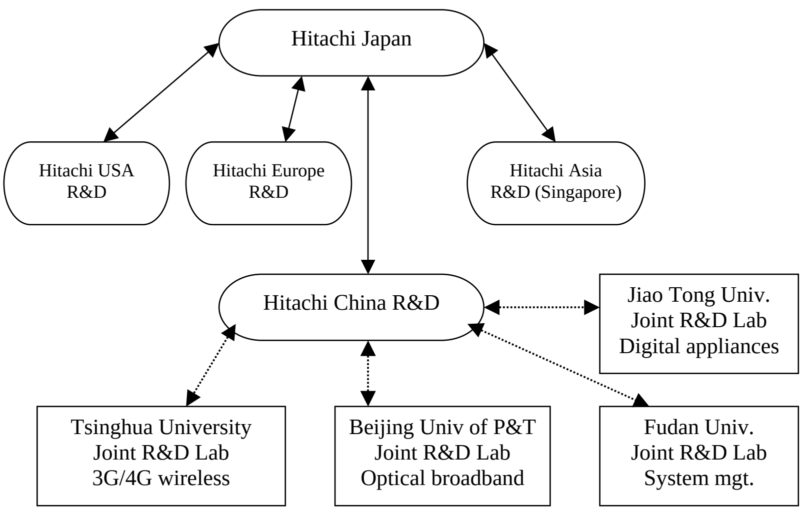


*Figure 6.2* Innovation system of HCR&D (Hitachi China).

fields, such as laser-processing technology, environment-friendly technology and digital TV. In 2006 HCR&D and Tsinghua University signed an agreement on a framework for cooperation. Following this agreement, there has been cooperation in a range of research fields, as well as in diffusion of knowledge through training programs and Hitachi's series of technical lectures.

Similarly, HCR&D and Beijing University of Post and Telecommunications (BUPT) have set up the BUPT-Hitachi Joint Laboratory to conduct research on optical broadband access network technology. HCR&D and Fudan University have set up the Innovative Software Technology Joint Research Laboratory to conduct research on system service and management. There is also cooperation in the field of chemical materials. HCR&D and Shanghai Jiao Tong University carry out joint research on applications related to digital home appliances, functional materials and medical image processing.

Talented researchers are one of the critical resources of HCR&D. Hitachi attaches a high priority to the cultivation of these talents. Hitachi periodically sends researchers to Japan for further training or organizes various on-the-job-training and technical programs and seminars to improve the competence of the staff. It also provides Japanese and Chinese language training for technicians so as to improve their communication and research efficiency. HCR&D invites famous experts from universities and research institutes to give professional lectures and organize training classes for the staff.

### *Host Country Implications*

- The Chinese have strong capabilities in the fields of middleware software and rapid prototyping software.
- The Chinese economy is growing rapidly. But such growth occurs mainly in mature products. In order to thrive in the growing economy, the business model for companies would be to participate in such mature technologies. In terms of R&D, contribution can only be made in customizing these products for the Chinese market. The market for totally new products and/or technologies such as environment-friendly products, where R&D can make a significant contribution, is still very small and not a commercially viable business in China. Such advanced and sophisticated markets demanding innovative products need to be developed in China.
- In China, once the standardization is done, prototyping is done very quickly. But personnel do not seek to find new things, reflecting weaknesses in original and innovative thinking. However, this problem arises not from the lack of ability among students, but because the education system is tuned to a top-down approach.
- Some MNCs, particularly those in high-tech areas, attract the best talents by offering them very high salaries. Therefore, the talents

available to the other businesses are not top ranking, but the next levels. This also leads to a high mobility rate (over 20 percent), disrupting activities and adding to training costs.

## 6.3 CHINESE COMPANIES

### Lenovo

Lenovo is a Chinese company dedicated to computer and related products: desktops, laptops, servers, and mobile phones. Lenovo emerged as an academic spinoff. It has a Six Sigma quality control. Main competitors for Lenovo in the Chinese market are Hewlett-Packard, Dell, Acer among MNCs and a number of local companies such as TCL. Lenovo faces the competition successfully with product differentiation. Lenovo competes by developing high-performing and more efficient products, while leveraging the low-cost base. In May 2005 Lenovo acquired the Personal Computing Division of IBM and became a leader in the global PC market, with approximately US$13 billion in annual revenue and products serving enterprises and consumers the worldwide. The deal brought IBM's technology to Lenovo and helped it to have a market reach beyond China and Asia.

Lenovo, as it is known now, originated as the Legend Group in 1984, when 11 scientists from the Institute of Computer Technology of the Chinese Academy of Sciences (CAS) established the company, with funding from CAS. In the beginning of 1985, as its first business deal, Legend took over the responsibility of receiving, checking and maintaining IBM computers imported by CAS and training the staff of the CAS. Based on the original concept developed by the Institute of Computer Technology, Legend developed the pioneering Legend Chinese Character Card that translated English operating software into Chinese characteristics and also achieved breakthroughs like PCs with one-button access to the Internet. Legend invested all its profits from servicing the IBM computers into the design, production and marketing of this card called 'HanCard.' "Subsequently, Legend became the largest supplier of personal computers in Chinese market. In October 1994, Legend was registered as the first civilian technology enterprise, and later in 1997 the company was reorganized into six groups under Legend Holding Co. in 1997" (Sigurdson 2005, p. 111).

To further signal this change in strategic approach and establish a brand name that could be extended to global markets, in 2003, "Legend changed its brand name to Lenovo, taking the 'Le' from Legend, a nod to its heritage, and adding 'novo,' the Latin word for 'new,' to reflect the spirit of innovation at the core of the company. The company's name changed from Legend to Lenovo a year later. A gradual change of logo and name took place during 2003–2004 and the company became clearly known as Lenovo before its alliance with IBM" (Sigurdson 2005, p. 111).

According to Wei and White (2004 p. 412), Lenovo adopted several key strategic approaches for growth: First, unlike the MNCs who sold older and slower model PCs, Lenovo offered PCs that contained the latest processors to Chinese customers. For instance, the MNCs were selling their older and slower 386-based PCs in China at higher prices, while marketing faster 486-based PCs in the US. Lenovo, realizing the opportunity, quickly incorporated the latest Intel chips into its PCs and sold them in the Chinese market. This strategy contributed to Lenovo's image-building as a fast and technology-intensive producer and to reducing the stigma of lagging technology attached to local brands by Chinese consumers (Business Week 1999).

Second, in addition to offering the latest technology in its PCs, Lenovo started designing its PCs to appeal specifically to Chinese customers (Gold et al. 2001). The PCs marketed by MNCs were not adapted to suit the requirements of local customers. Lenovo, in contrast, started designing specific products for different market segments, such as banks, large enterprises and SMEs in the corporate sector, as well as for diverse individual customer groups. Such innovations included: Lenovo's own operating system (LEOS)—home PC that can be turned into an entertainment unit at home, by playing DVDs and MP3, viewing digital photos as well as TV, without the need for Windows OS; boot-easy technology—patented technology that reduces system boot-up time by half; power- and thermo-easy technologies—automatically adjust power voltage and protect the central processing unit (CPU); and touch-screen technology—browses the Internet through touching the screen instead of mouse or keyboard) (Wei and White 2004).

Third, Lenovo adopted a strategy of competing on the basis of price. For comparable products, Lenovo's prices were about two-thirds of foreign-made PCs (*The Wall Street Journal* 1997). Lenovo managed to do this by maintaining a lower cost structure, mainly due to the relocation of manufacturing activities to China by foreign component suppliers, such as Seagate Technology for hard drives. This was quickly followed by the entry of a wave of Taiwanese firms into China from the mid-1990s providing access to supplies of components and peripherals of the same quality as those used by MNCs (Kraemer and Derick 2001).

Lenovo formally established a corporate-level R&D center with 200 personnel in 1990. However, its R&D approach at the time reflected the company's origin from an academic institution. Its researchers were more interested in developing leading-edge technologies, such as large-scale ICs and digital switches, rather than working on business-related tasks. Realizing this mismatch between its strategic business needs and the interest of its corporate R&D center, Lenovo transferred the R&D personnel to business units, thereby establishing several business unit-level R&D centers that answered to the managers of business units (Wei and White 2004; Sigurdson 2005). "The close interaction among R&D, manufacturing and marketing functions enabled Lenovo to implement its two-pronged strategy of low-cost manufacturing and innovative products matching the Chinese market" (Wei and White 2004, pp. 413–414).

In 2002, Legend's supercomputer, the DeepComp 1800, made its debut. It was China's first computer with 1,000 GFLOP (floating point operations per second) and China's fastest computer for civilian use, ranked 43$^{rd}$ in the top-500 list of the world's fastest computers. The same year Legend announced a joint venture to enter the mobile handsets business. In November 2003, Lenovo successfully developed DeepComp 6800, which was ranked 14$^{th}$ on the global list. In 2003, Lenovo developed and introduced an application technology, which heralded the important role Lenovo would play in the 3C era (computer, communications and consumer electronics). These and other market-leading personal computing products catapulted Legend to a leadership position in China for eight consecutive years with over 25 percent market share in 2004.

With the acquisition of IBM's PC division, Lenovo located the executive headquarters in New York (US) with principal operations in Beijing (China) and North Carolina (US). The company employs more than 19,000 people worldwide. Lenovo's global R&D centers in China, Japan and the US have produced some of the world's most important advances in PC technology (including those from IBM) and introduced many industry firsts.

### *R&D Centers*

China—Beijing 2 centers (Corporate R&D Center and BU R&D Center); Shenzhen 2 centers (Development Lab and Advanced System Design Center); Shanghai (Notebook/Mobile Phone Development Center); Xiamen (Mobile Phone R&D Center); Chengdu (Branch of Corporate Research).

US—Research Triangle Park, Raleigh, North Carolina (basic and advanced research).

Japan—Kanagawa-ken, Yamato (R&D on Think Pad).

As Wei and White (2004, pp. 416–417) note, Lenovo adopted a two-tier R&D structure, on the lines of what it calls 'technology for today' and 'for tomorrow and the day after tomorrow.' The first tier, with the responsibility for 'today's technology' for PCs, is located within the IT Business Cluster that includes the server, notebook, consumer IT and commercial desktop and is supported by specific labs. For instance, the Desktop PC Development Center includes five supporting labs that are responsible for parts and components, commercial systems, consumer systems, architecture and standards and application software. The second tier is corporate-level R&D and includes four centers. The Lenovo Research Center is responsible for the development of future key technologies. Its focus is on developing the technologies, protocols and applications that will make it possible to fuse different information devices, including home appliances, telecommunications and computers. The Software Design Center focuses on the development of applications software; the Industrial Design Center focuses on product appearance and attractiveness; and the Add-on Card Design Center develops motherboards and other parts and components to optimize the performance of Lenovo's products. However, Lenovo needs to invest more in R&D to develop leading-edge technology, and yet it is difficult for Lenovo to move up the value chain in the PC industry, which is dominated by major MNCs such as Intel and Microsoft.

According to an internal source in Lenovo, PC industry is a mature industry, where the innovations are mainly carried out by the component suppliers, such as Intel, Microsoft and motherboard suppliers. PC assemblers like Lenovo can only focus on developing new applications and/or design of the products (i.e., software). Therefore, the labs in China, in addition to software development, mainly focus on testing the performance of the products such as the battery life and radiation levels and on developing solutions to overcome performance related problems.

### *Corporate Innovation System and Knowledge Flows*

Lenovo realizes that the rapidly changing technologies and the variety of knowledge inputs required in the PC industry require collaboration with other organizations. Therefore, it has formed alliances with a number of companies such as China Telecom, Computer Associates, D-Link, IBM, Motorola, National Semiconductor and Texas Instruments. In August 2003, it established a joint venture R&D lab with Intel, the Lenovo-Intel Future Technology Advancement Center. This center is responsible for building reliable computation environments and key technologies for the next-generation Internet and for designing leading-edge products that unite computers and telecommunications.

Throughout, however, Lenovo maintained its special relationship with the Chinese University of Science and Technology that used to be an integral part of the CAS and on whose campus, the Legend Computer Company was initially founded. In addition, Legend established a number of relationships with other universities. These included Tsinghua University, Shanghai Shuichan University, Shanghai Ligong (S&T) University and Xian Dianzi (Electronics) Jishu University. "In a Silicon Valley centre Legend employed some 20 people under the direction of the Quantum Design Institute (QDI) that was responsible for Legend motherboards and also had the function of technology watch and collecting intelligence on changes in motherboard design and production" (Sigurdson 2005, p. 113).

## Hanwang Technologies Co. Ltd.

Hanwang, founded in 1998, is a leading company in China and a manufacturer of diverse intelligent pattern-recognition technologies and products. It is a spinoff from the research on automation technologies that was carried out by the Institute for Automation Technologies, Chinese Academy of Sciences (CAS), in the 1980s and 1990s. The research project was related only to handwriting recognition and was funded by the National Basic Science Foundation (Project A63). The researcher who established the company obtained a national patent on Chinese handwriting-recognition technology. The company was originally founded with another name and changed its name to Hanwang Technologies Co. Ltd. in 1998. The same year, Hanwang Production Co. Ltd. was also established.

### *R&D Capabilities*

In 1998, Hanwang licensed its embedded Handwriting Recognition System to Microsoft for incorporation into Windows CE and Pocket PCs. Hanwang is currently the leader in China's domestic market for recognition-technology products. About 90 percent of the mobile phones manufactured in China incorporate Hanwang's writing-recognition technology, including mobile phones manufactured by MNCs such as Nokia, Samsung and SonyEricsson. Compared to other languages, developing technologies for recognizing Chinese language characters is more complex. Since Hanwang has done it successfully, it has earned international recognition for its technologies. This complex technology can now be more easily applied to recognize other languages around the world. Microsoft licensed this technology to incorporate it into its Windows CE operating system.

In 2000, Hanwang's Handwriting Recognition Methodology and Systems won the first prize of the Beijing State's Science and Technology. In 2002, Hanwang's technology won the National Science and Technology Award. In 2006, Hanwang was awarded the title of 'innovation enterprise' by the Chinese Ministry of Science and Technology. In 2007, Hanwang's product design for the Rollick 0504 graphics tablet won the Red Star Award for industry design (all national awards only).

In addition to handwriting-recognition technology products, Hanwang manufactures a number of products based on its recognition technologies. These products include fingerprint recognition, face recognition and several communication-related products. Hanwang's OCR technology won the second prize for National Science and Technology Progress. About 70 percent of the scanners manufactured in China use Hanwang's OCR technology. This technology facilitates transformation of picture-type files from scanning directly into document-type (Microsoft Word) files. This technology has been further developed by Hanwang and applied in mobile phones. Hanwang's software package in the mobile phone can take a picture of a document and directly convert it into a Word document.

Hanwang further developed a new technology for tablet-PCs, which allows drawing pictures and words directly on the screen. This technology is mainly used in drawing cartoons. In the area of these technologies, a patent dispute arose between Wacom, a Japanese company, and Hanwang, with Wacom filing lawsuits in China and the US. Subsequently, both parties entered into an agreement, settling the dispute.

The 'core competence' of Hanwang is the 'recognizer' field. It has several patents in this area. Based on this core competence, Hanwang developed several application technologies and products. Hanwang develops two types of products: (1) embodied software—these packages are PC- or PDA-based and form part of the software packages supplied with or added to the PC or PDA; (2) embedded software—these software packages are embedded into the products (hardware) designed and manufactured by Hanwang to perform those specific functions, e.g., writing pad, scanner pad, scan pen, fingerprint recognizer, face recognizer and so on. Hanwang has its own factories manufacturing the hardware. Hanwang's next priority is to work on human-machine interaction.

In terms of global competition, Hanwang thinks that it is better placed than others in the handwriting-recognition technologies. Chinese characters are the most difficult to recognize. Hanwang managed to develop such complex technologies in the area of handwriting recognition. So Hanwang's technology can be applied more easily to other languages worldwide; whereas competitors' technologies can be applied only to certain scripts. Hanwang has different global competitors for different products/technologies: Meng Tian (Taiwan) for handwriting recognition; Wacom (Japan) for electronic drawing technologies and pen; and Innonce (US) for face-recognition technologies.

Hanwang has 30 branches all around China, Korea, Hong Kong, the US and Germany. In total there are over 1,000 employees in the company, with 200 in R&D, 200 in sales and administration and 400 people in the factory. Its annual sales turnover is around US$50 million. It has about 300 patents in China. Internationally, it has two patents each in the US, Japan and Germany. It also has two patents under PCT for new technologies.

### *Corporate Innovation Systems and Knowledge Flows*

Figure 6.3 depicts Hanwang's corporate innovation system and associated knowledge flows between Hanwang and its local and global external knowledge network.

Hanwang has a partnership with many MNCs in technology development. Hanwang developed a software package jointly with Intel, using Intel's platform (chip) to enable direct drawing on the screen of the EPC. The EPC is a micro PC developed by Oxus of Taiwan, which is suitable for drawing activities. But this micro PC has a keyboard for input. The joint Hanwang-Intel software package does away with the keyboard through direct input entry on the screen.

Similarly, E-Ink, a US company, developed a technology called E-Page, which looks like a page but has no input function (blank page). Using this

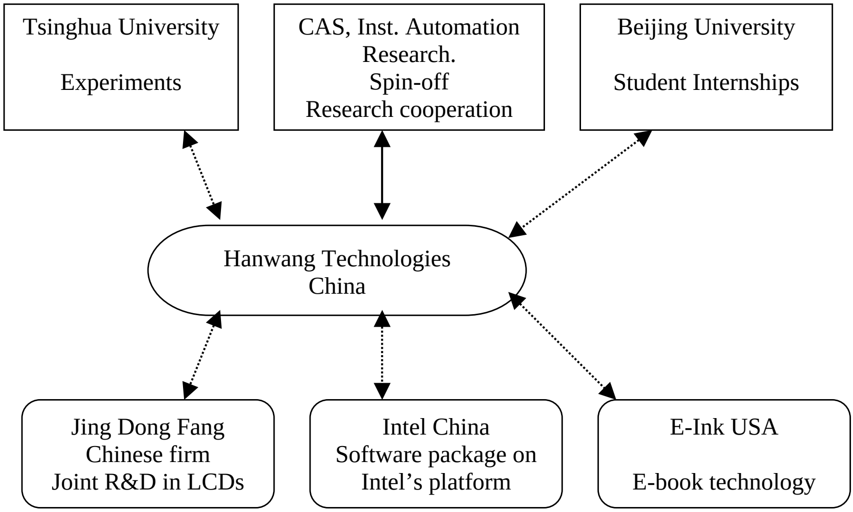


*Figure 6.3* Innovation system of Hanwang Technologies (China).

platform technology, Hanwang developed an application technology to directly impose (print) drawings and text on this e-page. The joint E-Ink-Hanwang technology is incorporated into the e-book products of Sony-Amazon and Samsung worldwide.

Hanwang also collaborates with local companies. For instance, Hanwang has joint R&D in developing liquid crystal displays (LCDs) with Jing Dong Fang, the largest manufacturer of LCDs in China. The collaboration is in the areas of improving the functioning of LCDs and in the refinement of manufacturing processes. Some US companies are also using these LCDs developed jointly by Hanwang-Jing Dong Fang.

Hanwang also collaborates with Chinese universities in R&D activities. It has links with the Institute of Automation Research, CAS, from which Hanwang originally emerged as a spinoff. It also has links with Tsinghua University. Links with these two academic institutions help Hanwang at the experimental level, e.g., proof of concept. Hanwang also provides internship opportunities to students from Chinese universities. For instance, students from Beijing University regularly do their internship at Hanwang. They work Hanwang's research projects during their internship.

Hanwang does not feel any difficulties with the globalization. It has an advantage by being based in China as it can utilize the vast talent pool available in the country and gain access to the basic research results in Chinese universities, at costs that are comparatively very low. It derives its competitive advantage by leveraging the talent at low-costs.

However, it feels that Chinese market is not suitable for innovation-based companies to grow. The local companies that license Hanwang's technologies do not pay royalties properly. For example, a mobile phone manufacturer may pay royalties for using Hanwang's technology in 10 phones, but actually uses them in 100 phones.

The biggest disadvantage with the global companies that license Hanwang's technologies is that they have a better bargaining ability. Because Hanwang is small in size compared to MNCs and is a company based in an emerging economy rather than in an industrialized country, it receives low licensing fees from the global companies. However, Hanwang feels that this disadvantage will disappear over time.

## 6.4 HOST COUNTRY IMPLICATIONS

According to Walsh (2003), from a strategic perspective, R&D-related FDI plays a critical role in China's long-term S&T development goals. One of the main objectives of China's scientific modernization is to fill the knowledge gap in transforming the basic research results into tangible products and processes by learning from foreign firms, and foreign R&D centers are helping China to fill this critical knowledge gap through their applied research activities. Foreign R&D in China also provides direct benefits at the enterprise level. Through a combination of strategic alliances (including in R&D) with foreign firms, Chinese firms have developed more modern product lines and have progressively implemented innovative and globally focused business strategies. For instance, in computer software, Chinese enterprises, such as Founder, Red Flag, UFSoft, Neusoft, Kingdee and Top Group, are both partnering and competing with foreign high-tech MNCs such as Microsoft, Oracle, IBM and Sun Microsystems.

# 7 Global Innovation in Brazil

The Brazilian subsidiaries of MNCs conduct R&D, but much of their R&D is focused on adapting and developing products and technologies to the local market and in some cases to the regional markets in Latin America. In a study of the telecommunications sector, Galina and Bortoloti (2004) concluded that there was no substantial involvement of Brazilian subsidiaries of MNCs in global product development (GPD). Both bibliometric and patent data suggested limited involvement of Brazilian subsidiaries in GPD in the telecom field. But the case studies of foreign subsidiaries in Brazil, presented by the Ministry of Science and Technology (MCT 2000), show the presence of R&D relating to local product development as well as partnerships with national universities and research centers. These case studies also showed that the subsidiaries are more involved with local or regional adaptation of products already created elsewhere than with global product development. Other studies (e.g., Galina and Plonski 2002), however, show that Brazilian subsidiaries of MNCs are certainly involved in GPD at least in some specific product or technology niches.

Several of the subsidiaries of MNCs in the ICT sector that are investing in local R&D are recipients of incentives based on an incentive law. The Information Technology (IT) Law (Law 8249/1991, updated by Laws 10.176/2001 and 10.664/2003) provides incentives to companies fulfilling certain requirements. One of the requirements of the law is that in order to avail itself of government incentives, a company must invest at least five percent of its local sales in R&D activities locally, and part of this investment (around two percent of sales) must be invested in collaborative projects with Brazilian universities or research centers (Dias and Galina 2004, p. 10).

While the adaptation type of R&D dominates in subsidiaries of MNCs in Brazil, since the late 1990s some change has been noted in the strategies of some MNCs. Now Brazilian subsidiaries are being made a part of global R&D strategies, by upgrading their technological activities and giving them new R&D responsibilities (Costa 2005). This strategy is noticeable mainly in the auto parts and automotive industries and in the electronics industry. In these industries MNCs have even reversed the earlier decision to downsize local R&D activities following the loss of local market share and have increased their innovation activities in Brazil (Queiroz et al. 2003; Furtado et al. 2003). The pharmaceutical industry, on the other hand, displays a reverse pattern, with only few pharmaceutical MNCs conducting R&D in Brazil, despite the availability of local capabilities and public laboratories (Costa 2005; Furtado et al. 2003).

The product-related R&D activities of automobile manufacturers in Brazil have been concentrated mainly on platform adaptations to local conditions, so-called 'tropicalization,' and to some extent on the development of local models or derivative vehicles from a global platform so as to suit local demand requirements. However, some major MNCs' subsidiaries (GM, VW, Fiat, Ford) have accumulated design competencies locally and therefore are becoming partners to their headquarters in global product development. Subcompact cars are the mainstay of automobile manufacturers in Brazil. As a result, they have built up specialized competencies in the design of small and efficient engines (up to 1,000 cc). The development of suspension modules is another competence of some of these manufacturers (GM and VW) (Consoni and Quadros 2006).

Borini et al. (2005) classify foreign subsidiaries in emerging economies, particularly in Brazil, into: traditional subsidiaries (ST), subsidiaries with limited relevance (SRL) and strategically relevant subsidiaries (SRS); they studied the factors that determine the dynamics of subsidiaries' role in MNCs. The traditional subsidiaries tend to be characterized by greater centralization of decisions and innovations in headquarters or regional centers. However, the Brazilian subsidiaries carry out small adaptations for the local market (e.g., automobile assemblers like Toyota and Renault). In a few cases STs may develop products meant exclusively for local markets. For instance, Ala, the powdered soap developed by Unilever Brazil, is a product aimed at the population with very low purchasing power mostly located in the northeast of Brazil.

The subsidiaries with limited relevance (SRL), particularly in emerging economies, are further categorized into: global platforms and specific creators. Typical examples of global platforms are the subsidiaries of automobile MNCs in Brazil, electro-electronic platforms in Asia and 'maquiladoras' in Mexico. These subsidiaries mainly implement innovations coming from headquarters, but they are more integrated with global business networks and thus have better possibilities to play a strategic role (Borini et al. 2005). For instance, an automobile MNC may designate a certain subsidiary as a center (platform) for production of CKD (completely knocked down) and main components that will be exported to several countries (Consoni and Quadros 2003). The Brazilian subsidiary of AGCO is one of the largest manufacturers of agritools in the world, and it became the center for manufacture of tractors (previously located in England), as well as the global department of engineering for conventional harvesters (previously located in Denmark). The Brazilian subsidiary was assigned these tasks not just because of the lower costs of production, but mainly due to the efficiency of the entire production system. Global platforms thus emerge from the delegation of strategic responsibility by corporate headquarters. The second category of SRL is the specific creators. In this case, the subsidiaries carry out innovations for the local market, which, after the product is launched, may be introduced in markets abroad by other subsidiaries of the MNC, i.e., local-to-global process (Borini et al. 2005).

For strategically relevant subsidiaries (SRS), the innovation processes may follow local-to-global and/or global-to-global. These subsidiaries tend to have a high level of strategic competences and act in strategic markets. SRS may have global or regional responsibility for a product line or a business area or for all the businesses of an MNC in a given geographical area, and usually they manage activities independent of headquarters (Birkinshaw and Morrison 1995). For instance, the Brazilian subsidiary of the UK-based MNC FOSECO is a typical example of local-to-global innovation. The Brazilian subsidiary developed a foundry process that is of better quality and lower cost, mainly in an effort to overcome the local competition. The Brazilian subsidiary is now designated as one of the four centers of excellence of the company, the other centers being located in the US, Germany and Japan (Borini et al. 2005).

Using the Paep Innovation Survey I results, Costa and Queiroz (2002) analyzed the extent to which foreign MNCs stimulate Brazilian industry to evolve from its status of foreign-technology user toward a position as an original generator of knowledge on the international technological frontier (p. 1433). The authors define innovation strictly as the generation of a world technological novelty, whereas the Paep defines it as encompassing both generation and use of knowledge. The authors developed "a third index, the 'imitation' index, which is computed using an unweighted average of the incremental change index and process change index. The hypothesis is that if a firm imitated a technology (making either a pure or a creative copy), it should previously have accumulated some capabilities in order to search for, acquire, assimilate, use, master and minor adaptations of the technology. In turn, the 'systemic effort index' is based on the proportion of R&D employees in the total number of employees in each category of firms and sector of activity. In addition to these proxies for functional-TCs [technological capabilities], two indices of meta-TCs are developed: the 'production chain linkage index' and 'S&T system linkage index,' based on external sources of information for technological change. The latter is composed of information on two sources: universities and research institutions" (p. 1438).

Considering the industrial sectors as a whole, foreign subsidiaries scored better than domestic firms on all indexes: 67 against 58 on imitation; 24 against 21 on the productive chain linkage; nine versus eight on the S&T system linkage; and the sharpest difference, 20 versus six on the systemic effort index (p. 1438). Brazilian domestic firms performed relatively better in only four out of 16 sectors, two of them being traditional textiles and leather products. The scores of foreign affiliates, in absolute terms, on the systemic effort index are considerably low, suggesting that their technological accumulation in Brazil is relatively low (Costa and Queiroz 2002, p. 1440).

### 7.1 MULTINATIONAL CORPORATIONS

## Motorola Brazil

Motorola's main business areas in Brazil are: mobile devices, networks and enterprise and broadband. At the end of 2006, the total number of employees in Motorola Brazil was 7,500, and its R&D staff had grown from 100 in 2001 to over 350 engineers at the end of 2006.

Motorola has offices and manufacturing facilities in São Paulo and Jaguariuna. Between 1995 and 2006, the company had invested US$500 million in manufacturing and US$225 million in R&D activities in Brazil. In 2005, Motorola Brazil exported products and services worth US$1.2 billion, of which US$44 million was accounted for by R&D services. The Brazilian R&D Center is the largest of Motorola's R&D units in Latin America. Motorola has software development centers in Argentina and Chile, but both these operations are much smaller in scale.

Jaguariuna is strategically located, with five major Brazilian universities and several research institutions (the closest being the University of Campinas) situated within a radius of 150 kilometers. Over 50,000 students are enrolled in higher education in the Campinas region alone. At Jaguariuna campus Motorola's activities include:

Manufacturing (cellular devices, network products, radio and iDEN);
Distribution center;
Networks and enterprise sales and support;
FreeScale Semiconductor Technology Center (IC design);
Brazil R&D Center.

### *Driving Forces*

- Brazilian Informatics Law—In order to be eligible for certain government benefits and incentives, a company in the business of ICT has to manufacture locally and invest approximately five percent of its revenues from Brazilian sales in local R&D activities; a further certain percent of this amount (about two percent of the revenue) should be invested in joint projects with not-for-profit organizations and universities. This law is applicable to both foreign and local companies. Initial R&D investments from Motorola in Brazil were motivated by this law.

- Strategic location—Brazil is a strategic location from the point of view of reaching the markets across the Latin American region.
- Technology and research—Brazil is also home to some world-class universities and research institutes. These institutions are carrying out advanced research in areas of interest to Motorola.
- Service infrastructure—Brazil has excellent infrastructural facilities to carry out R&D.

The FreeScale Semiconductor Technology Center is a spinoff company of Motorola, whose global semiconductor business was spun off into a new company. In 2006 the FreeScale Semiconductor Technology Center in Brazil had 130 development engineers working on designing ICs. It had no fabrication activities in Brazil. Its activities were completely oriented to FreeScale's global business.

### *Evolution of R&D Strategy*

The Brazilian Informatics Law, viewed from a company perspective, imposes a cost on the company by inducing it to conduct R&D activities, which otherwise would not have been necessary for the company. Therefore, in order to meet the obligations under the law, most companies tend make minimum efforts in terms of R&D. Several companies also classify normal operations as R&D activities. Between 1997 and 2000 Motorola made minimal efforts in R&D to satisfy the legal requirements. During this period, it created a core R&D team, but not much R&D was carried out.

By 2001, Motorola Brazil realized that it could make more effective use of its R&D resources in Brazil and thus convert this cost element into an expense element. Motorola decided to make full USge of its talented human resources in Brazil, by not just confining them to local R&D issues, but by linking them to Motorola's global R&D network. Following this new strategy, Motorola created three strategic approaches for its Brazilian R&D Center: (1) the Local Engineering Group; (2) the Core and Regional Support Group; and (3) the Worldwide Competitiveness Group. By linking up the Brazilian R&D Center to its global R&D network, Motorola converted an obligation into an opportunity. Since 2001, the R&D focus at the center has changed, and projects have become more globally oriented. However, implementation of this strategic change has not been an easy task, as the Brazilian R&D center now has to compete with other R&D units of Motorola for projects on the basis of cost, quality and timely delivery. Most global projects involve developing a specific part of the value chain and collaborating with other R&D units.

Some of the R&D activities undertaken in Brazil have evolved into Global centers of excellence for Motorola, like the Messaging Center of Excellence as well as the Brazil Test Center. These facilities do not exist in other centers in Motorola's global network. Some local/regional characteristics addressed by the Brazilian center have also now become global characteristics.

### *Corporate Innovation System and Knowledge Flows*

Figure 7.1 depicts Motorola Brazil's corporate innovation system and associated knowledge flows. As the figure shows, Motorola Brazil is strongly embedded into Motorola's global intracorporate R&D network as well as Brazil's local innovation system.

The Brazilian R&D Center is part of Motorola's global intracorporate R&D network. On the directions from headquarters in the US, it works together with Motorola's R&D centers in other countries. Within the network, Brazilian operations are strongly tied to headquarters. When Motorola started its R&D center in 1996 in Brazil, the pool of human resources with expertise in mobile phone and/or embedded software was limited, and the Brazilian center initially carried out its work with teams from the US and Asia.

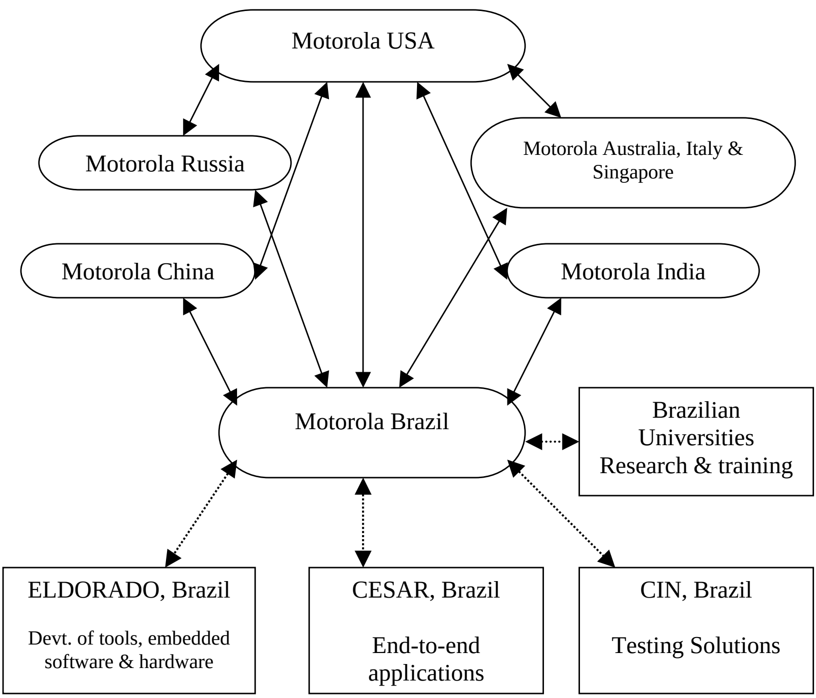


*Figure 7.1* Innovation system of Motorola Brazil.

Subsequently, the Brazilian center transferred development tools and simulators to different R&D units of Motorola across the globe. Using these tools, R&D units develop business solutions in specific areas of their competence (e.g., India for multimedia, Russia for Java solutions) and transfer them to the Brazilian center, which in turn integrates them into whole software packages for GSM/CDMA, together with the team from US headquarters. Among others, within the intracorporate R&D network, the Brazilian center works closely with headquarters in the US and global R&D centers in India, Russia, Italy, Australia, China and Singapore. Motorola Brazil's R&D Center also has links with the standards and regulatory bodies in the US and other countries.

The Brazilian R&D center of Motorola works very closely with three main external partners in Brazil: (1) ELDORADO—for development of tools, embedded software and related hardware, software integration and tests; (2) CESAR—a spinoff from university research, collaboration in the areas of enterprise solutions, server client and JAVA/end-to-end applications; and (3) Centro de Informática (CIN)—collaboration in developing testing solutions. Partnership with these three organizations helps Motorola gain access to a broad skills base. For instance, in addition to the Brazilian R&D center's in-house staff of 350 engineers, 600 more engineers from partner organizations work on Motorola's R&D activities, taking the effective researcher strength to 950. Motorola's collaborative projects draw on the research strength of the partners.

Brazilian Informatics Law also requires companies to spend part of their R&D investments in collaborative projects with nonprofit organizations, particularly those located in northeast Brazil. CESAR and CIN are located in northeast Brazil. In addition, Motorola also has research collaboration with a number of Brazilian universities and research institutes. In all the collaborative projects, the intellectual property (IP) belongs to Motorola.

By working with Motorola, many Brazilian universities have gained international recognition for their competencies. In addition to the Brazilian center, other R&D units of Motorola's global R&D network, as well as some of Motorola's competitors, began engaging the research services of these universities. In collaborative projects, universities get benefits in terms of greater learning opportunities and specialist knowledge inflows. Universities learn new management and process control techniques, product development methodologies, transfer of technology and so on. For instance, a department in a university was using games as a teaching aid, and thus this department built up technical competence in developing electronic/computer-based games. A spinoff emerged from this department and was under incubation in CESAR's campus. Motorola helped this company develop games for mobile phone platforms, which is a very complex task.

When Motorola set up its R&D center in Brazil, there were not many people with academic qualifications in the wireless domain. In 1999, Motorola linked up with 17 Brazilian universities to help in human resource development. Motorola helped these universities in the extension of curriculum and provided faculty in teaching these new disciplines at the universities, particularly in the development of M.Sc. and Ph.D. programs in the domain. It also provided extra training and internships to students from Brazilian universities.

Motorola also has been investing in a nationwide training program for university students, called Software Residency. This training program's aim is to fill the gap between what the universities teach (through their curricula) and corporate requirements (e.g., development and application of simulators, embedded software, configuration management and so on). This program was launched by CIn in partnership with Motorola in Brazil in 2003, and since then several hundred students have been trained. Companies, including Motorola, have recruited many of them. Motorola also provides facilities in-house to Ph.D. students from Brazilian universities on topics of mutual interest (e.g., Ph.D. in testing).

### *Host Country Implications*

Motorola's R&D activities in Brazil have attracted many companies, including its competitors, who have located their own R&D centers in Brazil after closely observing Motorola. So in a sense Motorola is contributing to the creation of an ecosystem.

## Rhodia

Rhodia is a France-based MNC in the business of specialty chemicals; it originally belonged to Rhone Pallonc, a pharmaceutical and chemical MNC. In 1999, Rhone Pallonc split into two companies: (1) the life sciences business merged with Hoechst and later became Aventis; and (2) the chemicals business became an independent company and became Rhodia Worldwide. But, in Brazil the company was always known as Rhodia since its inception more than 90 years ago. Rhodia is a Brazilian name, and it was later adopted as the global corporate name.

Rhodia has business and manufacturing operations in Asia, Europe, North America and Latin America. Its worldwide turnover is about  5 billion. It develops and manufactures specialty chemicals such as polymers, polyamides, silica, solvents, phenol and other chemical products.

Rhodia's management structure is organized into two sectors:

- Enterprises—all the production, sales and marketing operations come under this sector;
- Functions—R&D, human resources and legal services come under this sector. These functions come directly under the parent company's headquarters and are divided into four zones, Asia, Europe, North America and Latin America. The manufacturing plants also have R&D laboratories attached to them to solve immediate problems as well as to develop some products. But they report to the regional R&D

function manager and not the enterprise manager. For example, the R&D labs attached to the manufacturing plants in Venezuela do not report to the head of enterprise in Venezuela, but report directly to the zonal R&D head in Brazil.

Rhodia has five R&D centers worldwide: two in France, and one each in Brazil, China and the US. Together these five R&D centers constitute a global network, work together on many projects and support one another. The main focus of these R&D centers is to develop and offer customized products to the customers in the region.

### *Driving Force*

Rhodia's strategy is to be in proximity to the market in order to understand the market needs and develop suitable products for customers. Rhodia also feels that it is important to employ local/regional people in R&D functions to better understand the market. Hence, Rhodia has been conducting R&D in Brazil since the early 1970s.

Rhodia Brazil has 120 researchers, accounting for about 10 percent of Rhodia's global R&D workforce. About 18 percent of the 120 have Ph.D. degrees, 11 percent master's degrees and the rest bachelors in engineering, chemistry and pharmacology. It has a turnover of 15 percent among the R&D personnel. In addition, at any given point in time, Rhodia has over 30 students from Brazilian universities working in its laboratories. They are mostly Ph.D. students or postdocs working on their theses. In 2006, Rhodia Brazil filed for seven patents under the PCT. The Brazilian R&D center has a Documentation Center that carries out literature survey and files for patents.

In the regional market Rhodia has several competitors, but they are different for different product groups. For instance, its major competitors include DuPont (plastics), Oxiteno (Brazilian company), Dow Chemicals and Shell (solvents) and BASF (silica). These companies are competitors in certain product categories as well as customers in some other product categories.

The Brazilian R&D center does not carry out basic research. It mainly carries out applications and adaptations of products for the regional/local market. For instance, in some products like shampoos and soaps, the Brazilian market has unique characteristics that are different from other regions. Brazilian consumers prefer more foam. This requires changes in the chemical formulation of shampoos and soaps, and some new raw material needs to be developed. Sometimes chemicals used in a product developed in another region may not be available locally in Brazil or in the Latin American region, which requires R&D on material substitution with locally available raw materials (adaptation of the formula).

Rhodia has some specialist competencies and facilities in Brazil that it does not have in other R&D centers. In such cases, the Brazilian center carries out R&D on worldwide products. Similarly, there are some products that are manufactured in Brazil, but corresponding specialist laboratories do not exist in Brazil. So the product development R&D takes place elsewhere in the network.

Rhodia also has two manufacturing plants in Brazil, one for textile chemicals and the other for engineering plastics. These two plants have R&D units attached to them for product development as well as production support. These R&D units report to the head of the Brazilian R&D center and not to the business managers of the plants.

Over the years, some products developed for the Brazilian market have become worldwide products. For instance, Brazil has a large leather industry, which uses large amounts of chemicals in leather processing, raising environmental concerns. Rhodia Brazil has developed a line of ecologically friendly products based on organic materials for treating leather. These products are now being manufactured and sold in Asia and other regions that have a leather industry.

### *Corporate Innovation System and Knowledge Flows*

Figure 7.2 depicts the corporate innovation system of Rhodia Brazil. As the figure shows, Rhodia Brazil is strongly integrated with its global intracorporate R&D network as well as with Brazil's local innovation and production system.

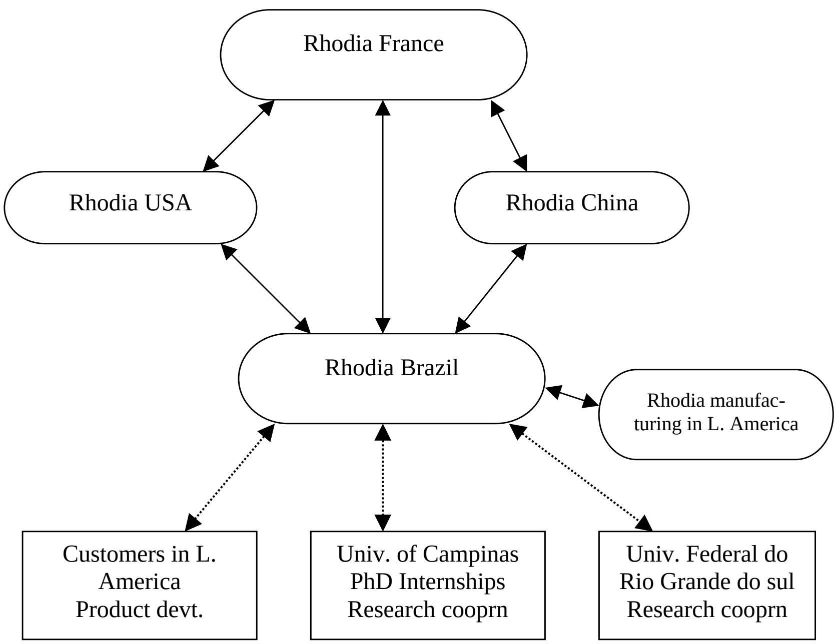


*Figure 7.2* Innovation system of Rhodia Brazil.

Rhodia works very closely with the customer in developing products. Such interaction opens up learning opportunities and facilitates exchange of knowledge. For instance, in one project, the customer, the largest shoe manufacturer in Brazil, approached Rhodia for jointly developing a product. The project involved developing a tolerant-free formulation for the glue that is used in attaching the shoe parts. There are several types of glues based on a solvent called 'tolerin.' But glues based on tolerin faced problems in Brazil because of its smell, which is considered harmful to children wearing shoes. So the Brazilian government banned the use of glues made of tolerin. Rhodia and the customer developed a new formula based on a new solvent. Rhodia gained deep knowledge about the shoe manufacturing process, which is an important industry that uses Rhodia's products. The customer gained knowledge relating to chemicals and their bonding.

Rhodia's R&D center in Brazil also has an analytical laboratory with specialized equipment. It can test whether any of Rhodia's products are giving problems to its customers, based on the sample provided by the customer.

The interaction between different R&D centers of Rhodia takes place in several different forms:

1. Independent projects—in these projects, the Brazilian unit or another R&D center works together with customer partners and when a solution is found or a new chemical is developed, the knowledge/technology is passed on to other R&D units. For instance, the R&D center in China developed special silica for shoes that can convert rubber into a transparent form (e.g., transparent shoe soles). This technology was passed on to Brazil, where it is now manufactured for Latin American customers.
2. Joint R&D projects—in these projects, part of the work is carried out in Brazil and the rest in another R&D center in the network. For instance, Brazilian and Chinese R&D centers jointly developed the low-density polyethylene for shoe soles.
3. Worldwide database—all the R&D units in Rhodia's global R&D network share this database. This database contains information on completed and ongoing projects, technologies/competencies available in each of the centers and so on.

Latin American and Asian regions have many common industries, such as leather and shoe manufacturing. These industries are not large in Europe and North America. So the Brazilian R&D works closely with the Asian region (R&D center in China) in product development.

Rhodia has research linkages with several Brazilian universities, most strongly with the University of Campinas (Unicamp), which is located just five kilometers away. Rhodia allows students pursuing Ph.D. or master's degrees at Brazilian universities, particularly Unicamp, to use its laboratories. The students can work partly or entirely on their theses at Rhodia's laboratories. The only conditions are that the subject must be of interest to Rhodia, and before the thesis is published Rhodia should vet it. Students have access to a lot material/information in the laboratory, and Rhodia would like to protect confidential information that affects its competitiveness.

There are several types of association with the universities:

1. A student's topic may require the use of Rhodia's laboratories and access to Rhodia's knowledge. The student and the professor approach Rhodia to permit the student to work in Rhodia's laboratories. In this case Rhodia does not provide any financial support.
2. Rhodia itself may be interested in working on a particular topic and approaches the professor in the subject. The professor assigns either a Ph.D. or a master's level student to work on the issue. In this case, Rhodia pays the student to carry out the work and the professor for supervising the work. The professor makes regular visits to Rhodia's lab to monitor the project.
3. Sometimes the government supports projects in special areas (e.g., nanotechnology), so that companies like Rhodia can apply for financing to the government (usually together with a university), in which case the professor assembles a team of students with master's and Ph.D. level competencies. The government provides only part of the funding. Rhodia provides the laboratory facilities, pays for the supplies, materials and equipment, and the government provides scholarships to the students.

Rhodia also has research collaboration with another university in Federal do Rio Grande do Sul. It is located in the southern part of Brazil, so that it is difficult for the university's researchers to visit Rhodia often. In this case, Rhodia pays the student and the professor to carry out the work at the university premises itself. Rhodia's experts visit the university once in three months to monitor the progress of the work. This project was initiated by Rhodia.

Usually Rhodia identifies a project idea that may be of use for it in the future. Rhodia discusses the idea with the university professor. The university in turn analyzes the technical feasibility of the project. If the project is technically feasible to be implemented, then an agreement is signed. Universities tend to be slow in implementing projects, so that Rhodia enters into collaboration with universities only on projects that may be required in the long-term.

Rhodia feels that research collaboration with universities is mutually beneficial to both parties in terms of knowledge flows and learning opportunities:

- A university may have the specialized knowledge that Rhodia does not possess in-house, and through collaboration Rhodia gains access to such knowledge.

- University researchers are dedicated to work on that specific project, whereas Rhodia's in-house researchers work on several projects at the same time. Such focused efforts and dedication allow deeper analysis of the project and the possibility of finding qualitative solutions.
- By working with university students, Rhodia can also identify talent for recruitment. Often a candidate may have an excellent profile, but may turn out to be too theoretical in approach and not suitable for commercial R&D. But long-term joint projects help in identifying the right talent and also in training the student to industrial requirements. Rhodia can also observe whether the student is adaptable.
- Universities gain access to finance, raw materials and equipment by collaborating with the industry.
- In an R&D value chain, universities possess knowledge relating to the early activities (e.g., chemical rules, data analysis and so on). They do not have much knowledge on downstream activities like pilot scale development and scaling up of production, which in turn have implications for the entire value chain. By collaborating with the industry, universities have opportunities to gain such knowledge.
- Universities also gain knowledge relating to project management, cost over-runs, delivery schedules, as well as market conditions and so on.

### *Host Country Implications*

Rhodia has no problem recruiting chemical engineers or organic chemistry graduates. Brazil has no shortage of such people. But in certain specialized areas like personal care products, the company is finding difficulty in recruiting researchers. This is partly because there are many companies dedicated to the personal care business in this region. This business constitutes only a small portion of Rhodia's product portfolio. From a career point of view a specialist researcher would prefer to work in a company that is dedicated to personal care business. So, Rhodia recruits nonspecialist graduates and trains them in Italy or the US, but then it faces a high turnover rate among these recruits.

Rhodia makes use of the Brazilian natural resources in developing products. As early as in the 1940s, Rhodia developed chemistry based on sugarcane alcohol. This sugarcane used to come from the northern Brazil. But during World War II, the Germans cut off communication between the north and south of Brazil. So Rhodia bought a sugarcane farm (the location of the present R&D center) in the Campinas region, extracted alcohol from sugarcane and sent it to São Paulo for conversion into chemicals. Even today, Rhodia has several products that are based on sugarcane alcohol. Besides alcohol, Rhodia presently has a research program on 'glycerol,' which is a product of biodiesel. Rhodia is interested in the chemistry of glycerol to develop new chemicals from it for the future market.

## Siemens

Siemens is an MNC based in Germany; the company is active in engineering, electrical and electronics businesses. Its business areas include: automation and control; information and communications; transportation; medical equipment; power; lighting and others. Siemens is an innovation-driven company. In 2005, 75 percent of its sales revenues came from products that were five years old or younger, 19 percent from products that were six to 10 years old and six percent from products that were more than 10 years old. The same figures in 1985 were 55 percent, 29 percent and 16 percent, respectively. In 2005, Siemens spent €5.2 billion on R&D worldwide. It has 47,000 R&D employees (of which 30,000 are software engineers) in 150 R&D locations spread over 30 countries worldwide. In 2005, Siemens generated 8,800 invention disclosures (of which 5,700 patent filings were made) and in total had 53,000 active patents.

Siemens spends 95 percent of its R&D investment in: operating groups, regional units, subsidiaries and associated companies, for development of products, systems and manufacturing processes. The remaining five percent of R&D investments are made in Siemens's Corporate Technology Units, located in Germany (Berlin, Munich, Erlangen), the US (Berkeley, Princeton), the UK (Romsey), Japan (Tokyo), Russia (St. Petersburg, Moscow), China (Beijing, Shanghai) and India (Bangalore). These Corporate Technology Units are focused on research, technology development and consulting.

### *Siemens's Innovation Strategy:*

- Comprehensive visions: 'Pictures of the Future';
- Deep knowledge about customers' businesses and processes;
- Technology leadership;
- Strong patent portfolio/strong player in standards;
- Use of synergy/platforms;
- R&D presence in leading markets;
- Optimized innovation processes;
- Cooperation with topnotch universities;
- Strong innovation culture, network of excellent people.

### *Siemens Brazil*

Siemens entered Brazil as early as 1867; with the supply and installation of a telegraphic line between Rio de Janeiro and the state of Rio Grande do Sul. In 1905, it founded the Cia Brazileira de Eletrecidade Siemens-Schuckert-werke in Rio de Janeiro. In 2005 Siemens celebrated 100 years of operations in Brazil. In the same year the net sales from Brazilian operations amounted to R$ 6,609 million of which exports accounted for R$ 1,064 million. During that year Siemens spent R$ 136.5 million on R&D

operations in Brazil (about two percent of sales). Its R&D investments have been growing rapidly every year from R$ 68.0 million in 2002 to 79.6 million in 2003 to 108.3 million in 2004 to 136.5 million in 2005.

During the financial year 2005, Siemens employed a total of 577 people in R&D and engineering activities in Brazil (six percent of the total employees in Brazil). In addition, Siemens collaborated with a number of partners in Brazil (about 20), and 493 people from these partners also worked on Siemens's Brazil's R&D activities.

Siemens Brazil has a broad portfolio of products, solutions and services for infrastructure. It consisted of six business areas:

1. Information and communications—communications; Siemens Business Services.
2. Automation and control—automation and drives; industrial solutions and services; Siemens Building Technologies.
3. Power—power generation; power transmission and distribution.
4. Transportation—transportation systems; Siemens VDO Automotive.
5. Medical—medical solutions.
6. Lighting—OSRAM.

Siemens's R&D centers in Brazil are located in:

- Curitiba—enterprise communications and carrier communications.
- Jundiai—high voltage transformers; medium voltage panels; and industrial turbines.
- Guarulhos—automotive electronics.
- São Paulo—automation and control.
- Rio de Janeiro—information and management systems.
- Canoas—residential outlets and switches; and sensors.

Brazilian R&D units also export their technology. Such exports include software and worldwide platforms. These exports could be both a part of the value chain of a product or the complete product. For instance, Brazil has Siemens's Global Center of Competence in the PABX product category. This center is responsible for the entire product range and the complete value chain (world product mandate).

Brazil is the headquarters for two centers of business and 26 competence centers, responsible for 26 technologies worldwide. The main focus of Brazilian R&D centers, however, is product development for the local and regional markets and adaptation of products developed elsewhere. The local product development is aimed at filling the gaps between local needs and the company's global product portfolio, so that local market opportunities are captured (e.g., equipment in automation and control). However, with changing technologies and globalization such local opportunities are becoming weaker in recent times.

### *Corporate Innovation System and Knowledge Flows*

In terms of the global intracorporate network, there does not seem to be a close integration of the Brazilian R&D units with the rest of Siemens's global R&D network, although the decisions regarding the portfolio of R&D projects to be undertaken by the Brazilian units are usually decided centrally at the corporate level. This could be partly because internally the R&D centers located in over 30 countries compete with one another for projects. The Brazilian center perhaps loses out on relative costs and the availability of people. However, Brazil has a lot of strengths such as similarity to European culture, openness to different cultures and the population's well-recognized skills and competencies.

Siemens has research collaboration with a number of Brazilian organizations. Among them are: the University of São Paulo (USP), the University of Campinas (UNICAMP), CESAR and INST. ATLANTICO.

Siemens Brazil is very open to accepting and integrating new technologies and ideas that originate in Brazil. Toward identifying these, it has started a 'Technology Portal,' where universities and research institutes can advertise their competencies, the infrastructure available to carry out research in that area and the way in which the university/research institute would like to collaborate with Siemens. Siemens's experts analyze these online expressions of interest, and, if they are found interesting, the experts approach the teams. This is an innovative idea to mine local competencies. It also helps Siemens in monitoring technology developments and gaining knowledge relating to topics of interest.

### *Host Country Implications*

In terms of implications for the host countries, Siemens had earlier tried to foster entrepreneurship among its employees by promoting spinoffs. But it did not succeed for several reasons including: employees were not prepared to be entrepreneurs; changes in the marketplace were faster than expected; and the Brazilian market became unpredictable with liberalization and competition from lower-cost countries. Siemens, however, is continually looking to foster entrepreneurship in Brazil by seeking investment opportunities in innovation-based startup companies that may be working on technologies of future interest for Siemens.

## 7.2 BRAZILIAN NATIONAL RESEARCH INSTITUTES

## Centro De Pesquisas Renato Archer (CenPRA)

CenPRA is a national research institution under the Ministry of Science and Technology (MCT). It is located at Campinas in São Paulo state. It has 230 researchers and 12 laboratories.

CenPRA's operations cover five technological areas in which it is involved in technological development, consulting, advisory, technological viability demonstration and services, performed through specific product and processes innovation projects:

- Information technology product and process qualification.
- Information technology product and prototype engineering.
- Special research projects.
- Infrastructure, environment and socio-economic systems.
- Cooperative network.

CenPRA's technological focus includes: software products evaluation; hardware systems design; electronic products analysis and qualification; software process assessment and improvement; robotics and computational vision; product development; distributed systems software; electronic assembling and packaging; enterprise management; information displays; micro systems; network technologies; and information security.

CenPRA provides technological services such as: capillary and flat cells prototyping; electronic devices; systems design, prototyping and validation; display repair; display design, prototyping and validation; electronic systems and devices qualification, reliability, characterization and failure analysis; IC and electronic systems assembling and packaging in ceramic capsules, COB, SMT; microsystems prototyping and characterization; PCB and PCBA qualification; photolithographic masks; rapid prototyping in medical applications and mechanical parts; SAW devices prototyping; software process assessment and improvement (CMMI and ISO/IEC 15504-SPICE); and software product evaluation.

### *Contract R&D*

CenPRA has been collaborating with MNCs like Hewlett-Packard (HP) since 1999. Its collaboration with HP started with a project to set up a software test lab at CenPRA. This test lab was set up to test the image (display) in computers (e.g., problem translation, drivers and so on) manufactured by HP. Earlier CenPRA had developed a methodology to test computer software. The image test searches for software errors in the computers and fixes them. HP, which manufactures computers, wanted to utilize the R&D services of CenPRA. This lab tests products that are marketed in the Latin American region and Mexico.

### *Driving Forces*

- The main driving force for HP to enter into research collaboration was the Brazilian Informatics Law, which requires a company to

undertake collaborative research projects with local research institutes in order to receive incentives.
- The government regulations also require testing and certification of electronics products by an authorized institute. HP preferred working with CenPRA, perhaps because it is under the Ministry.
- Having worked together on some projects, HP recognized the technological competence available at CenPRA and started using its R&D services for HP's worldwide products.
- It is also cost-effective for HP to utilize the services of CenPRA.

As a sign of HP's growing confidence in CenPRA's capabilities, the two partners are working on a more research-intensive project on display technologies. Presently, there are plasma and LCD technologies. HP and CenPRA are working on a new display technology called 'nano crystal emission display' (NCED). The project involves developing and testing the new display technology. The new technology allows manufacture of large-sized displays. CenPRA is responsible for developing the software, microelectronics and automation. CenPRA has strong technological competencies in this area. HP plans to incorporate these displays in its new range of printers.

In joint projects, CenPRA demands joint holding (50 percent) of intellectual property (IP).

CenPRA being a government institution, the facilities of the testing lab are open to other companies also. Because HP is the joint holder of the IP, it does not pay any fee, but other companies using the facilities have to pay a fee. However, in practice, HP also may not want to reveal its confidential data to other companies. So for the time being only HP is using the facilities of the testing lab.

### *Knowledge Flows and Learning*

In the case of setting up of a test lab, the learning opportunities are limited. CenPRA had already developed a proven methodology, and HP wanted to use it. However, the methodology used needed to be fine-tuned to suit different categories of computers. About four times a year, two to three researchers from CenPRA were sent to HP's headquarters in the US for training on the new line of computers that were to be tested. CenPRA thus had the opportunity to gain knowledge relating to computer hardware, technology evolution and market trends. Such knowledge helps in updating CenPRA's testing methodology as well as in transferring such knowledge to other areas of its operations. In addition, these joint projects also provided opportunities to learn new project management techniques to ensure timely deliveries. CenPRA has worked with other companies such as Motorola and Ericsson in testing components and in developing prototypes.

In the joint project to develop display technologies, the learning opportunities were much more extensive as the project involved carrying out more research. There are also other teams of HP located in different countries working on similar technologies, so that there was a lot of exchange of knowledge. HP also placed its own expert at CenPRA to work on this project. Research collaboration with MNCs also helps CenPRA in getting more finances, which help it in restructuring some laboratories, buying new equipment and so on.

CenPRA also collaborates with other research institutes in Brazil. For instance, testing methodology was developed together with another Brazilian research institute, ATLANTICO.

Although there are no spinoffs from CenPRA, during the years it had developed a large pool of highly qualified workforce. Many young researchers have found jobs with new companies, contributing to diffusion of knowledge.

### *Host Country Implications*

R&D activities of foreign companies are good for the host country because they bring new research activities and knowledge relating to product development. Emerging economies like Brazil gain both directly and indirectly from such activities. The most important thing is that the host country should absorb such new knowledge and apply it elsewhere for economic development.

## Centro De Pesquisa E Desenvolvimento Em Telecomunicacóes (CPqD)

CPqD was established in 1976 as part of the industrialization efforts of the Brazilian government during the 1960s and the 1970s. The then ruling military government focused on infrastructure sectors such as roads and telecommunications to integrate the country. State-owned companies were to lead in strategic industries like steel, oil, electricity and telecom. Since its inception, CPqD's evolution has been closely tied to the telecom sectoral (now broadly ICT) policy of the Brazilian government. Today CPqD has 1,200 staff working in six technological areas.

Until 1962, permissions for companies wishing to provide telecommunications services in Brazil were issued by federal, state and municipal governments, independent of one another. As a consequence, telecommunications grew in a disorderly manner, with few technical or operational regulations. At that time, there were about 1,000 telephone companies operating in Brazil, and interconnectivity between them was usually a major problem. This situation required an urgent reform, particularly focusing on standardization in technical and operational domains. In 1962, a federal law, the Brazilian Telecommunications Act (Federal Law No. 4117), was approved to regulate all services related to telecommunications, including several aspects of radio and television broadcasting. Under this law, in 1965, the government established the state-owned EMBRATEL to operate long-distance trunk lines and in 1966 bought the Companhia Telefónica Brasileira (CTB) from its foreign owner, Brazilian Traction. CTB was the incumbent telephone service provider in the politically and economically important states of Rio de Janeiro, São Paulo and Minas Gerais. In 1967, a reorganization of the federal cabinet created the Ministry of Communications (MC), with responsibilities over telecommunications, broadcasting and postal services. Following the model of AT&T in the US, Brazil decided to create a subordinate Research Laboratory. So in 1972, TELEBRÁS (Telecomunicacóes Brasileiras S/A) was established as a state-owned holding company to control and coordinate financially, technically and operationally all the state and local telephone operators.

As in most sectors, even in the telecom sector, from the beginning Brazil followed an import substitution policy. However, the Brazilian equipment market was dominated by MNCs. The majority of network equipment was being imported, with local production restricted to assembling with imported components. The government tried to stimulate equipment production in Brazil by creating incentives for locating manufacturing plants in the country and by increasing local content requirement. In the 1970s, telecom was in transition from analog to digital systems, and the Brazilian government wanted to take this opportunity to develop homegrown equipment manufacturers. The government announced that the digital switching equipment should be developed in Brazil, while MNCs were allowed to offer space-switching technology from abroad. At the same time, MNCs were given incentives to form joint ventures with Brazilian-owned firms so that the local manufacturing capacity could be strengthened.

In the initial period of TELEBRÁS it was inconceivable to immediately create an R&D center, because of human resource constraints as scientists and engineers educated in the telecom-related disciplines were limited. TELEBRÁS tried to overcome this problem by entering into contracts with university research groups to carry out R&D, as well as to multiply competence, which was dispersed in several Brazilian universities. In 1976, TELEBRÁS formally created its own R&D center, called CPqD, in Campinas (in proximity to the University of Campinas). The CPqD was created within the organic structure of TELEBRÁS in order to implement its principal objective that CPqD should work exclusively on the equipment to be used in the national telecommunications system. CPqD defined a strategy to take advantage of the opportunities opened up by the ongoing technological changes (emergence of digital technologies) and to achieve competence in these emerging technologies. TELEBRÁS, through CPqD's R&D contracts with universities, introduced scholarships and other incentives to attract good students to its projects. Some universities, however, created an almost separate structure to manage these projects, with general infrastructure and support personnel paid for by CPqD's R&D contracts (Loural et al. 2006). As a result of this separate entity, the establishment of telecom technology as an academic discipline suffered in the initial years.

Until the 1990s, CPqD was the nodal agency for R&D, including subcontracting to universities and technology transfer to Brazilian manufacturing companies. The conditions for transfer of technology were that the recipient company should be in the private sector and owned by Brazilian nationals. Telecom companies demanded R&D services. MCT gave policy and financial support through TELEBRÁS. From the engineering perspective each state/operating company had a special requirement to be catered to. CPqD realized that Brazil did not have a critical mass of human resources to support such a variety of demands on R&D. So it subcontracted R&D to universities and to employ Ph.D. and master's level students in the projects to develop advanced technologies as well as product development (prototypes). A similar situation existed in private Brazilian-owned companies that received CPqD's technologies. Many of them were new ventures created under the stimuli provided by the industrial policy and R&D contracts provided by TELEBRÁS. Often, teams from these companies worked under CPqD coordination and facilities, rather than their own. This procedure was good for the technology transfer process, but the companies failed to develop in-house R&D capacities.

In spite of such drawbacks, CPqD was able to transfer technologies for more than 90 products to 56 companies. These technologies included: voice digital switching; digital transmission; optical and satellite communications; data switching; terminals; outside plant; optical fibers; and electronic components. The main factor that contributed to the success of technology transfer was the flow of personnel from universities to CPqD and from CPqD to companies, sometimes at the cost of depleting the critical mass of well-trained professionals in the institution of origin. For instance, the entire team on the digital switching project (Trópico) was transferred from the University of São Paulo (USP) to CPqD. Similarly the key technology managers in the technology recipient companies have been previously leaders in CPqD projects, e.g., as in an optical fiber technology company. The new Brazilian companies that were created with CPqD technologies included: Elebra; Promon; SID; Multitel; Avibrás; and ABC-Xtal (Loural et al. 2006, pp. 301–302).

From the early 1990s, Brazil started liberalizing its trade provisions very quickly, making the Brazilian-ownership requirement for telecom equipment manufacturing companies redundant. The Law No. 4117, which was in effect since 1962, was replaced in July 1997 by a new law to organize telecommunications in Brazil. The Law No. 9472, known as 'Lei Geral de Telecomunicacóes' (LGT) (Telecommunications General Law), provided a new framework based on principles of competition and universal service. Among its provisions are (Loural et al. 2006, pp. 305–306):

- The executive branch of the government was authorized to sell its shares in TELEBRÁS, thus privatizing the telecommunications system.
- A new regulatory agency, ANATEL, was created.
- The government was obliged to enact a bill creating a fund for financing Brazilian technological development in telecommunications.
- The government was obliged to preserve CPqD's R&D capabilities.

However, the law creating the fund, FUNTTEL, for supporting Brazilian telecom technology development was approved only in November 2000. FUNTTEL was constituted basically by levying an excise of 0.5 percent on the gross revenue of telecommunications services provided by the companies. A fixed percentage of the fund's annual income was to be awarded to CPqD to carry on R&D projects. This percentage was 20 percent in the first year and 30 percent in subsequent ones. Today FUNTTEL's funding amounts to 50 percent of CPqD's budget.

About one year after the general law came into effect, TELEBRÁS was sold in an auction. Its subsidiaries were reorganized in groups according to geographical and size (number of subscribers) criteria. Mobile and fixed operations were separated. The telecommunications business in Brazil was divided into three regions. The four large companies that were formerly under TELEBRÁS became interstate fixed line operators (national operators); in addition, five or six smaller companies were given the mobile telephone operations. Privatization brought a lot of MNC investors, such as Telefonica (Spain), Telecom Italia, Sprint/MCI and foreign private investment companies.

CPqD already by the beginning of the 1990s sensed the ongoing economic changes and devised its own survival strategy. Globally, by 1988–1989, the external signs of liberalization wave and technological changes in the telecommunications industry had been noted and the changing trend toward services was being discussed. There were broadly three levels or areas in a service firm that demand R&D generated knowledge: the physical system or infrastructure that supports services (in the telecommunications case, the network); the operation of this system, including control and maintenance; and the services offered by the firm (Mitchell 1990). In the early 1990s, the economy was in a state of flux with liberalization and moves toward privatization. Although CPqD was to transfer technologies only to Brazilian companies, political pressures compelled it to transfer some switching technologies to Alcatel, a French company (Loural et al. 2006).

From 1990 onward, CPqD redirected its activities to:

- Generation of technologies that could be transferred to the TELEBRÁS group, in the form of support to technical specifications, to network and services evolution and to the definition of architectures, topologies and new systems;

- Development of software systems for operations support and automation, network planning, billing and business support, in a joint effort with operating companies;
- Participation in the development of products in cooperation with other companies;
- Acquisition of competence in strategic basic telecommunications technologies;
- Provision of technological services to the industry, to the TELEBRÁS group and others, by offering technological consulting services, specialized services and knowledge transfer (Loural et al. 2006, p. 309).

Following this new strategy, CPqD was to:

- Conduct R&D in niche products.
- Identify the needs of TELEBRÁS and other subsidiary companies. These companies demanded development of operating software systems (OSS) and business support systems. CPqD at the time had no profile in these areas, but quickly adapted itself, and by the end of 1990s, it had installed a lot of OSS in Brazilian telecom companies.
- Provide technical services, such as testing and certification services. At the time of liberalization, a lot of companies wanted to enter the Brazilian telecom market. The Brazilian government placed a requirement on the companies that they should be certified by CPqD to be eligible to participate in the telecom market.

From then on, CPqD reduced its previous efforts aimed at equipment development to become mostly a research center dedicated to cater to the technological needs of TELEBRÁS subsidiaries and the development of specialized products required for the group. In 1998, when TELEBRÁS was privatized, CPqD was given a new legal status, a 'non-profit private foundation.' The new foundation incorporated the physical and technological assets of the earlier CPqD. After the privatization of the TELEBRÁS group, the most urgent tasks of the new telecom operators were the expansion of their networks and their subscriber bases. However, the new telecom operators had to rely on CPqD to provide operation and business support systems as well as technical services.

In spite of such an adverse scenario, however, CPqD finds that there are still some opportunities for local creation of innovative services and related products. Services and applications are areas that are highly local and strongly depend on the social and cultural characteristics of the target population. Furthermore, the complexity of current telecommunications system is enormous because different technologies have to share space in the operating companies' networks. These companies need to connect their networks and deploy services on different platforms to reach various target users. So CPqD changed its strategic positioning to focus on applications, service platforms and integrated management of network and services. Moreover, the convergence of telecom and information technologies opened up new opportunities for technological development.

### *Present Strategy*

CPqD is now diversifying its clients-base, as the expertise in large operations and business support systems that were previously developed for telecommunications could be deployed in other areas such as infrastructure utilities and large companies that have their own telecommunications network and information technology resources. FUNTTEL continues to be the principal source of financing to carry on R&D. CPqD's present portfolio has a mix of projects, in three different fronts (Loural et al., 2006):

- Some R&D projects are devoted to developing leading-edge technologies such as optical packet-switching and wireless ad-hoc networks. These cater to niche markets that may be explored later by the remaining Brazilian-owned equipment manufacturers;
- The second front is dedicated to more incremental innovation that can be applied to public interest situations, as in the case of low-cost telecommunication systems and special communication solutions for physically impaired people;
- The third front is dedicated to developing operations and business support systems to compete globally. The Brazilian government is starting a program to promote export of software products and services, and CPqD already has products operating in several foreign countries, including the US, where is has opened a subsidiary and is competing in the CLECs market.

Today MNCs enter into collaboration with research institutes such as CPqD because of the Informatics Law. Ericsson entered into a partnership with CPqD for a strategic technology in the area of optoelectronics. A former Brazilian professor of optoelectronics spent some time in Sweden and had the opportunity to inform Ericsson of the competencies that are available in CPqD. The project involved basic R&D. The Informatics Law only focuses on domestic market and does not mention anything about the intellectual property (IP) of the technologies developed. So in this project the complete IP was assigned to Ericsson. CPqD started commercializing some software technologies on its own. For instance, CPqD has developed some geographical information system (GIS) products and sold them to GIS companies.

### *Host Country Implications*

Foreign R&D is beneficial for Brazil. It should be more aggressive in providing R&D outsourcing services.

The R&D activities of CPqD have led to the emergence of spinoff companies. For instance, the Trópico digital switch evolved into a next generation network (NGN) packet-switching solution, which is being manufactured and marketed by a joint venture between CPqD, Promon and Cisco (US). 'Cleartech' is another joint venture, among CPqD, DBA (a Brazilian software development company) and EDS (US), that provides clearing services between telephony operators. Another spinoff is the 'Padtec,' which develops and manufactures optical wavelength division multiplexing equipment, with minority participation of a Brazilian private investment bank.

CPqD also has some employee spinoffs. For instance, some of its researchers started two companies. One company, called OPTO LINK, develops and manufactures equipment for optical technology applications for the media industry. Another company develops and manufactures opto-electronic components.

R&D collaboration with MNCs is beneficial to both parties in terms of new learning opportunities and knowledge flows. However, it depends on the type of projects. Most of the projects involve only the use of sophisticated technical skills. But in basic research projects (e.g., the project with Ericsson, although the IP was assigned to the company) new knowledge is developed through deeper understanding of the field. The most important are the learning opportunities in terms of project management techniques.

# 8 Global Innovation in South Africa

During the apartheid regime, necessitated by international economic and political sanctions, South Africa had built up a strong S&T system, particularly in the defense- and energy-related sectors, through twin strategies of import substitution and self-reliance. However, unlike the East Asian countries, South Africa did not aim to build up a strong export-oriented industrial structure. As result, South Africa has not been closely integrated with global corporate production and innovation networks. Export of technology-intensive goods is considered a measure of an economy's knowledge base. An increase in the ratio of technology-intensive goods in the total exports indicates an economy's growing demand for knowledge. However, as Maharajh and Pogue (2008) point out, the global value chains and production networks may present a distorted picture, as more complex activities within a production process may be located in a country other than the one exporting the final good. As a result, a high proportion of technology-intensive goods in total exports of a country does not necessarily reflect the knowledge intensity in domestic industrial activities.

In the case of South Africa, there is evidence of a shift toward more to knowledge intensity in manufacturing with an increase in the real value of medium-low technology exports from 22 percent of total exports in 2003 to 27 percent in 2007. At the same time, the share of low-technology manufactured goods decreased from 15 percent to 11 percent of total exports. Between 2003 and 2006, total exports of manufactured goods grew at a compound annual growth rate of 8.6 percent. Exports of high-technology goods registered the fastest growth at 16.2 percent, followed by medium-low goods at 14.4 percent and medium-high technology goods at 10 percent. The exports of low-technology manufactured goods recorded a negative compound annual growth rate of–1.6 percent (Maharajh and Pogue 2008, p. 20).

Lorentzen (2005), through case studies of 25 companies, analyzed the absorptive capacities of automotive component manufacturers in South Africa. The study indicated differing performances by firms, with some firms designing and manufacturing innovative products and others simply upgrading their technological capability or striving to attain efficiency in execution. The root cause for the differential performance seemed to lie in their strategic use of advanced technical skills and the type of learning opportunities about frontier technology opened up by the in-house R&D. The automotive industry is the third-largest sector in the South African economy, after mining and financial services, and in 2002 accounted for 29 percent of the manufacturing output and 6.3 percent of the GDP. The share of automotive goods in total exports roughly tripled to 12.8 percent from the 1995 figure. South Africa has become the most important supplier of catalytic converters to the EU and the second most important to the US and holds 12 percent of the world market (p. 1158). Lorentzen (2005) categorized the 25 case firms into four groups: (i) innovators, (ii) followers, (iii) mandate executers, and (iv) cliff-hangers. Among the 25, six firms are considered innovators, with one of them holding multiple international product patents and even licensing its technology to major OEMs. Another firm participated in a government-sponsored research consortium that led to a patented process (p. 1161).

In terms of innovation environment, South Africa now has a comprehensive S&T policy framework that provides a clear direction and a strong commitment to promote coordination among different government departments, as well as a series of strategic instruments such as incubator projects, centers of excellence and investment incentives (Kahn 2006). Among the government incentive mechanisms, the Technology and Human Resources for Industry Programme (THRIP) and the Innovation Fund (IF) Programme are most likely to involve joint participation by universities, industry and government, with specified functions for each partner. “They are both designed to ensure multi-institutional and multi-sectoral cross-transference of technological knowledge to advance research, human resource capacity and the technology outputs of research. The IF is devoted to the promotion of commercialization of university research, while THRIP is focused more strongly on the current technology needs of firms” (Kruss 2008, p. 670).

For South Africa to become a location for global innovation activities as well as innovation-based entrepreneurial firms, two organizations have been playing a catalytic role: The Innovation Hub (Pretoria, Gauteng province) and The Cape IT Initiative (Cape Town).

## THE INNOVATION HUB (TIH)

The Innovation Hub was created in February 2000, as a private company to manage the project. Its mission is to support the Growth and Development Strategy of Gauteng province, particularly in the knowledge-economy sectors by supporting the development of a critical mass of knowledge workers in clusters of innovative businesses; the development and growth of entrepreneurs in high-technology sectors in the province through incubation facilities and CoachLab activities; the commercialization of local innovative technology development; and the creation of innovation business clusters by developing customer-centric business services within a structure of measurable value-added services.

Its vision is "(to grow the wealth and quality of life of the people of Gauteng, living in a Smart Province generated through innovation) by the full implementation of The Innovation Hub Science Park and in support of the Provincial Innovation Strategy" (TIH Annual Report 2009).

The Innovation Hub is a full member of the International Association of Science Parks (IASP). TIH Science Park has a rich mix of MNCs, established domestic firms, innovative startups and entrepreneurial projects in incubation. TIH has become a cluster for innovation activities carried out by its enterprise tenants as well as by the nearby national research labs such as the Council for Scientific and Industrial Research (CSIR). The industrial sectors represented by the tenants include: biosciences, electronics, engineering, ICT, smart manufacturing and professional services.

TIH is an important actor in the implementation of Tshwane's Smart City Initiative that is focused on facilitating interconnectivity and information accessibility among people, enterprises, institutions and countries to support the Gauteng province in its positioning as a Global City Region.

The flagship schemes of TIH, among others, include:

- *The Maximum Business Incubator*—it supports the entrepreneurship development. The participants are accepted on the basis of a business plan and its fit with the TIH's focus areas of ICT, electronics, biosciences, advanced materials and manufacturing. For previously disadvantaged entrepreneurs, it even offers a pre-incubation program, where a business concept could be developed into a proposal with the help of mentors from TIH. By the end of 2009, cumulatively 59 companies have participated in the incubation programs, and 29 of these have successfully exited the program and graduated to the next phase in the startup growth.
- *The CoachLab*—it is part of the value-added services offered by TIH. It is envisaged as an 'intrapreneurial' program for fast-track development of world-class human resources for the local high-tech sector. Participants, who are mainly ICT postgraduates, are trained to enter the marketplace as active and industry-ready knowledge workers. The program is designed and managed as a partnership between TIH, industry and higher education. TIH provides state-of-the-art infrastructure and an entrepreneurial environment (including access to entrepreneurial service providers), and the industry partners EPI-USE, Cisco Systems, MTN, Standard Bank and Talentek provide the project work, mentorship and supervision. CoachLab participants get to do real-time industry projects with an emphasis on delivering innovative, value-adding solutions. Talented postgraduate students in

ICT-related subjects are recruited from the University of Pretoria, the Tshwane University of Technology and the University of South Africa (UNISA).

## CAPE IT INITIATIVE (CITI)

CITI was established in 1998 by a group of businesspeople who realized the potential and the need for an ICT networking and cluster development organization that could bring together people, ideas and capital to create a strong ICT community in the region and to enhance the attractiveness of the Cape as a location for IT investments. Its mission is to stimulate and support the growth, promotion and transformation of the ICT cluster in the western Cape, in collaboration with business, government, academia and other stakeholders.

"The founding vision of CITI was the creation of an ICT cluster that is regionally and internationally recognized for excellence in its ability to innovate, generate investment, create jobs and grow revenue (all in a way which is inclusive of all communities within the Western Cape)" (www.citi.org.za).

Among CITI's objectives are: to develop ICT skills and experience through close collaboration with all industry bodies, academia and other stakeholders; To develop, promote and help transform the ICT cluster, by hosting events and roundtables and networking between different actors; and to influence ICT policy through participation in national processes and commissioning of relevant research.

CITI 'initiates' projects that meet its mission and objectives. Such initiative includes identifying, creating, sourcing finance and monitoring the progress of the project. Among its flagship projects is the 'Bandwidth Barn' (BWB). BWB is a subsidiary of CITI, which had started as an ICT incubator in 2000 and has now progressed into a full-fledged Business Accelerator. It supports startups by reducing the cost of their overhead services through shared office environment and by providing networking opportunities for entrepreneurs. BWB offers, through CITI's funding, business development programs to equip both tenants and other entrepreneurs in the ICT sector with the necessary skills to graduate from the startup stage to the profitable and stable company stage. It has also recently launched a program called the 'Accel Business Development Programme.'

Another project called 'My Mentor Project' was launched in 2005, targeting ICT entrepreneurs who have developed valuable technology or business concepts, but are unable to transform them into successful businesses. The project provides personal and professional support to such potential entrepreneurs. By September 2009, 56 companies have passed through this program, and 98 percent of them are still in business. Among other projects is the 'Youth in ICT,' a roadshow aimed at attracting youth to pursue careers in ICT and also to bridge the gap in ICT skills, particularly among previously disadvantaged youth.

## 8.1 MULTINATIONAL CORPORATIONS

### DaimlerChrysler and Council for Scientific and Industrial Research (CSIR)

In 1997, DaimlerChrysler decided to initiate a technology transfer project to South Africa that will have a large social impact. DaimlerChrysler has a long association with South Africa, where it manufactures Mercedes Benz cars. Mercedes C-class cars (W203 RH) (right-hand driven) are manufactured in South Africa for the worldwide market. Among others, these right-hand driven cars are exported to the UK, Australia and Japan.

Around the time DaimlerChrysler was planning to launch the technology transfer projects to South Africa, two developments took place in the global business environment:

- European Union (EU) legislation was passed making car manufacturers responsible for disposal of old cars by 2011. This put pressure on car manufacturers to incorporate environmentally friendly components;
- The Motor Industry Development Program (MIDP) of the South African government encouraged car manufacturers to use locally supplied parts and materials. Under this program car manufacturers who increased the local content and export components/cars would get incentives in the form of credits that offset import duties (e.g., for import of completely manufactured cars).

In order to be ready to meet the EU obligations on the disposal of vehicles, DaimlerChrysler has been conducting some basic research in Germany on the potential use of natural fibers in the manufacture of some components. Sisal fiber from Brazil and some other countries was one of the natural fibers tested by DaimlerChrysler. But it did not work out due to difficulties in the manufacturing components using this fiber.

In 1997, DaimlerChrysler approached the South African Council for Scientific and Industrial Research (CSIR) for collaboration in the project. The same year a natural fiber workshop was conducted in South Africa and the CSIR, surveying the locally available materials, capacities and capabilities. The targets for the project were: (a) components must be used in the new Mercedes C-class cars that would be manufactured in South Africa; and (b) at least two components must be developed using the natural fiber. A four-member team composed of two people each from DaimlerChrysler and CSIR was constituted to evaluate the natural resources that could be used and the capabilities available in South Africa. Because DaimlerChrysler already had some experience with sisal fibers from other countries, the team started analyzing the properties of sisal fiber available in South Africa. The sisal available in South Africa had characteristics similar to glass fiber and could be used to make components.

Natural fibers were chosen because they are carbon dioxide neutral, environmentally friendly and recyclable. In addition, cost savings are possible compared to plastics and glass fiber. These components once developed would directly replace the components hitherto manufactured in Germany with glass fiber and plastics. The rear window shelf is the target component initially. DaimlerChrysler earlier worked with some other natural fibers such as flax. Earlier in Brazil, DaimlerChrysler also worked on making car seats and head rests with polymer impregnated rubber and coconut fiber. South Africa was the second country for DaimlerChrysler's experimentation with natural fibers.

The evaluation team proposed the establishment of the entire value chain from the production of sisal, processing and manufacturing of components. CSIR started working with farmers. The idea of the project was that small farmers would produce the sisal, but this required privatization of state-owned farms. Moreover, black farmers should be given priority to buy these farms, as the post-apartheid government desired. CSIR identified two farms that could supply sisal in necessary volumes. But this involved working with the farmers in improving the quality, producing consistent quality and so on.

The saplings of sisal plants are cultivated in nurseries for a couple of months before they are replanted in the field. Plants take four years to mature and then can be harvested for eight years, leading to more production and work. Water is required in the harvesting process to extract the fiber from the plant. About 20 tons of leaves per hectare could be harvested. In the process only three percent (0.6 ton) of fibers is extracted, with the rest of the pulp being used as fertilizer or cattle feed. The fiber is then dried, combed and baled into bulks of 250 kilograms each, which could fetch a price of about R1,000. These bales are transported to processors that cut the 800-millimeter lengths of fiber into bits of 60 to 80 millimeters and almost weave it into a mesh with a needle punching machine. But in the case of the Mercedes compartment the fiber has be mixed with waste cotton to achieve the desired result. Phenol resin is currently still used to bind the material to produce the fleece mat. This mat (fleece) goes to the component manufacturer where a polymer (an organic plastic) is injected into the mat as a binding agent and a machine then presses this into the shape of the component ready to be fitted into the Mercedes.

Joint R&D work was undertaken by DaimlerChrysler and CSIR. Most of the work was done in Germany by DaimlerChrysler. Much of the R&D work on behalf of DaimlerChrysler was carried out by Johann Borgers GmbH, a Germany based components manufacturer. Borgers had earlier developed the technology to manufacture flax-based (a natural fiber—flax-seed oil) components. But for this new natural fiber (sisal), much of the experimental and development work had to be done at the component manufacturers' premises on site. A polymer specialist from CSIR worked with the German team in South Africa. Within two weeks the first prototypes were made and sent to Germany for testing. "Of two fleece mats, one feels similar to wool and is very soft, it is made up of 20 percent sisal and 80 percent cotton. Another mat consists of 70 percent sisal and 30 percent cotton and it bristles like a straw. Both were prototypes created in developing the best possible fleece mats."

Much of the work done in South Africa was related to manufacturing process technologies. For instance, sisal has properties similar to glass fiber, so with it came some manufacturing difficulties. Because of the hardness of the materials, the needles in the punching machine frequently got ruined. This required a lot of development work. Similarly achieving the right blend or composition of sisal fiber, waste cotton and organic polymer also required a lot of experimental and development work. In the beginning, there were problems in producing the fleece. Through trial and error, however, about 30 types of fleece samples were made. After 18 months of experimentation, one clear winner emerged, which was a thin fleece mat made of 60 percent sisal and 40 percent cotton. The process of evaluating fleece was carried out by a German company, Johann Borgers GmbH, which has been a long-term DaimlerChrysler supplier and worked with natural fibers earlier.

Many South African fleece producers showed interest in supplying to DaimlerChrysler, which promised to be a profitable undertaking, but none of these companies had worked with sisal before. The competing companies were stringently tested throughout the selection process. Critical evaluators scrutinized the process and assessed the technological capabilities of the competitors. Among them, the National Converter Industries (NCI), as component manufacturer, and Brits Textiles, as fleece mat producer, emerged as winners. Brits Textiles, though located in Durban, which was not the best location, was the youngest of the competitors and was highly motivated. It had the most modern machines and was the smallest company with about 180 workers. But most of what Brits Textiles produced was polyester, and sisal was never used. Brits Textiles did not have a specialist for natural fibers, but was confident that it could learn what was needed. DaimlerChrysler had already planned for a scenario in which should it decide to work with Brits Textiles, it would send two South African technicians to Borgers's German facility for five days, where the experts at Borgers would train them in the sisal fleece process.

After the mats are made, the sisal production process moved on to the components producer. NCI of East London was chosen as it has experience with natural fibers and had a strong relationship with Borgers. NCI also had all the machines needed to transform the fleece mats into rear window shelves. The technology transfer from Borgers in Germany to NCI in South Africa had already been discussed.

### *Knowledge Flows and Learning*

Figure 8.1 depicts the innovation system involved in the project and the associated knowledge flows.

Borgers transferred the manufacturing process technology to the two South African enterprises (SMEs), Brits Textiles for fleece making, and National Converter Industries (NCI) for component manufacturing. A lot of experimental work took place at the premises of these companies, strongly exposing their personnel to the technologies involved. In addition, personnel from these two companies were sent to Borgers's facilities in Germany to gain experience in the processes involved. In addition, Borgers supplied the equipment, machinery, molding technology and component manufacturing know-how. Another German company provided the

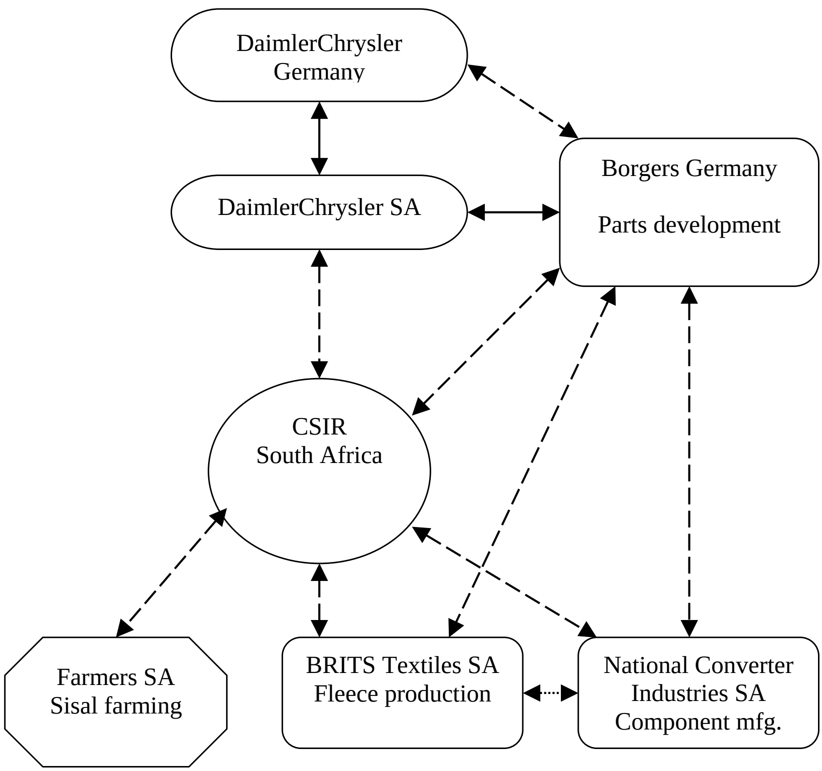


*Figure 8.1* Innovation system of DaimlerChrysler/CSIR Innovation system (South Africa).

technology relating to the blending of different fibers. Transfer of these technologies was very important, as a complete line had to be developed and South Africa had no prior experience in processing sisal.

An important aspect of the project was the creation of larger social impact. So as per the project agreement, CSIR on its own had to develop new applications for sisal. The quantities involved in component manufacturing are not large enough to keep two farms going. There was a need to find alternative uses/applications for sisal. One of the products developed by CSIR was a solar cooker (box type). It was commercialized in partnership with a local company. The German Development Agency, GTZ, commissioned this local company to manufacture a certain number of these cookers for distribution in developing countries. The other sisal products developed include riding hats and building materials. CSIR also developed new components for cars such as the wheel arch and the parcel shelf.

Over time, CSIR added a Natural Fiber Program to its portfolio of research areas and started working with several fibers including hemp, sisal, kenaf flex and paper-based product. There is now a large interest in South Africa in exploring industrial applications for natural fibers available in the country. The South African government (the Department of Trade and Industry—DTI, and the Department of Science and Technology—DST) has also signed an agreement with Airbus Industries to develop overhead bins with natural fiber.

There was an exchange of personnel among the partners involved in the project. CSIR's researchers spent three months in Germany at DaimlerChrysler's facilities. Similarly, DaimlerChrysler's researchers spent six months at CSIR. During these exchanges a lot of knowledge was transferred both ways.

### *Host Country Implications*

The initiative thus included integration between agriculture and industry, preserving the environment, empowering rural communities, transferring technology from Germany to South Africa and creating jobs. Jobs have been created in the northern province by producing the fiber, and South African producers have learned the process of enhancing the fiber's properties and in making a component from natural fiber. In view of these benefits for the host country, the project received financial support from the World Bank and the Development Bank of Southern Africa. These institutions have contributed toward the initial investment of R100 million in the project. DaimlerChrysler and CSIR made a joint application to the World Bank for project support. CSIR also shared the costs of this project.

Due to the project, the quality of Brits Textiles' and NCI's existing processes and products improved vastly, meeting world-class manufacturing standards. Brits Textiles diversified its business by investing in a new activity of processing the sisal fiber, which created additional jobs and increased turnover. NCI's sales increased and operations improved with new management techniques (e.g., just in time process) and gained international exposure as a supplier of sisal components for the automotive industry.

## 8.2 SOUTH AFRICAN COMPANIES

### Tellumat

Tellumat was established with the management buyout of the technology and innovation unit of Plessey in South Africa, which had a long heritage of innovation in the electronics industry. Plessey was founded in 1917 in the UK and established a South African presence in the early 1960s; it was listed on the Johannesburg Stock Exchange (JSE) in 1995. In 1998, after Plessey was acquired by Dimension Data, Tellumat was established from existing ex-Plessey business, as a privately owned company. Today Tellumat has 500 employees, with 100 engineers working in the R&D department.

Since its inception, Tellumat has completed the development of new products in nine key product families, with an investment of R80 million in R&D and drawing on the intellectual capability provided by its engineers and technologists. Tellumat received prestigious awards from the South African Department of Trade and Industry (DTI) in 2002, including awards for manufacturing excellence (large and medium enterprises), export achievement (large and medium enterprises), BEE (empowerment) and The Overall Business Enterprise of the Year Award.

#### *Mission*

Tellumat's stated mission is to be a world-class business focused on innovation, offering its customers dynamic and competitive technology products and services, aimed at the communications, defense and contract manufacturing markets. It is also open to forming long-term strategic alliances with enterprises in similar business worldwide. It uses two key strategies to develop the group's businesses:

- A product strategy that involves defining, developing, manufacturing and marketing innovative products for South African and world markets;
- A services strategy that seeks to provide a comprehensive range of services that complement its products and meet its customers' needs.

Tellumat's business operations cover three broad areas:

- Communications—(a) telecoms—'Tellumat Telecoms' is a leading supplier of customer premises equipment (CPE) to the local and African

market lace, e.g., call centers, PABXs, voice recording, broadband, telephones and so on; and (b) wireless solutions—'Tellumat Wireless Solutions,' located in Cape Town, is focusing on providing a means of communication for Africans through software solutions.
- Defense—(a) defense CT—supply and support of advanced radar, navigational, avionics and naval systems; (b) radar—'Tellumat Radar' specializes in long-range mobile air defense radar systems; and (c) SIA solutions—'SIA Solutions' supplies, installs, commissions and supports navigation, approach and airport systems.
- Manufacturing—(a) electronic—Tellumat's electronics assembly and manufacturing facility offers end-to-end operational services for specialized products, demanded by industries requiring advanced technical electronics. Core manufacturing processes include surface-mount assembly, component insertion, wave solder, in-circuit and functional testing, system integration and configuration and mechanical assembly; and (b) mechanical—'Laingsdale Engineering' is a single-source contract manufacturer specializing in the field of precision mechanical manufacture and assembly. With its origin in the defense industry, Laingsdale is focused on fuses, safe and arm devices, kinetic energy weapons and a variety of naval countermeasures such as mine clearing devices and moored mine cable cutters.

After Tellumut was established, it developed its own telecom switch together with another local company. But later the switching technologies started changing, requiring huge investments in R&D. So Tellumut started focusing on providing software solutions to third-party products/hardware.

Tellumut has developed a number of products for mobile telephony based on GSM technology. These products are based on what is called in local operations 'community platform.' These products have beneficial implications for many developing countries and for poor people. For instance, in Africa the penetration of fixed line telephones is very limited. Moreover, the poor in Africa cannot afford to own an individual telephone. They require a community pay phone that can be used by several people on pay per use basis. When the GSM infrastructure was rolled out in Africa, Tellumut recognized the business opportunity of providing mobile services to the poor and designed and developed a mobile community pay phone for GSM infrastructure. The individual who buys this can become an 'entrepreneur' by offering mobile phone services to others on a payment basis. The complete phone, called MOBICOM, was designed and developed by Tellumut. This includes design of the instrument, printed circuit board (PCB), software, two embedded platforms, the interfaces with the PC and management information systems. The phone is not like the normal GSM mobile handset, but Tellumut's product works as a PABX on a mobile infrastructure. The device is designed in such a way that several other connected services can be offered through software applications. The handset was manufactured in South Africa, with the import of some components, including semiconductors from Texas Instruments (TI) and plastics from China and Taiwan.

Now MNCs like Siemens and local companies such as Zitec have become competitors to Tellumut on this product. In fact almost all the mobile phone companies are entering this business.

### *Corporate Innovation System and Knowledge Flows*

Tellumut actively collaborates both with local and foreign organizations. For instance, its first switch was developed together with another local company GAP. Tellumut is also collaborating with Africa Product Robust.

Tellumut outsources work to local companies. A limited amount of work is outsourced to laboratories in Russia and the UK, mainly for certification and approvals, such as radio emission testing.

Tellumat's international partners include: Mitel Networks Corporation (US)—a company focused on full value Internet protocol (IP) Communications and business process integration; KIRK Telecom A/S (Denmark)—a company in the business of wireless communications, including wireless servers and repeaters.

Tellumut also has research collaboration with the University of Stellenbach in South Africa on long-range radios.

In an ongoing project, Tellumut is at an advanced stage on a product called SIMPHO, which is a medication management design. An internationally renowned medical doctor, David Green, approached Tellumut to develop a device that can send a message to a central database whenever a patient opens the drug bottle. Such a device would effectively monitor the administration of drugs to patients and their compliance, a very important aspect in treating poor people in remote areas of developing countries. The technology has been patented in South Africa and Europe and won many awards in South Africa. Currently the product is undergoing trials conducted by SIMPHO Pty Ltd. More than 25 countries have shown interest in this technology and product.

### *South Africa as a Location for R&D*

Tellumut feels that there are more business opportunities in Africa than elsewhere in the world. South Africa has well-educated human resources, and it is easy to come up with new solutions. However, in certain areas of technology the number of people available in South Africa is not adequate.

Tellumut is also committed to do work on its part toward corporate social responsibility and actively contributes in the areas of education, sport, social issues and environment. It also prioritizes recruitment of previously underprivileged people (black empowerment) in its operations as well as in engaging outsourced services.

Because of the short-term nature of management practices in South Africa, many companies miss the opportunities in Africa. The high costs of operating in South Africa and the competition from the Chinese are some of the major problems facing the South African businesses.

## The Naledi3d Factory

The Naledi3d Factory is a startup firm located in the Innovation Hub, the science park in Pretoria. Its core competence is in developing three-dimensional (3D) simulations using virtual reality (VR) software technologies. It uses a Swedish VR technology platform to design novel virtual learning content that overcomes literacy and language barriers for clients ranging from nongovernmental organizations (NGOs), such as UNESCO, to governments and mining companies such as AngloGold Ashanti.

The Naledi3d Factory uses VR to communicate concepts and practices in a wide range of areas, including industrial training and safety awareness, health and sanitation, heritage, new technology concepts, as well as applications that can have impact on community development. In addition to the African market, the Naledi3d Factory has built up relationships with, and developed VR simulations for, companies in Europe and the US.

The Naledi3d Factory focuses on innovative ways of applying a new First World technology (VR) to the needs of emerging communities in Africa—what is referred to as 'Social VR.' In Africa, poor literacy and limited resources pose a huge challenge to learning, at schools as well as in adult education programs and in areas ranging from science to history, farming and health. The Naledi3d Factory's work so far has covered themes as diverse as basic hygiene in Uganda; HIV/AIDs in Ethiopia; land-use planning in Soweto, South Africa; alternative power-generation technologies as well as beekeeping, soil conservation and other aspects of farming with farmers in Zimbabwe.

### *Vision*

- To become the most respected VR and 3D multimedia knowledge company in Africa by working in the knowledge paradigm, to develop international partnerships and build a global reputation for its work in Africa.
- To use the visually interactive nature of virtual reality to communicate ideas and concepts to address the training and skills needs of diverse communities and to help overcome the literacy and language barriers to learning.

### *Product Range and Areas of Application*

- Industrial training and safety awareness: **3d-Trainer** is a novel tool that can address one or many related training or learning concepts and is an interactive training tool to help build Africa's scarce skills base. Many South African companies are starting to see this approach as a cost-effective way of providing realistic, visually interactive and flexible training solutions to their employees;

- Educational: **interactive 3d learning objects** provide an engaging, interactive learning experience that can also incorporate audio, video and text and have the ability to teach a range of different subjects. The language components can also be adapted to suit local conditions and the learners' linguistic needs—a simple procedure that requires some basic multimedia sills, but not programming or VR development skills or tools;
- Marketing and sales: **3d marketing—**through interactive 3D digital content, manufacturers and retailers can convey their message to their global market with ease. 3D marketing can be used to market through the Internet or on in-store touch-screen kiosks;
- Architectural and town planning: **Plan 3d-Viz** is based on a digitalized VR process that presents the viewer with a rich 3D environment (such as planned office buildings, sports venues, railway lines, roads, airports, dams, shopping centers, hospitals, factory buildings) where users can see as well as change things in the way they want to, leading to greater understanding of complex plans, designs and ideas;
- Culture and heritage: **3d-Heritage** is a novel way to visually represent and highlight Africa's deep, rich history and heritage. The main power of 3d-Heritage lies in the fact that it can simulate how a historic site looked during its peak. The audience is also able to interact with the VR model and explore personal perspectives;
- Manufacturing: **Product 3d-Viz—**Inventors often have wonderful ideas, which they find it hard to convey to others. Using Product 3d-Viz, one can more easily present ideas and concepts, which can be modified prior to the expense of detailed product design. For large companies, Product 3d-Viz provides a cheaper way of visualizing prototypes in a simulated three-dimensional environment.

### *Selected R&D Projects of Naledi3d Factory*

The Naledi3d Factory, in addition to typical commercial product development, has also involved itself in the field of social VR in a major way by developing projects that have a larger social impact:

#### *Understanding Malaria: Prevention and Its Treatment (Funded by UNESCO)*

This project involved the use of VR to engage the learner in developing a deeper understanding of malaria—what it is; how to prevent or avoid infection; and how to treat a person infected. It is intended that this material will be made available to multipurpose centers as part of community awareness programs run by various health agencies. The project uses VR to raise awareness especially on preventive steps, e.g., spraying, netting and protective clothing and so forth. In addition, the project provides basic knowledge relating to malaria that will cover the treatment of the disease as well as the elimination of breeding grounds. The learning system presents users a 3D simulation of a rural village that includes a well, a nearby stagnant pond, a running stream as well as a number of dwellings. Users are presented with various health challenges relating to malaria that they must resolve to achieve a specific learning outcome. The village communities are presented with a hands-on experience on how to understand and, most important, how to be empowered to be better able to combat malaria. Audio and text are used to supplement the visual learning messages wherever appropriate.

*Rural Hygiene Project, Nakaseke, Uganda (Funded by UNESCO)*

Another project developed by the Naledi3d Factory in this area was one of the early research projects, piloted in a multipurpose community telecenter in Uganda, which teaches basic good rural hygiene practice. At Nakaseke (Uganda), about 60 percent of the community is functionally illiterate and therefore unable to easily use facilities such as computers. However, the VR simulation was well received at all levels. This VR model addresses basic issues that lead to water-borne diseases such as typhoid, dysentery and cholera as well as diseases such as malaria and bilharzia. Emphasis is on visual and audio cues to transfer the message, but not the written word. The Nakaseke product simulates a typical rural settlement, which includes a kitchen, latrine, bathing area, house, river, animals and fruit trees. Together, these offer an environment in which users can explore and trigger learning points.. Feedback from Uganda shows that the Rural Hygiene simulation has led to a drop in dysentery in the village and the district of Nakaseke and is still being used eight years after its implementation.

*Interactive 3D Learning Object and Water (Funded by UNESCO)*

This UNESCO Virtual Multimedia Academy (VMA) project had a number of objectives: to create locally relevant content on the topic of 'water,' to share this content locally, to explore and incorporate the concept of 'Learning Objects' into the material and finally, for the five 'country teams' (Ethiopia, Mozambique, Senegal, Sudan and South Africa) to explore ways of working together. Using water as a theme, each of the five country teams selected topics relevant to their local needs. The South African team (Naledi3d Factory) developed the simulations on:

(1) how to build a pit-latrine; (2) how hydroelectric power is generated; and (3) maintenance aspects of the AFRIDEV PUMP. These interactive 3D learning objects were built in such a way that the language elements (audio and text) could be easily modified (localized) to suit local needs. The methodologies developed in this project were evaluated and used by Dakar University (Senegal, French) and Eduardo Mondalane University (Mozambique, Portuguese).

*Industrial Safety—Showing the Impact of a Mine Mudrush (An AngloGold Ashanti Project)*

Operations in mines in developing countries, and particularly in gold mines, can be highly hazardous. Consequently, large resources are invested into safety awareness and training. In the case of a 'mudrush,' a blocked chute can result in thoUSnds of tons of rock and water accumulating behind it, which rushes out as soon as the blockage is cleared. Unsafe procedures lead to fatalities. Through VR, the Naledi3d Factory, in the first of several safety simulations, demonstrated good and bad practice and the consequences of each. The virtual mine haulage-way includes a chute, rail line and work platform (safety area). The chute is used to feed ore to the train, which consists of three hoppers. Normally, the ore is loaded into the hopper. However, occasionally a blockage occurs, and any miners in the wrong location are either fully or partly buried when the blockage is removed. Naledi3d's product simulates these scenarios in an interactive way.

*Beekeeping Skills (W. K. Kellogg Foundation and World Links Zimbabwe)*

The purpose of this project was to teach basic beekeeping skills to the community-land (smallholding) farmer who aspires to keep bees as a new source of income, as well as existing aspirants who can improve their returns by avoiding basic mistakes. The learning system places the learner in a 3D world based on a typical smallholding farm. Due to the interactive nature of the medium, learners are able to explore and discover for themselves (using either SHONA or ENGLISH) the main 'do's and don'ts' of African beekeeping. An interface links users to 'Nhapitapi Farm,' where users learn (interactively) how to start up and manage and how to extract honey. Marketing issues are also addressed briefly. The success of this project led to further work addressing soil and water conservation, farm pests and the growing of sorghum.

### *Corporate Innovation System and Knowledge Flows*

Figure 8.2 depicts the corporate innovation system of the Naledi3d Factory and the related knowledge flows.

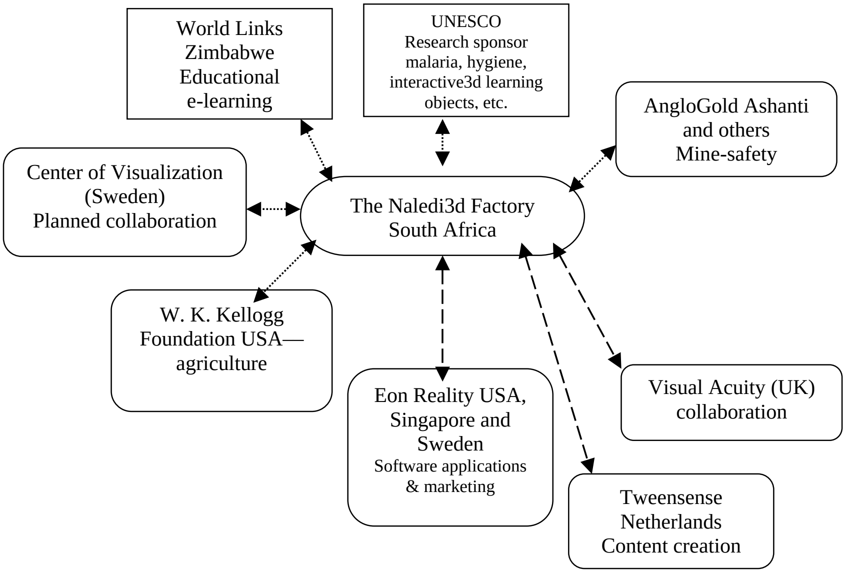


*Figure 8.2* Innovation system of the Naledi3d Factory (South Africa).

The Naledi3d Factory collaborates actively with external agencies both within South Africa and internationally because it has developed a clear vision for how and where the company wants to grow. It believes though that these goals can only be achieved through collaborations with other companies and organizations both locally and globally. Toward this end, among others, it has collaboration with the following organizations:

- Eon Reality Inc. (US), which develops and manufactures PC-based 3D interactive simulation solutions for use within marketing, e-commerce, architecture and training. The Naledi3d Factory represents EON Reality in sub-Saharan Africa and distributes EON Reality's software and hardware systems in the region. The Naledi3d Factory also develops software application products to work on EON Reality's hardware products.
- Over the years, UNESCO has been a great and consistent supporter of the Naledi3d's educational initiatives. The company's relationship with UNESCO dates back to 2000 and the early years of the company. Funding from UNESCO, from the Paris office as well as the UNESCO Cluster Office in Addis Ababa (Ethiopia), has enabled the Naledi3d Factory to establish virtual reality technology as a viable educational tool in Africa.
- W. K. Kellogg Foundation—A W. K. Kellogg pilot project to teach basic farming skills to smallholding farmers in Zimbabwe has sparked

what promises to be the biggest interactive 3D agricultural training initiative of its kind in the world and has thus far addressed aspects of soil and water conservation, pests, beekeeping, farm implements and sorghum growing. Naledi's partnership with the Kellogg Foundation (together with World Links) is expected to revolutionize agricultural training in Africa and to set a new benchmark for computer-based learning.

- World Links Zimbabwe—the Naledi3d Factory signed a Memorandum of Understanding (MOU) with World Links in November 2003. World Links Zimbabwe is part of an expansive global network of education professionals with a focus on connectivity within schools and has 46 centers in Zimbabwean schools alone. The Naledi3d Factory has built up a close relationship with World Links Southern Africa over the years, as a natural alliance between two organizations that have a shared goal of bridging the global digital divide by using cutting edge ICTs to educate the peoples of the developing world. The relationship with World Links Zimbabwe matured through their initial collaboration on the development and implementation of beekeeping learning material and grew to encompass the development of broader rural skills, through funding support from the W. K. Kellogg Foundation.
- KCTCS (Kentucky Community and Technical College System, US)—as part of its commitment to developing Kentucky's workforce, KCTCS opened the KCTCS Interactive Digital Center, providing cutting-edge visualization technologies to support the delivery of high-quality simulation-based training to local industry. Located in the middle of the Kentucky coal-mining belt, the center has helped many local companies to shorten learning cycles and reduce training costs. The Naledi3d Factory and KCTCS signed a collaborative agreement in 2009.
- Visual Acuity (UK)—the Naledi3d Factory has built a close relationship with Visual Acuity in the UK, a leading consultancy, offering long-term, independent and unbiased strategic, consulting, design guidance and operational advice to clients in all areas of new-media, visualization and ICT technology. The company has worked on many global projects, including Freedom Park in Pretoria, Hellenic World in Athens, the Haydn Planetarium in New York and the California Academy of Science in Golden Gate Park.
- Doncaster Knowledge Exchange (DKE) was established as an EU center of excellence in Doncaster, South Yorkshire, UK, and provides local businesses with a bespoke service enabling them to utilize leading edge 3D and revolutionary 4D technologies in all areas of their operation from product development to sales and marketing
- Center of Visualization, Gothenburg (Sweden)—the center strives to stimulate growth in the field of digital visualization, helping to spread

visualization technology into new and existing industry segments. The center recently partnered with the *Media Development Authority* in Singapore, and it is planned to extend this relationship to South Africa through the Naledi3d Factory.

- Tweensense was an innovative startup company located in Delft, the Netherlands. By combining 3D models and interactivity, Tweensense produced 'virtual reality solutions' for desktop-level applications, and Tweensense partnered with the Naledi3d Factory as a low-cost content creation facility in South Africa. However, the partnership ended when the activities moved to Kiev (Ukraine) where the development costs were found to be even lower.

# 9 Implications for Innovation Systems

The dynamic business environment analyzed in Chapter 2, suggests that no single firm however large can master all the technologies needed for its operations in-house or find them in one location. That is why firms globalize their R&D, including through 'outsourcing' and 'open source' innovation models.

The case studies presented in the earlier chapters clearly indicate that the scope of R&D activities carried out in emerging economies has broadened in recent years. In the past, R&D activities performed in developing countries (including emerging economies in the study) were limited to adaptation and/or at the most product development for the local market. Developing countries were mainly locations of technical services. The location of animal and farm facilities for testing of veterinary products, pesticides and agricultural products was mostly in tropical countries (Behrman and Fischer 1980).

By the mid-1980s, however, the global business environment had changed considerably. Companies needed to access science and technology (S&T) resources from a geographically wider area than earlier. By this time, several developing countries had also built up technological capabilities that could support R&D activities. The performance of higher-order R&D in developing countries by MNCs is a relatively recent phenomenon. The earliest date of establishment of a global technology unit (GTU), which focuses on worldwide products, in India (which is seen globally as an 'R&D hotspot'), was 1985. The regional technology units (RTUs) in India, which develop products for Asian and other developing country markets, have evolved from the earlier indigenous technology units (ITUs), which developed products exclusively for the local market, facilitated by the liberalization of international trade (Reddy 1997).

Based on the case studies presented in the earlier chapters this chapter analyzes the implications for corporate, host and home country innovation systems.

## 9.1 CORPORATE INNOVATION SYSTEMS

Since the last few decades, MNCs have been focusing on building a global innovation network consisting of R&D units located in clusters close to the centers of excellence around the world (Frost et al. 2002). Several studies have shown that the subsidiaries of MNCs tend to tap into external knowledge sources in their respective local innovation systems (Reddy 1997). The question of whether such knowledge-related links actually improve the firm's overall innovative capability is still understudied (J. Singh 2008). In a study of 65 Japanese pharmaceutical firms, Penner-Hahn and Shaver (2005) found that firms that internationalized their R&D tended to produce more patents than did the firms with only domestic R&D units. In addition to the benefits arising from knowledge spillovers from the local innovation system, geographically distributed R&D also provides other benefits for innovation; for instance, geographically spread out R&D personnel tend to avoid "group think" and open up their minds for new solutions. Thus, geographically dispersed subsidiaries of MNCs tend to develop capabilities that are more unique, providing opportunities for novel combinations (Nobel and Birkinshaw 1998).

J. Singh (2008, p. 79), in his empirical analysis of patents filed by 1,127 firms during the period 1986–1995 (where he interpreted forward citations received by a patent as an indicator of technological and economic value of the underlying innovation), shows that, in general, the geographic dispersion of R&D activities did not result in more valuable innovations. On the contrary, according to Singh's analysis, it resulted in a decrease in the average value of a firm's innovations. This suggests that the benefits of access to global sources of knowledge do not materialize from multilocation presence per se alone, but also from a firm's ability to actually integrate geographically dispersed knowledge. Singh's analysis, however, also reveals that innovations originating from cross-regional integration of knowledge are in fact of greater value, because of a positive interaction effect among distributed R&D units.

As Doz et al. (2006) point out, the knowledge inputs required for innovation in most sectors are spread out geographically across the world. However, only a few firms are able to gain effectively from such dispersed capabilities, as the coordination across units is weak; standardized processes and systems are lacking; and the necessity for a team of people with international experience is not sufficiently recognized.

In order to remain competitive in a dynamic business environment, companies feel the need to disperse innovation networks, in spite of the associated risks. How can companies ensure that they configure their new networks for cost-effectiveness? "First, they can accept that there are only two valid reasons to add a node: (1) to cost-effectively access critical knowledge that could not otherwise be tapped, and (2) to locate capabilities where they can deliver results better, faster and cheaper than anywhere else in the network. Compared with traditional innovation networks, these leaner, more consciously designed networks can achieve 37 percent faster time-to-market and lower costs by 24 percent, according to estimates based on the aggregate experience of survey participants. This statistic suggests that when possible, companies should be frugal while expanding and as objective as possible when assessing their innovation networks" (Goldbrunner et al. 2006, p. 2).

### 9.1.1 Access to Scarce S&T Human Resources and Infrastructure

As always there are usually multiple factors (not a single one) responsible for a phenomenon, including the one relating to location of global R&D in emerging economies. The case studies of MNCs' R&D activities have indicated that the primary driving force for locating global R&D activities in emerging economies has been technology-related, i.e., to gain access to R&D personnel of required quality and expertise. This factor as the main driving force has come out quite clearly even in the results of a questionnaire survey carried out in India a decade ago (see Reddy 1997). The case studies also suggest that emerging economies in the study have achieved an international reputation in certain S&T areas. MNCs are attempting to gain access to such knowledge and skills by making R&D investments or by linking up with universities and research institutes in these countries.

MNCs, for an overwhelming proportion of their R&D, continue to utilize the resources available in their own home countries (mainly industrialized countries). In recent years, due to rapidly shrinking product life cycles, MNCs have increased their R&D activities, thereby increasing the demand for R&D personnel. The supply of R&D personnel with required specialization in their home countries cannot meet the current demands of MNCs. This factor has been given more than twice the importance as a motive by the R&D units dealing with new science-based technologies (Reddy 1997). In discussions with managers in the corporate headquarters of MNCs, it became evident that in recent years gaining access to personnel has been the most important factor for locating R&D abroad.[1]

Emerging economies in the study, particularly China and India, have been building up large pools of well-educated scientists and engineers in a range of fields. Among them Brazil has been producing a large number of Ph.D.s in S&T subjects, and the Brazilian government provides scholarships to these doctoral students to spend up to one year in universities abroad, mainly in the industrialized countries. As part of their efforts at innovation capability building, dating back to the 1960s, these countries have also established internationally reputed universities and research institutes that have become centers of excellence (CoEs) in relevant fields. Case studies presented earlier show that MNCs have established strong linkages with the S&T infrastructure in their respective host countries.

Another important driving force for globalization of R&D has been the companies' need for 'resource flexibility.' Global firms are often faced with situations where they need to ramp up the R&D teams significantly within a short period of time or even downsize the teams quickly. Given the shortages of suitable personnel in the industrialized world, such flexibility is not possible in the home countries of some MNCs. At the same time, emerging economies with their reserves of S&T human resources offer such flexibility.

Firms also require access to a variety of skills, ranging from broad-based knowledge to highly specialized expertise in order to carry out an innovation process. Most often it is difficult to find these skills in one location or country.

So firms try to seek such knowledge wherever it is available. Given the size of emerging economies discussed in this study, they seem to be able to provide such skills or expertise, particularly through their CoEs. The interviews conducted in this research also indicated that the education system in the industrialized world is producing high-quality experts in highly specialized fields, which are necessary for research at a certain level. Companies, however, also require broader skills that can be used in a range of activities in the innovation chain. The graduates from the emerging economies in the study seem to fit the requirement of the MNCs.

Another important factor, particularly for outsourcing of R&D, has been that firms would like to pursue several alternative methods/solutions to solve a particular problem so that they can choose the most optimal solution among them. Given the rigidity of technological trajectories of in-house R&D, firms often outsource to, or form alliances with, external organizations for new approaches, while pursuing in-house R&D on the same research task. By locating in or outsourcing such R&D to emerging economies, a firm can work on a larger number of alternatives as the costs of carrying out R&D in these countries is much lower.

### 9.1.2 Cost Advantages

Even though it may not be equally crucial, another major driving force for the location of R&D in emerging economies has been the cost-related factor, particularly in the case of outsourcing of R&D. The total costs of carrying out R&D in emerging economies such as India and China is much less compared to the industrialized countries, mainly due to the lower-wages of R&D personnel in these countries. In general, wage costs account for the largest proportion of total costs in R&D activities.

In discussions with MNCs, the cost factor did not assume the same importance as gaining access to personnel as a primary driving force. This is because sometimes, in emerging economies, the advantages of lower-wages are usually eroded by higher material, communications and other costs. For instance, some of the inputs may not be available locally and may need to be imported under special conditions, and this adds to the total costs. Similarly, lack of infrastructure facilities may require MNCs to invest in captive facilities, adding to the total costs; e. g., shortages of power may require investing in backup facilities, or poor communication lines may require investing in a communication network.

### 9.1.3 Access to Local/Regional Markets

Another primary driving force for location of R&D in emerging economies, particularly in Brazil and China, has been the need to be in proximity to regional markets. Part of the reason for this is that MNCs' R&D units in these countries are closely linked to their own and/or customers' production units located in the region (see the case of Rhodia, Brazil). R&D performed in these units is also mainly that of product design and development, i.e., engineering aspects. With an R&D presence in the region, an MNC can identify and meet specific needs of the customers in the region without delays.

This factor, particularly in recent years, has become very important. The emerging economies in the study have large populations, with potential market sizes that are bigger than the home countries of MNCs. For instance, China and India are now the first and second largest markets, respectively, for mobile phones in the world, even surpassing the US. Even at an individual company level, the mobile telecom company Nokia's largest markets are China and India, respectively. At the same time, there is heavy competition in these markets as several competing MNCs are attempting to strengthen their positions in the market. So an R&D presence in these countries becomes important for firms interested in exploiting these markets. An R&D presence facilitates better understanding of the local market needs, trends, consumer preferences, as well as local standards and regulations.

Moreover, products developed in these emerging economies seem to be better suited for markets in other developing countries both within the region and worldwide. Local R&D personnel in emerging economies are more sensitive to local and regional market needs so as to come up with better-suited products. Simply adapting products developed in home countries (mainly industrialized countries) does not seem to bring much success in developing countries. Consumer affluence in emerging economies is growing fairly rapidly, placing greater demands on companies catering to such markets. Consumers in emerging economies are demanding products with the same high functionality and quality as those sold in the industrialized world, but at much lower prices. 'Emerging Products for Emerging Markets' seems to be the motto, if a company wants to prosper in these large markets. In these markets, the business strategy should focus on making profits by selling volumes rather than earning higher profit margins on low volumes. It is difficult for R&D personnel located in the industrialized world to understand these unique characteristics, as their focus is more on products with higher profit margins. So MNCs are locating R&D facilities in emerging economies to exploit these markets through development of innovative products. For instance, Nokia designed and developed low-cost mobile phones in India and exported several millions of these phones to Africa and other developing regions. Similarly, Proctor and Gamble is developing baby diapers that are affordable to the mass market in India and other developing countries. There are several cases of such R&D being conducted by MNCs in collaboration with national research institutes in emerging economies.[2]

## 9.2 HOST COUNTRY INNOVATION SYSTEMS

The assessment of the implications of international corporate R&D activities for host countries is generally fraught with difficulties, particularly for the emerging host countries, as the trend is still new and the numbers are small. However, through in-depth case studies, this research investigates: (i) the type of linkages established by the MNCs' R&D activities to the local systems of innovation and the potential for diffusion of technologies; and (ii) the types of spillovers from the international corporate R&D activities and their effects on the host economy. The host country implications are analyzed in the conceptual framework of NSI.

As Dunning (1992) pointed out, in general there are two opposing views regarding the impact of MNCs' R&D on the host countries. One view considers R&D-related FDI to be beneficial to economic growth, as it provides new technology and managerial skills, which in turn create indirect positive effects for the host country at a lower cost. These positive effects include technical support to local suppliers and customers, contract jobs from foreign R&D units to local research institutes and so on. On the other hand, the counterview argues that R&D activities by foreign firms tend to tap into unique local R&D resources with little or no benefit to the host country. Concentrating on problems of little relevance to the local economy, such R&D activities, may be a little more than disguised "brain-drain," diverting scarce technical resources from more useful purposes.

However, in the context of emerging economies, where the scientific and technical resources have so far been underutilized, the counterview may not hold much validity. The benefits are larger, while the costs involved may be marginal. In the case of emerging economy hosts, the cost factor could be that such R&D activities may create islands of "high-tech enclaves" with little diffusion of knowledge into the economy. But knowledge and skills cannot be isolated over the long term. The mobility of personnel, the need for local procurement of human and material resources and other factors are bound to diffuse technologies throughout the economy.

While analyzing the implications for the host country's innovation system, it is also important to consider the type of R&D being performed and its effects. Depending on the type of R&D being carried out, the effect on the innovation capability of the host country varies.[3] The strength and breadth of the ties with the local systems of innovation varies across the five types.[4] The ties are limited in the case of TTUs, because these only involve adaptation of the parent's technology to local conditions and are better done within the manufacturing unit. However, previous studies (Reddy 1997) indicated that even they had some linkages with the local innovation system in India. This is mainly because of the slightly higher level of technical activities undertaken by them. The previous policy environment in India and other emerging economies required local material substitution in products due to import restrictions or sometimes to keep the costs lower, and hence, TTUs had to perform more than just tinkering with the parent's technology. ITUs were in general supposed to have stronger ties with the local S&T system because of their product development activities, even though they basically re-do the designs supplied by the parent. However, these stronger links are better reflected in the case of GTUs and CTUs, which have stronger ties both to the local innovation system and to the global research networks. Hence, the scope for the diffusion of new knowledge to the local innovation system would be higher in the case of GTUs and CTUs, whereas TTUs, ITUs and RTUs (in recent years, these are performing activities similar to GTUs) mainly utilize and adapt the knowledge already available within the corporate system. However, a lot of learning takes place in such activities from the innovation system perspective (Reddy 1997).

This does not imply that TTUs, ITUs and RTUs have no important implications for the host economy. Since the conversion of research results into manufacturing products occurs in the same place, it may lead to other benefits such as the development of supplier networks and technology transfer to domestic small and medium enterprises (SMEs). On the other hand, GTUs and CTUs being de-linked from the operations of production and marketing, their innovations are less likely to lead to manufacturing-related benefits for the host country (Reddy 1997). These higher order innovation activities are more closely integrated with the corporate global strategy, and therefore the local economic considerations are given low priority.

The case studies in emerging economies indicated that the MNCs' R&D activities in these countries are establishing strong linkages with the local systems of innovation (no 'enclave'-like situation). Such linkages are mainly with the local universities and research institutes, as well as with the local companies in some cases (e.g., Intel, China). The case studies also show that these R&D activities are well integrated into the MNCs' global R&D networks. In most cases MNCs' R&D projects involve joint work among their R&D units in Brazil, China and India, as well as the R&D units of MNCs located in home countries and other industrialized countries (e.g., Motorola, India and Brazil; Rhodia, Brazil). MNCs also send their R&D personnel in emerging economies to the R&D centers at headquarters for training (e.g., Hitachi, China). Joint projects lead to the exchange of complementary knowledge and help in building up core competencies in each of the R&D units in an MNC's network, including those located in emerging economies.

The density and strength of the local linkages established by MNCs' R&D in the host country depend on the age of the R&D units. It takes time for an MNC's R&D unit to identify the expertise available in other local organizations and to establish a reliable and meaningful relationship. R&D being a critical activity, with a potential for leakage of confidential information in relationships, MNCs tend to tread carefully before establishing linkages. Many global technology units (GTUs) established in emerging economies are of recent origin. As the case studies in this book reveal, the local linkages are likely to enhance and strengthen in the future.

However, there are also instances of MNCs utilizing national research institutes in a host country as an 'entry mode' for internationalization of R&D into emerging economies. Some MNCs (e.g., DuPont, GE) have collaborated with Indian research institutes such as National Chemical Laboratories (NCL), Indian Institute of Chemical Technologies (IICT) and Indian

Institute of Science (IISc) for a number of years in their global R&D activities before they established their own GTUs in India. In such cases, the MNCs' R&D units have strong local linkages from the inception. MNCs also use outsourcing relationships to test the innovation capabilities available in a country before deciding to invest in setting up their own R&D unit in that country.

Based on the cases presented earlier, there are two kinds of benefits that can accrue to the host countries: direct benefits and indirect benefits (or spillover effects).

### 9.2.1 Direct Benefits

In terms of direct benefits, the creation of jobs, particularly high-value-added jobs for scientists and engineers, and the inflow of foreign direct investment (FDI) into the host country are very obvious. The creation of high-value-added jobs contributes significantly to the economic wealth of the country.

In addition, the global R&D activities of MNCs are creating 'new types of organizations' that did not exist before in the emerging economies:

#### *9.2.1.1 Stand-alone R&D units*

Previously due to the nature of R&D performed (the adaptation of products and processes developed in home countries), MNCs set up R&D as part of their manufacturing units in emerging economies. But in the case of global R&D (GTU and CTU), MNCs have set up stand-alone R&D units that are linked neither to local manufacturing nor to marketing. The core business activity of these units is to provide R&D services to the parent company. For instance, Motorola India, Texas Instruments India and GE India have all been established as GTUs. These units perform only R&D for intracorporate business units worldwide. Such organizations did not exist previously in emerging economies.

Following this trend, several Indian companies have also spun off their R&D units as separate companies, de-linking them from other business activities. This has become a practice particularly among the large pharmaceutical companies (e.g., Ranbaxy Laboratories, Dr. Reddy Laboratories). This enables the stand-alone R&D company to offer R&D services not only to the parent company's business units, but also to other corporate customers, including MNCs. As mentioned earlier, establishment of such organizations is a new phenomenon in emerging economies, which until recently carried out very little corporate R&D.

#### *9.2.1.2 R&D Outsource Service Providers*

As the case studies in India indicated, several companies are emerging to provide purely R&D services to MNC customers. Although these companies are mainly in the domains of ICT and pharmaceutical, even in fields such as mechanical product design and engineering services new outsource service providers are emerging (see the case of QuEST Global in India). The appearance of such new types of organizations in emerging economies is the direct result of global R&D activities of MNCs in these countries. These new organizations are in turn contributing significantly to the local economy, including foreign exchange earnings.

### 9.2.2 Indirect or Spillover Effects

Indirect or spillover benefits are numerous and not easily quantifiable. From an NSI perspective, global R&D activities show their effects on almost all the organizations and institutions of the host country's NSI. The analysis below follows Edquist's (2005) conceptualization, where organizations and institutions are the main components of systems of innovation. Organizations are formal structures that are established for an explicit purpose, such as firms, universities, financial institutions and public agencies responsible for innovation and competition policies and regulations. The institutions refer to common habits, norms, routines, established practices, rules and laws that regulate the relations and interactions between individuals, groups and organizations.

#### *9.2.2.1 Organizations*

*Enterprise Sector*

As mentioned earlier, MNCs' global R&D activities are facilitating the emergence of new business areas, such as R&D outsource service providers, in host countries. Some of these R&D service providers (see the Indian cases) are also developing their own products (in some cases licensing them to MNCs for further development). This seems to be something similar to computer original equipment manufacturing (OEM) suppliers from Taiwan progressing through original design manufacturing (ODM) to original brand manufacturing (OBM) by marketing products of their own design and brand name (e.g., Acer).

MNCs also, in some cases, are involved in technology transfer (mainly for by-products from their R&D) to local companies in host countries. For instance, Astra Research Centre India (ARCI––now part of AstraZeneca) transferred the know-how for producing the basic tools of DNA-recombinant technology to a then-new local company called GENEI (Gene India), which was founded by two Indian scientists, who formerly worked at the Tata Institute of Fundamental Research (TIFR). The idea for the establishment of Genei arose when an Indian scientist, who was residing abroad, was on a consultancy assignment at ARCI. The financial support to the new firm was provided by the Technology Development and Information

Corporation of India (TDICI), a venture capital company. Prior to ARCI's technology transfer these products were being imported. Genei now exports some of these products to the US and other countries. By 2000, Genei had built up its own R&D facilities and now manufactures over 100 products that include restricting and modifying enzymes, DNA molecular weight markers and nucleic acids. From ARCI's perspective such transfer of know-how to local firms, apart from generating royalties, reduced its dependence on imports and provided a stable supply of inputs (Reddy 2000).

Case studies presented in this study also indicate that in emerging economies, MNCs' R&D units have established linkages with local companies by way of subcontracting (i.e., outsourcing) of R&D or joint R&D work, particularly in software and embedded software systems. Such linkages involved knowledge flows between MNCs and local companies, broadening and strengthening the knowledge base and technological capabilities of local companies.

Although not quantified, the R&D activities of MNCs and the liberalization of the economy (increased competition) have also led to an increase in the R&D by domestic companies,[5] particularly through collaboration with national research institutes. Domestic companies in India have also increased their dependence on national research institutes. For example, by the mid-1990s, Bharat Electronics and the Indian Institute of Science started a joint-venture R&D to develop high-quality compound semiconductor films for device applications. This project's aim was to develop gallium wafers grown by a metal organic chemical vapor deposition process, which has application potential in the defense, space and information industries.[6] Similarly, IISc and Metur Chemicals collaborated in making India self-sufficient in silicon manufacture.[7] Similarly, as the case of IISC in India illustrates (see Chapter 5, this volume), many local companies have started seeking the IISc's research support after observing MNCs establishing such linkages with the institute.

### *Universities and National Research Institutes*

As the case studies reveal, one of the most important positive spillovers has been that the global R&D activities are infusing the scientific community in emerging economies with commercial culture. The sponsorship of research or subcontracting of R&D to the academic system also contributes to diffusion of such a culture. In other words, MNCs' global R&D activities are fine-tuning the innovation system in host countries to be competitive in generating knowledge. MNCs are also encouraging the scientists in host countries to venture beyond just proving the principles and to develop tangible products as a contribution to the benefit of society.

MNCs are also establishing 'chairs' in local universities as well as adding new research equipment in university laboratories. Such chairs are giving further thrust to research activities in the universities. In emerging economies where universities have scarce research funding, such sponsorship of chair professorships creates a significant impact on research (Reddy 2000).

In all the cases presented earlier, MNCs as well as local companies (with the exception of R&D outsource service providers) conducting global R&D activities in emerging economies have established linkages with the local universities and research institutes. While companies do gain access to expert knowledge through such linkages, the universities are also gaining knowledge from companies, particularly from MNCs, in terms of knowledge relating to product development. In the past, in a developing country like India, one of the main reasons for not reaping the benefits of its scientific capacity had been the lack of application to convert its knowledge into products. MNCs, through their global R&D activities, are contributing to the diffusion of application skills to the researchers in the universities and national research institutes.

> As the director of the National Chemical Laboratories (NCL)[8] India puts it, "[T]he trigger for identifying a research problem comes from the industry. The industry has several problems and limited solutions, whereas research institutes have a lot of solutions, but do not know what the problem is. So, researchers want to be linked to companies with strong knowledge base. MNCs have such knowledge base and the academic research community gains a lot of knowledge through interaction with them. Among others such knowledge includes issues relating to systems and processes involved in turning a concept into a product as well as managerial and decision processes."

For instance, in a particular case, NCL India conducted research on a problem (developing a new material) for a European MNC. But, the material could not be developed on time. From the MNC's perspective the project was a failure, and so it stopped the project. But, the director of NCL was intrigued by the research problem and recruited a Ph.D. student to work on the problem. Three years later, a solution to the problem was found, and it resulted in a Ph.D. thesis, several papers in international journals as well as four US patents.

As case studies reveal, some MNCs are also collaborating in establishing technology institutions for imparting education (see Motorola Brazil; QuEST Global India). Similarly, in the mid-1990s, Motorola India collaborated with the Pune Institute of Advanced Technologies (PIAT) in offering a postgraduate degree in advanced telecommunication engineering with a software focus. The faculty consisted of both the staff at PIAT and the experts from Motorola (Reddy 2000). While such efforts make it easy for the MNCs to recruit the graduates of required specialization, they also help in introducing such a specialized subject in the host country. Almost all the cases presented from Brazil, China and India are contributing to curriculum development in local universities.

Other effects on the innovation system of the host country include the diffusion of knowledge related to patents and other IPRs. Firms and scientists in emerging economies are realizing the importance of patenting and are acquiring the knowledge related to it. With the growing importance of innovation both by MNCs and local companies in their countries, even the academic institutions in emerging economies have come to realize the importance of teaching the aspects of IPRs to students. For instance, in India, institutes like the IITs and the IISc have started offering a course on IPRs for their science and engineering students.

*Government*

Governments worldwide have for some time recognized the importance of innovation and R&D activities, particularly those conducted by MNCs. R&D-related FDI has become the most sought-after economic activity by governments of both industrialized and developing countries. As discussed in earlier chapters in this volume, governments have started using various policy instruments, such as incentives in terms of tax rebates, performance-related requirements and setting new standards and regulations, in order to induce and compel MNCs to locate innovation activities in their territories. Such an enthusiasm for innovation activities, particularly in developing countries (including emerging economies) is unprecedented.

Governments have also reversed several earlier policies such as not permitting foreign companies to conduct early phase clinical trials for new drugs in their countries. They have also strengthened the intellectual property rights (IPRs) regimes in their countries, although mainly due to the commitments to the World Trade Organization (WTO) under the Agreement on Trade-Related Intellectual Property Rights (TRIPS). R&D service has become a key item in the WTO negotiations on the General Agreement on Trade in Services (GATS) (e.g., Mode 3).

Governments are also investing more on domestic R&D as shown by figures on R&D as a percentage of GDP. They are spending more on increasing the quality and volumes of science and technology graduates. As a part of these efforts, governments are also focusing on establishing and strengthening centers of excellence (CoE), as well as science parks in order to derive positive cluster effects.

#### *9.2.2.2 Institutions*

*Human Resources*

The case studies show that MNCs' R&D units are also involved in continuous development of their researchers through training programs both within the country and abroad (e.g., Hitachi China, Rhodia Brazil). With the mobility of researchers from one company to another such skills get diffused throughout the economy. The discussions with MNCs in emerging economies revealed that the turnover of the researchers ranges between 10 and 15 percent. If these personnel move to domestic firms, there will be significant diffusion of knowledge to the local firms.

*Entrepreneurship among Scientists and Engineers*

In recent years, several small high-tech firms have been established by technocrats in India, especially in ICT and biotechnology (e.g., the cases of R&D service providers in India). The researchers felt that MNCs' R&D and their need for special talents are giving them an opportunity to take up challenging tasks based on their knowledge and at the same time to try their potential as entrepreneurs. Such opportunities were not available in India in the past.

In another instance, the Astra Research Centre India (ARCI) (an MNC) licensed its technologies for byproducts to local scientists, contributing to the emergence of a new class of entrepreneurs, i.e., 'scientific entrepreneurs' (Reddy 2000). The global innovation activities of MNCs in emerging economies is creating enthusiasm among scientists and engineers to become entrepreneurs, either by providing R&D services to MNCs or by developing a product/service by themselves.

*Diffusion of R&D Culture*

Until recently, very few companies in developing countries (including emerging economies) performed R&D. They mainly depended on technology transfer from abroad through licensing and adapted such transfers to suit the local conditions. With the entry of MNCs' R&D activities into emerging economies, local companies have realized the importance of innovation for the long-term sustainability of business, particularly in the light of growing global competition. MNCs' R&D presence gave the local companies a growing confidence in the human resources and research institutes available in their countries to invest in R&D activities. Several Indian companies that approached the Indian Institute of Science (IISc) for research collaboration have admitted that the IISc's research work for MNCs made them realize the talent and knowledge available in Indian academic institutes.

#### *9.2.2.3 Potential Negative Spillovers*

One negative spillover of global R&D activities in the host country has been that MNCs are able to recruit and retain the cream of the available talent, due to the higher salaries, advanced training and other career growth opportunities they can offer. Domestic firms, on the other hand, cannot match the MNCs in these aspects and therefore, have to make do with the rest of the talents. This, in turn, may affect the enhancement of technological capabilities in domestic firms. This, however, is a perennial problem even among domestic firms. It becomes important for any firm, whether local or MNC, to provide job satisfaction to its staff either through monetary or nonmonetary benefits in order to retain talent.

The R&D units of MNCs may remain as closed 'enclaves' with little or no linkages with the rest of the host innovation system. The case studies presented earlier showed that this is not a valid argument against R&D-related FDI, as all of them have established strong linkages with local research institutes and firms. Even in a situation where an MNC's R&D unit remains an enclave diffusion of knowledge cannot be prevented in the long run due to the mobility of people.

The new trend of local companies in emerging economies focusing on developing products for global markets may have some negative aspects. These companies had until now been focusing on catering to the local market with unique and low-cost products. Some companies that have higher innovation capability are now developing products for industrialized markets where the profit margins are higher. This is likely to deprive local consumers. This is particularly true of the large Indian pharmaceutical companies, which are now focused on developing drugs (new and generic) for diseases mainly prevalent in rich countries. This affects the supply of low-cost drugs for tropical diseases. In such a situation, the governments of developing countries may have to conduct research on developing drugs for tropical diseases and license the technology to multiple drug manufactures to keep the flow of novel drugs to treat these diseases at low cost.

### 9.2.3 Policy Implications for Host Countries

The increasing science base of new technologies and growing competitive pressures to be innovative are necessitating multisourcing of corporate technologies. In their search for additional sources of technologies, MNCs have also started tapping S&T talents in emerging economies. In the overall phenomenon of the globalization of R&D, these patterns are only of marginal significance. However, from the perspective of the developing host country, the implications assume greater significance. In the beginning such R&D activities may be directed by the needs of the MNCs' strategic interests, subordinating the national interests, but a rapid expansion of the local technology base and market in the host country may prompt extensive local production and expansion of R&D activities, thus shifting the relative balance in favor of the host country (Reddy 2000). The case studies presented earlier show that this has already happened in Brazil, China and India. For instance, Motorola India and Texas Instruments India, which started their R&D activities exclusively for their global operations, have now begun to cater to the fast-growing local market. In August 2005, Motorola announced India as its headquarters for high growth markets (HGM) and for developing ultra-low-cost mobile handsets.[9]

The most important reason for locating global R&D activities in emerging economies has been the availability of trained personnel. The host countries should ensure that this supply line is not dried up. For instance, in India, there are already reports of competition for recruitment of trained personnel between the domestic and foreign firms. This requires increasing the intake of students into science and engineering subjects, which in turn, may require adding more colleges or universities. Since the quality standards of the graduates need to be maintained if not enhanced, it may call for investments in establishing advanced equipment and sophisticated laboratories. With technological specialization increasing, there may be demand from enterprises, both domestic and foreign, to develop new specialties in the universities. Development of such specialties may require the initial financial support from the government (Reddy 2000). In order to encourage more young people to study science and technology subjects, the Indian government is now offering one million scholarships, dispersed through competitive selection, to high school children pursuing these subjects.

Even if a country does not have a big domestic market, having large pools of talented personnel would attract global innovation activities. The growing global R&D activities of MNCs in countries like the Czech Republic, Poland and Romania are evidence of this. Such supply-side policies would be more effective in attracting and retaining R&D-related FDI than would be demand-side policies such as location of R&D as a performance requirement for market entry or for receiving an incentive. Such demand-side policies would only compel firms to do the basic minimum activities to meet the requirements of the law, but not substantial innovative work.

In order to increase the positive host country effects of global innovation activities, such interaction of R&D with local industry and other parts of the local innovation system, including related production or marketing needs, to be encouraged. To be able to reap the positive benefits of such R&D, the national system of innovation must have sufficient strength. The national policy-making agencies must build up local S&T capabilities to assimilate and exploit foreign technologies in order to sustain frontier national research capabilities in some areas and to provide an environment conducive to technology-based innovation and entrepreneurship (Granstrand et al. 1993).

In the case of emerging economies, such global innovation activities will help stem the brain drain. The rapid growth in industrial R&D in the 1950s and 1960s led to the migration of talented scientists and engineers from the developing world to corporate laboratories in the industrialized countries, especially the US. But today there is a greater pressure on MNCs to employ such people in their own countries, often through collaboration with local institutions, but increasingly by establishing own laboratories (Fusfeld 1995).

In addition to the benefits of employing its scientists and engineers, global innovation activities will lead to several other benefits for the host countries. Hence, emerging economies should create an attractive policy and innovation environment to attract such R&D-related FDI. Such a policy environment includes favorable FDI policies (particularly sector-specific policies); tax and other incentives; and nondiscrimination between indigenous and foreign firms in their access to national scientific resources. Most important, from the perspective of R&D-related FDI, streamlining of patent and other intellectual property protection laws in accordance with the international practices is essential (Reddy 2000).

In order to attract global innovation activities, a host country should provide its national research institutes the freedom and motivation to collaborate with foreign firms and to undertake subcontract R&D work from them. Worldwide, academic institutions are forging closer links with industry, and governments are encouraging it through various means. In some countries, academic institutions are even launching commercial ventures of their own or in collaboration with the corporate sector (e.g., China). In order to enhance the innovation capability and economic benefits through university-industry collaboration, the establishment of science or technology parks may assume importance. Such parks may attract both foreign and domestic firms to locate R&D, if the parks are situated in proximity to reputed academic establishments. In recent years, the establishment of such parks has become an important part of regional development plans, particularly in Europe. To strengthen university-industry linkages, senior managers from both domestic and foreign firms may be appointed to the management boards of universities and national research institutes. This will facilitate designing university educational courses to suit industry requirements, and industry will become more aware of the innovation capabilities of the national universities.

Scientists and engineers with origins in emerging economies, who are working in industrialized countries (diasporas), are playing a major role in MNCs' R&D activities in their home countries either by leading the R&D facilities of MNCs in their respective countries of origin or by entering into alliances with MNCs or by undertaking R&D activities on a contract basis for MNCs through their own firms or laboratories. These expatriate scientists and engineers may be further encouraged to contribute to their home countries by appointing them to the management boards of national research institutes, universities and public sector industries or as advisers to government ministries.

The ongoing phenomenon seems to offer emerging economies some fresh opportunities. Just as internationalization of production activities benefited the East Asian host countries, globalization of R&D activities can be expected to benefit the emerging host economies. Most important, international R&D would be an impetus to the R&D being performed by indigenous industry in emerging economies. For instance, the Indian pharmaceutical industry used to spend an average 1.2 percent of sales on R&D a year, but by 2008 the figure rose to about 10 percent, largely due to the entry of MNCs' R&D and marketing activities and the TRIPS Agreement. Similarly, in the face of stifling competition in the domestic market, Indian auto majors such as Tata Motors, Mahindra and Mahindra and Baja have increased their R&D investments significantly and introduced innovative competitive products in the market.[10]

If, by creating a proper investment climate, the host countries could persuade the MNCs to commercialize the research results in the country, the benefits would be even larger and quicker. From the perspective of developing countries in general, although R&D-related FDI provides long-term benefits, manufacturing-related FDI inflows brings quicker and wider benefits. R&D-related investments provide international prestige as well as employment opportunities for the highly educated. In developing countries, including Brazil, China, India and South Africa, however, the vast majority of the population is unskilled and uneducated. For the economy to show substantial improvements in such large countries, the capabilities of this majority of the population need to be enhanced and utilized. This can happen more effectively through manufacturing-related investments, as they tend to have greater multiplier effect, particularly for employment.

## 9.3 HOME COUNTRY INNOVATION SYSTEMS

The globalization of R&D is likely to increase further with MNCs as well as startup companies locating more and more activities away from their home countries. While the US remains one of the most attractive locations for R&D, the emerging economies are also increasingly becoming attractive locations for global innovation. Technological and commercial capabilities of some large companies from emerging economies are gradually increasing, narrowing the gap with the best of the MNCs from the industrialized world. The availability of qualified manpower, the presence of internationally reputed universities and research institutes, the low costs of conducting R&D, growing markets with unique characteristics and attractive investment opportunities are likely to favor the BRICS (Brazil, Russia, India, China and South Africa) group of countries for global R&D. The industrialized world, however, would continue to be the home for major investments in fundamental research and in the generation of advanced technologies for several decades to come. It is important for industrialized countries to recognize that their monopoly over innovation and technological development would now face competition from new entrants.

Globalization of innovation activities has significant implications for home countries. First, by globalizing some of the non-core or peripheral R&D activities, the home country firms could concentrate their resources on higher-value-added and/or core activities and in developing leading-edge technologies. This is facilitated by the changing dynamics of innovation processes that enable divisibility of innovation process. Second, through the increased competitiveness that their companies derive through globalization of R&D, home countries can enhance the overall strength of their economies. In this respect, emerging economies could become collaborative partners. Third, industrialized home countries, however, are likely to feel competitive challenges from emerging economies in a number of markets, including their own domestic markets, but mainly in third-country markets.

Industrialized home countries could strengthen their innovation systems by analyzing the global business environment. In order to build a globally competitive industrial/service (technology) sector that generates sustainable revenues and jobs, a country requires companies performing a broad range of activities (product, processes and services) within the sector. Product innovation is very important, but an entire technology sector cannot be developed with individual product innovations alone. In this respect, home countries could analyze the changing innovations dynamics and use this analysis to facilitate the emergence of firms in a wide range of activities in the innovation chain (Reddy 2007).

### 9.3.1 Changing Innovation Dynamics and Opportunities for Home Countries

As shown in Chapter 2 , the innovation processes in several industries is becoming modular and submodular in nature. This innovation dynamics has opened up commercial opportunities for new firms to emerge in every activity (or even subactivity) to provide specialist innovation services to other companies in their innovation process. The service providers are also innovation-based companies, since they develop new processes and platform technologies. R&D service providers are not just a low-cost phenomenon, and this is reflected in the healthy growth of R&D services business in the US. Therefore, home countries (particularly the European countries), apart from promoting basic research and product innovations, also have the opportunity to promote the emergence of companies that can compete in the growing global R&D outsource services business.

### 9.3.2 Commercial Opportunities

#### *9.3.2.1 Large Markets with Growing Affluence*

The emerging economies (Brazil, Russia, India, China and South Africa) are large economies with growing affluence. For instance, China and India have already become the first and second largest markets in the world for mobile telephones. History shows that such large economies (in terms of population, market size and breadth of their industrial and other technological capacities), with similar socio-economic conditions, growing rapidly together simultaneously, is a new phenomenon (hence the term BRICS). If a firm can gain entry into or expand its market share in these countries through an R&D presence, the home country of the firm would benefit from the growing business:

- First, with the near saturation in industrialized countries in many sectors, their companies (e.g., MNCs) might have to depend on these emerging markets for growth. Therefore, it is almost imperative for some R&D activities to be located in these countries, particularly because the consumers in emerging economies and other developing countries share some common attributes that are different from the consumers in industrialized countries (e.g., functionality and quality at low prices and low profit margins but high volumes).
- Second, through an R&D presence in emerging markets, an MNC can pre-empt the emergence of local companies as competitors by developing suitable products for the developing world (e.g., Texas Instrument's single-chip solution for mobile handsets and Nokia's low-cost mobile handsets).
- Third, by locating R&D in emerging economies, MNCs based in industrialized countries can also overcome an important competitive advantage of the firms in emerging economies, which is the low cost of operations, while competing with them in the global markets. For instance, MNCs from industrialized countries such as IBM, Accenture and PWC have located their R&D units in India to meet the competitive challenges posed by Indian IT companies such as TCS, Infosys and Wipro, which are partly derived from the low cost of operations, for securing business in global markets. Thus, the home countries of MNCs could benefit from the resources available in emerging economies. However, the benefits, particularly in terms of jobs, may have to be shared with emerging economies.
- Last, firms based in emerging economies are also showing interest in forming marketing partnerships with foreign companies, facilitating entry of foreign companies into their markets.[11].

#### *9.3.2.2 Potential to License-in Innovations from Firms Based in Emerging Economies*

Many companies from emerging economies are now concerned with developing products and services for the global markets as the case studies in this book reveal. Although these companies have the innovation capabilities to do so, most often they do not have the necessary 'complementary assets' needed to carry through the innovation to the commercial stage and/or to access global markets. So they seek to collaborate with MNCs or other foreign firms that have these 'complementary assets' either by licensing these innovations or by entering into marketing alliances. Both research-intensive startup companies as well as large companies in emerging economies are adopting this strategy. For instance, some large pharmaceutical companies are now focused on developing new chemical entities (NCEs). But due to lack of resource to carry out multicentered clinical trials and the global distribution networks, they have been licensing these NCEs to major pharma MNCs in industrialized countries. In addition to receiving royalties, these companies would like to retain marketing rights for the domestic market.[12]

#### *9.3.2.3 Potential for Location of Non-core R&D and Other Technological Operations*

Availability of large pools of well-qualified scientists and engineers at substantially lower wages compared to those in industrialized countries and the presence of several centers of excellence in S&T fields that are willing to collaborate with industry make emerging economies attractive locations for innovation activities. With the WTO-complied IPRs legislation in place, the perceived risk of leakage of know-how is also reduced. The establishment of science parks with state-of-the-art facilities in emerging economies has taken care of the required infrastructural facilities for innovation activities of foreign and domestic companies. Presently, the shortage of S&T personnel is hampering the growth of home-based companies in industrialized countries. Location of core- and non-core technological activities in emerging economies could be a viable and profitable solution to these companies and other research organizations. Such location can be done either through R&D-related FDI in creating facilities or through technology alliances or outsource relationships with local organizations.[13]

Similarly other opportunities are also available for R&D collaboration with firms from emerging economies. For instance, Biocon India has entered into R&D collaboration with Nobex Corporation of the US to jointly develop oral insulin for the global and Indian markets. Biocon also established a strategic partnership with the New York-based Vaccinex to discover and co-develop at least four therapeutic antibody products. As part of these partnership deals, Biocon will make equity investments in both Vaccinex and Nobex (Ernst & Young 2005, p. 75).

### 9.3.3 Competitive Challenges

#### *9.3.3.1 Competition in the Global Markets*

Companies from emerging economies, at least in the near future, are not in a position to pose a threat to MNCs in industrialized country markets (including MNCs' home countries). But they may put some competitive pressure on MNCs' branded products in these markets through innovative and low-cost substitutes. The success of automobiles from South Korea and consumer electronics from South Korea and Taiwan in the European and American markets at the cost of homegrown companies provides an illustration of this competitive pressure. In addition, these innovative and cheaper products from emerging economies seem to be more appealing to the consumers in other developing countries than are the high-cost alternatives from MNCs. Companies from Brazil, Russia, India, China and South Africa (BRICS) may not only gain from their huge domestic markets, but also establish themselves in one another's markets as well as in other developing countries, mainly because their innovative products seem to meet the precise requirements of growing markets in developing countries, better than do the perceived overengineered products from the industrialized world. The penetration of the Chinese company Huawei Technologies, a telecom systems manufacturer, into several markets of Asia, the Middle East and Africa in direct competition with the telecom majors from the industrialized world is an indication of competitive challenge.

#### *9.3.3.2 Competition in Mergers and Acquisitions (M&As) of Companies Worldwide*

In recent years, companies from emerging economies have been acquiring and/or merging with strategic companies in the industrialized world. Such activity, so far, is mainly seen in the acquisition of ailing companies in industrialized countries. The acquisition of the Bentley and Land Rover automobile companies in the UK by Tata Motors of India is an illustration. While such acquisition can be attributed to the financial strength of the acquiring company, the main reason for acquiring an ailing company is that the acquirer feels that it has the necessary technological/innovative and managerial skills to transform the ailing company into a successful company. The companies from emerging economies are also acquiring successful companies in the industrialized world, sometimes even outbidding MNCs from the industrialized world.[14]

### 9.3.4 Policy Implications for Home Countries

In order to address the question of how home countries respond to the globalization of R&D, it is important to better understand the driving forces for globalization of R&D, the type of R&D moving away from home countries and the technology sectors in which the most substantial R&D is moving away, before designing policy responses to address the issue. If the driving forces for R&D being relocated abroad are market-related or technology adaptation type (e.g., TTU), there should not be much concern. If the driving forces for R&D relocation are technology-related (including access to S&T personnel) or cost-related and the type of R&D relocated is related to global product development (GTU) or corporate basic research (CTU), there is definitely a need to better understand the specific reasons. The studies conducted in the industrialized world until now tend to group together all types of driving forces, R&D and technology sectors and arrive at a conclusion that all is well. The high-tech industries have a higher propensity to globalization of R&D as these technologies allow divisibility of innovation, de-linking R&D from manufacturing, and are highly human resource-intensive. To operate in science-based high technologies such as biotechnology, software or electronics, substantial industrial experience is unnecessary as much of the knowledge is codified (i.e., move from a 'learning-by-doing' situation to 'learning-by-training'). Emerging economies with their large pools of S&T personnel with lower costs can be ideal locations for MNCs from industrialized countries to carry out their strategic R&D (Reddy 2000).

If the driving forces for relocation of R&D from a home country are related to 'systemic rigidities' (e.g., overspecialization of education at the undergraduate level, lack of interdisciplinary approaches at higher levels) in the national systems of innovation system (NSI) or weaknesses in the NSI, such as being unable to produce adequate human resources in S&T, then the policies need to address these issues urgently. Otherwise, if a competitive advantage lost once it is lost forever, as other successful economies are likely to have greater learning opportunities.

It is also, however, natural for companies to look outside the national boundaries for their technology requirements. If companies are prevented from seeking technology from outside their home countries, their long-term sustainable growth may be affected. The innovation system in some industrialized countries (particularly in Europe) is inward looking and has incentives to keep it so. As Narula (2003, p. 77) points out, sometimes companies may not be in a position to search outside their national boundaries for advanced technologies because of the 'systemic lock-in' into NSI. 'Systemic lock-in' refers to "the extent to which firms are embedded and interdependent on the external domestic (non-firm) actors that comprise the SI [systems of innovation]." Such a lock-in may be an efficient outcome under certain circumstances, particularly in sectors where the NSI are competitive. However, it can have negative consequences, especially when radical innovations or technological discontinuities are externally generated, and the NSI cannot respond to the challenge adequately.

#### *9.3.4.1 Establishment of "Centers of Excellence"*

The emerging economies, particularly China and India, following the former Soviet Union model, built up national research centers (in the present form of centers of excellence) to conduct research for building up S&T capabilities, whereas universities focused on providing education. For many decades, these institutions worked in isolation from industry, but carried out internationally acclaimed research. At the time, the industry in emerging economies was mainly interested in manufacturing products (mainly engineering and consumer) for the domestic market by using imported technologies. In protected markets the industry did not have any motivation to carry out its own R&D or to collaborate with the centers of excellence. However, with the emergence of new science-based technologies and their pervasive influence over a wide range of products, the centers of excellence have suddenly become prominent. Recognizing the competence available in these centers (e.g., through internationally published articles), several MNCs started using them for some of their R&D activities. After noticing the interests of MNCs in linking with their national research institutes, the domestic companies of emerging economies have started realizing that these research institutes have a lot to offer in terms of technological solutions and that they need not always look for technology transfer from abroad.

Unlike in the past, in the new techno-economic paradigm, innovations require inputs from several disciplines. The traditional university structure in industrialized countries (where much of the research is presently carried out) in the form of different departments, based on disciplines and/or subdisciplines, can still perhaps meet the requirements for innovation. But it requires a lot of networking and collaboration between different departments. Consequently, the traditional structure imposes certain transaction costs in networking and likely time delays due to imperfect coordination (systemic rigidity). On the other hand, the centers of excellence employ researchers from different disciplines under one roof, and these specialists also get exposure to working in teams with other specialists. They all work in one organizational culture. Such a culture better equips the teams to overcome technical problems and also makes it easy for the industry to seek their collaboration.

#### *9.3.4.2 Research Collaboration Agreements with Emerging Economies*

In recent years, several industrialized countries have been entering into science and technology collaborative agreements with emerging economies. For instance, India and the UK would collaborate in a series of high-end research projects under a new multimillion pound program. The areas proposed for research include the next-generation communications technology, biotechnology and nano technology.[15] Such collaborative agreements would help in leveraging the skills and capabilities available in emerging economies that could be used for finding solutions for national as well as global problems. The inevitable question that arises, of course, is who captures the value in such collaborations? It is also important to acknowledge that given the technological/innovative capabilities of the emerging economies and their economies showing faster growth rates, some sharing of returns may be inevitable.

#### *9.3.4.3 Attract Foreign Direct Investment (FDI) from Emerging Economies*

In the last decade or so the emerging economies have become important destinations for FDI. But what has been overlooked is that in recent years these economies have also started becoming important source countries for global FDI flows. Companies from Brazil, Russia, India, China and South Africa are increasingly looking for investment opportunities in other countries. While much of such investments goes to other emerging economies (or developing countries), substantial investments are also being made in industrialized countries. From the perspective of innovation systems, such inward FDI from emerging economies into industrialized countries tends to be technology-related, i.e., these companies would like to gain access to advanced technologies through FDI. Companies from emerging economies have been investing in locating R&D units in industrialized countries, just as their counterparts from the industrialized world are investing in their countries. This is an indication that industrialized countries and emerging economies have 'complementary' rather than 'competitive' knowledge bases. Such investment inflows would help in revitalizing innovation management practices in both countries.

# 10 Innovations in Emerging Economies

## Implications for Other Developing Countries (South-South Dimension)

The previous chapter analyzed the implications of global R&D in emerging economies for the innovation systems of the main actors, the companies, the host countries and the home countries. In addition to these main actors, innovations in emerging economies have implications for other developing countries. Recognizing the innovation capabilities of the emerging economies, companies from other developing countries have started locating R&D activities in emerging economies. Companies from China, South Korea, Thailand and Singapore have established R&D centers in India. Similarly, South Korean companies have also located R&D units in China and Russia. By investing in R&D facilities in emerging economies, companies from other developing countries are able to access skills and knowledge that are not easily available in their home countries. Such South-South flow R&D-related FDI and trade in know-how and technology-intensive products are likely to increase in the near future.

As an illustration of the ongoing trend, India has become a major supplier of medicines and ICT-related products and services to other developing countries, particularly in Africa. India has also built a pan-African ICT network that is linked to India to provide 'telemedicine' services form India to hospitals in Africa. In July 2006, India launched a 'telemedicine' project in Ethiopia at a cost of US$2.13 million. The technologies provided allow doctors at Ethiopia's Black Lion Hospital to connect with doctors in India for consultation. The Black Lion Hospital is connected to remote Nekempte Hospital, which is located about 250 kilometers west of Addis Ababa. The high-speed connection allows doctors on both sides to flip electronically between charts and to use light pens to highlight important parts of the records. Medical charts not only fill the displays, but also provide a small window in which the doctors can see one another.[1] This is part of a larger program to connect all 53 African nations by a satellite and fiber-optic network with India that would provide effective communication and connectivity among the nations. The proposed network would mainly provide telemedicine, tele-education, Internet, video conferencing and VOIP services and also support e-governance, e-commerce, infotainment, resource mapping and meteorological services. The entire program, called 'the pan-African e-network,' is a joint development of India and the African Union, with an estimated cost of about US$136 million. The network is designed to have 169 VSAT terminals, with three of them in each country to provide tele-education, telemedicine, and heads of state (VVIP) connectivity, with a satellite hub earth station located in Senegal. The tele-education services are provided from reputed universities in India and five leading regional universities in Africa. The telemedicine services are provided through 12 super specialty hospitals in India and five super specialty hospitals in Africa (TCIL 2007[2]).

China has designed, built and launched satellites for developing countries such as Nigeria and Venezuela. Similarly, Brazil and South Africa are playing vital roles in supplying innovative and technology-intensive products to other developing countries, particularly in their respective regions. Developing countries, which previously could not get access to such technology-intensive products and services either due to their high cost or because of their unsuitability to local conditions, are now able to derive the benefits of new products and services that originated in another developing country in knowledge-intensive sectors.

At a broader level, innovations in emerging economies have implications for other developing countries at three levels:

i. Access to technology-intensive innovative products (with full functionality and quality) at affordable prices. Such products provide and enhance individual consumer welfare. Products such as low-cost mobile telephone handsets developed in emerging economies (see Texas Instruments' single-chip solution case in this chapter) also provide societal benefits by enabling the handset owner to participate in economic activities such as agriculture trading from the rural areas;
ii. Innovation capability available in emerging economies can be utilized for solving many of the problems faced by developing countries, particularly the least-developed countries (LDCs). For instance, one of the major problems faced by the global aid agencies involved in immunization programs in developing countries has been the lack of refrigerated facilities to store vaccines, particularly in the remote areas of LDCs. Millions of vials of vaccines have gone bad for this reason. Now the Bill and Melinda Gates Foundation is working with the National Chemical Laboratory (NCL), Pune, India, on the possibilities of developing vaccines that do not require cold storage facilities. Similarly, the Siemens Corporate Technology Unit in Bangalore, India, is researching deploying medical-imaging solutions in a simple manner. Presently, the solutions for medical imaging are deployed within hospitals using high-end, compute-intensive workstations, which are complex and expensive and therefore beyond the reach of most developing countries. Providing medical-imaging solutions on user-friendly, small and convenient devices such as palmtops and laptops requires significant

challenges to be addressed in client server technologies, networking and imaging applications areas. Siemens Corporate Technology Unit in India has been successful in developing such breakthrough solutions, opening up new cost-effective solutions, without compromising the functionality, to hospitals in developing countries.

iii. Potential to utilize and learn from emerging economies to build the ability to exploit natural resources available in developing countries. Most of the developing world is endowed with huge natural resources, which are now underutilized. The cases from South Africa presented in Chapter 8 reflect the enormous potential to use these resources. Naledi3d used 'virtual reality' technologies to improve learning in African countries. Similarly, Tellumut's community mobile handset brought widespread benefits to African countries. South Africa's CSIR shows the way for other developing countries by developing car components using the naturally occurring 'sisal' plant. South Africa's program on the utilization of natural resources is something that all developing countries can learn from. The national research institutes and companies (including MNCs) in emerging economies (Brazil, China, India and South Africa) have built up capabilities to identify, isolate, extract and purify active ingredients from plants for application in several industrial sectors such as pharmaceuticals, cosmetics and industrial enzymes. Other developing countries have the opportunity to engage the services of these organizations in emerging economies to develop organic compounds and/or products from the flora available in their respective countries. These organizations located in emerging economies are open to providing R&D outsource services, and the cost of conducting R&D will be within the affordable limits of other developing countries.[3]

To a large extent, developing countries tend to rely on technologies and products that were basically designed and developed for markets in the industrialized world. These products tend to be expensive and beyond the reach of the average consumer in developing countries. Such technologies/products are adapted to suit the operating conditions in developing country markets and the affordability of the consumer. In order to make them more affordable in developing countries, products are stripped down to the basic function without the additional functionalities that are available to consumers in the industrialized world. The other extreme solution has been to focus on 'appropriate technology' for developing countries. These appropriate technologies, while very useful in improving the productivity of the people at the bottom of the pyramid, unfortunately cannot facilitate a developing country's progress from a low-value-added economy toward becoming a high-value-added participant in the global economy.

With the entry of the BRICS (Brazil, Russia, India, China and South Africa) group of countries into the global scenario, particularly since the turn of the century, high technology (products and services) solutions designed with a focus on customers in emerging economies started appearing. The primary reason for this has been the shift in the techno-economic paradigm (see Freeman and Perez 1988; Perez and Soete 1988). All the emerging economies in this study had built up huge research capabilities since the early 1950s. But the old technology paradigm required even greater 'accumulated knowledge' (because of the weight of 'tacit knowledge') and a 'learning-by-doing' type of approach to accumulate such knowledge. So these research facilities built up by the BRICS countries remained 'islands of excellence' without any tangible benefits (other than research publications). But with the emergence of a new techno-economic paradigm in terms of new science-based technologies (particularly since the 1980s), where the distinction between basic research and product development is blurred, the S&T infrastructure built up by the BRICS countries has finally started yielding the results that were expected of it in the first place. The new science-based technologies reduced the 'tacit' element of the technology, as much of the knowledge is codified, and thereby reduced the need for long experience in industrialization and accumulated knowledge for economic application. In short, the new techno-economic paradigm moved the economic activity from 'learning-by-doing' type of approach toward a 'learning-by-training' approach. The East Asian countries were the first to benefit from the shift in the techno-economic paradigm by developing capabilities in the electronics industries. But they could not offer much in terms of a South-South dimension, as their focus was more on manufacturing activities than on innovation. Being relatively small countries, they did not build up much S&T infrastructure, at least in those days.

The entry of the BRICS is different in the sense that they are all very big countries with dual economies, where some sectors are on a par with the most advanced sectors of the industrialized world while some sectors reflect the characteristics of the least-developed countries (LDCs). In order for these countries to achieve sustainable growth, they need to bridge the gap between the dual economies that exist in their countries. They are being helped by two developments in this respect: (1) the usefulness of their old S&T infrastructure in the new techno-economic paradigm; and (2) the almost stagnant growth of markets in industrialized world, for various reasons including demographic changes. Therefore, emerging economies with large markets are becoming the major source of growth for companies worldwide (including MNCs). The dual characteristics of economies in BRICS countries make them attractive both as potential competitors and as collaborators, with competitive challenges and opportunities. One the one hand, MNCs could rely exclusively on one segment of the market, the affluent one, to sell products with high profit margin (the same strategy as in the industrialized world), while leaving the whole mass market in emerging economies to be exploited by local companies. If they do so, as Porter (1986) predicted, companies in emerging economies would benefit from the scale of economies and would pose a greater challenge to MNCs in the global markets.

MNCs have realized that in order to capture the mass markets in the fast-growing emerging economies, where consumer affluence is making them boldly express their preferences, the old method of adapting the products made for industrialized country markets to emerging country markets by stripping down the functionalities to reduce the price would not work. An additional challenge to MNCs has been that, with the liberal trade practices in emerging economies, the really affluent can buy those products abroad and ship them home. There was really no need to cater exclusively to the upper end of the market through local presence. On the other hand, local companies in emerging economies, taking advantage of the windows of opportunity provided by the new techno-economic paradigm (Perez and Soete 1988), started competing with the MNCs in their own home as well as in other markets in several market segments. These companies have started capturing the mass markets by selling products of a quality higher than or equal to those sold by MNCs, at a fraction of the MNCs' prices, in their home countries. The successes of Nirma in washing powder and 'Thumps Up' cola in India reflect the limitations of MNCs, which base their products and brand names on the same trajectories as their success in industrialized home countries. Moreover, these firms from emerging economies started competing in other developing country markets, where the consumer preferences are more or less similar to the emerging economies. There is also a potential challenge that these companies would enter the markets in the industrialized world to cater to the low-end segment with their qualitative and cheaper products. These individual successes of companies from emerging economies have awakened MNCs from industrialized countries to recognize the potential of mass markets in emerging economies, which runs contradictory to their business philosophy of deriving higher profit margins per product sold rather than higher profits through higher volume of sales.

MNCs have started designing new innovative products from scratch for emerging markets. These are often dubbed as *Emerging Products for Emerging Markets*. With the markets in industrialized world growing slowly, MNCs have to rely on fast-growing emerging markets for sustainable growth. The best way to address these market needs is by locating R&D units in these emerging economies. Local researchers are more sensitive to local consumer needs, preferences and habits, in contrast to researchers in the home countries of MNCs. Given the large size of these emerging economies (BRICS group), it is a worthwhile investment for MNCs to make. Moreover, these so-called emerging products for 'emerging markets' can also be sold in markets with similar characteristics worldwide (e.g., other developing countries), benefiting millions of consumers with low purchasing power, but with aspirations to use technology-intensive products to improve their living standards.

The following cases of 'emerging products' for 'emerging markets' illustrates the concept and benefits of these innovations for hitherto marginalized people across the world. They are, in many ways, the real examples of 'inclusive innovations.'

## 10.1 THE 'SINGLE CHIP SOLUTION' FOR MOBILE PHONES AND OTHER ICT PRODUCTS

Texas Instruments (TI), a US-based MNC in the business of electronics and semiconductors, was perhaps the first global technology unit (GTU) to be established in a developing country (India), back in 1985, to carry out product development for the global markets. At that time, TI was not selling any products in India, and it did not have any manufacturing facilities in the country. TI set up a stand-alone R&D center to focus exclusively on product development for global markets. Back then, the infrastructure in India was very poor, with large pools of highly qualified engineers and scientists whose wages were much lower than their counterparts in the US.

Among other R&D activities, TI India set up a Mixed Signal Products (MSP) Design Center in 1988 for the design of mixed signal integrated circuits as part of TI's worldwide team. The group has been involved in developing design methodologies for mixed signal designers worldwide, and on the design front, the group has been focusing on mixed signal ICs, where complex digital signal processing and analog interface are integrated onto the same chip. The group has been concentrating on three mixed signal applications: graphics palettes (embedded ASICs), telecommunication and multimedia and hard disk drives. These designs range from above 125 megahertz devices to ultra-low- power applications to suit the emerging market needs. The group also develops mixed signal libraries for its worldwide design community (see Reddy 2000, for a complete case study of TI India).

During the two-plus decades since TI India was established, the Indian economy has gone through a rapid transformation. With the liberalization of the economy, economic activities have expanded and consumer affluence began growing. As a result, the demand for many products such as mobile phones and consumer electronics, which use TI's semiconductors, started multiplying rapidly. Although TI does not have a manufacturing facility in India, a proportion of its R&D resources in India are now devoted to conceiving, designing and developing semiconductor chips for the local market in India and other similar markets.

> As the chairman of Texas Instruments (TI), Tom Engibous, put it, "India has become a design destination for many companies because people here understand the long-term benefit of having the knowledge to develop entire systems. For example, we just announced the first cell

> phone to be conceived, designed and manufactured in India. This is a great milestone not only for TI and for our customers, but also for the country. By becoming an expert in the design of full systems for communications and entertainment applications, India will set itself apart from others."[4]

The comments above refer to the 'single-chip solution' for mobile handsets. It has been estimated that about 80 percent of the world's population has been covered by wireless telecom networks. But only about 20 percent of the population subscribes to wireless services. This is mainly due largely to the cost of mobile handsets, according to the GSM Association. This situation provides a huge business opportunity for delivering mobile services to large sections of the world's population, subject to the cost of handsets coming down significantly. In 2005, in India alone, roughly 11 percent of the total population had telecom connectivity with a mobile subscriber base of 58 million, according to the Telecom Regulatory Authority of India, June 5. TI's cost-effective single-chip cell phone solution enables mobile phone manufacturers to tap the huge market opportunities in India and other emerging markets worldwide. The wireless solutions will be more useful in developing countries where the availability of landline networks is limited. According to Engibous, "TI developed its single-chip solution specifically to narrow the 'digital divide.' Our customers can use this technology to make ultra-low-cost handsets affordable in largely untapped consumer markets such as India, China, South America, Eastern Europe and other emerging markets."[5]

In December 2004, TI announced that it had developed the industry's first single-chip solution for mobile phones. A mobile phone typically requires multiple chips to operate, which adds to the overall costs. Based on TI's 90-nanometer CMOS manufacturing technology, the 'single-chip' solution is aimed at mobile phones designed for the voice-centric mass-market segment. Using TI's digital RF processor (DRP) technology, TI's single-chip solution integrates functions performed by different electronics in the handset onto a single chip to significantly reduce cost, power requirements, board area and silicon area, the main performance factors that are crucial for high-volume entry-level mobile phones. TI's solution, developed initially for GSM/GPRS handsets, is facilitating development of additional wireless interfaces. The GSM Association (GSMA), realizing the need for affordable mobile handsets in developing countries, launched its 'Emerging Markets Initiative' in 2005. The GSMA has been working with manufacturers to deliver mobile phones at a price below US$40 (from the prevailing lowest price of about US$80 to US$100, beyond the reach of most people), in order to create opportunities to add 100 million connections per year. Such an expansion in subscriber base will also dramatically increase the demand for GSM-based communication systems (e.g., base stations).

Simultaneously, TI also announced the first cell phone built entirely in India, from concept to design to production. Based on TI's TCS chip-set family, including the single-chip Bluetooth module and other logic/linear components, these designs will serve as platforms for the development of a variety of mobile handsets for different market segments, from ultra low-cost to mid-range voice- and feature-rich data-centric handsets. The market launch of the first phones based on TI and BPL (India) cooperation was scheduled for September 2005 and the Primus (India) phones for production at the end of 2005.[6]

With the global launch, in August 2005, of its single-chip mobile solution, which was designed and developed at TI India's development center in Bangalore, manufacturers such as Nokia, Motorola and Ericsson were expected to launch handsets based on the single-chip solution within nine months. This solution, which was specifically designed for India, involves putting on the same slab of silicon two disparate sets of circuits: the digital audio portion that handles voice capability and the radio frequency (RF) circuits that send the signal to and fro, as radio waves. According to Ramachandran, the director-general of the Cellular Operators Association of India (COAI), this technological solution will help in realizing the dream of an INR1,000 [US$20] mobile and boost cellular penetration to achieve the target of 250 million phones by the end of 2007.[7]

At the 2005 3G summit in Mumbai, India, Texas Instruments India announced the launch of the 'eCosto' chip, its single-chip solution meant to foster the development of low-cost 'multimedia rich' phones. By integrating the radio frequency (RF) transceiver and analog codec with the digital base band, the platform substantially reduces board spaces, extends battery life and makes a more powerful and versatile handset. eCosto's 'multimedia rich' capabilities include: advanced video capture, playback and streaming with up to QVGA screen quality at 30 frames-per-second, digital still camera up to three mega pixels with sub-second shot-to-shot delay, plus color LCD and interactive 2D/3D gaming with graphics. TI's strategy for emerging markets, as they evolve beyond voice-centric and basic multimedia applications, is to support the integration of more advanced features into single-chip cell phone solutions.[8]

Soon after TI delivered the industry's first integrated single-chip solution for mobile phones, TI and Nokia announced a cooperation whereby Nokia will incorporate TI's single-chip solution into its future mobile phones to offer more cost effective advanced handsets, especially in high-volume entry markets. The launch of the single-chip solution fulfils a commitment TI made in 2002 when the company announced its intention to integrate the bulk of handset electronics on a single chip and to test the first product in 2004.[9]

By incorporating TI's single-chip solution, Nokia within nine months shipped more than 20 million handsets from its manufacturing facilities in

India to markets in India and Africa. Motorola came out with a series of ultra-low-cost handsets designed without losing on functionalities.

Following TI's pioneering innovation, several other semiconductor manufacturers announced their own single-chip solutions, providing mobile handset manufacturers a variety of alternative semiconductors to choose from. For instance, NXP, a semiconductor company founded by Philips, announced its own single-chip solution that enables feature-rich handsets: Delivering complete system-level operation in a single monolithic integrated circuit (IC), NXP's multimedia solution is designed for ultra-low-cost (ULC) mobile handsets, with complete dual-band GSM/GPRS modem and external ICs required for power amplifier and memory. By integrating analog and digital base bands, NXP's solution allows handset manufacturers (OEMs/ODMs) to deliver higher levels of rich multimedia content to entry-level cell phone users in a reliable, cost- and power-efficient package. In addition, the ULC+ multimedia solution enables a music phone with color screen, MP3 playback, removable flash memory card and FM tuner for a total bill of materials under US$20. Entry-level users in emerging markets like China, India and Latin America now desire the same value-added functionalities available in the industrialized world. NXP's solution also allows significant flexibility in network planning, particularly in emerging markets where network coverage tends to be sparse in rural areas, as well as in oversubscribed urban areas where sub-par RF performance can create interference on neighboring channels, thereby impacting overall cellular network efficiency. NXP's India Center played an important role in the development of the solution, the PNX4903 subsystem.[10]

Following the successes of the single-chip solution developed by the IC manufacturers for GSM/GPRS standards, Qualcomm also embarked on finding a similar solution for its CDMA standard, which is traditionally cheaper than GSM products/systems. Through its single-chip solution, the US technology major Qualcomm is expecting CDMA handset sales numbers in India to match those of the GSM-based handset sales numbers in 2006. More than half of the CDMA handsets sold in the Indian market are priced below US$50. Qualcomm holds the global patents for CDMA-based products and solutions. Mobile handset manufacturers such as LG, Samsung and BenQ have an agreement with Qualcomm to develop CDMA handsets. Qualcomm has two R&D centers in India employing 300 engineers, with an expected addition of a few hundred more in 2006. India would be one of the first markets where Qualcomm's single-chip product would be launched. Qualcomm's single-chip solution offers mobile phone manufacturers the flexibility to use the same chip to develop handsets at different price points. The single-chip solution will enable manufacturers to develop handsets that could be priced below US$50, as well those handsets in the US$60 to US$100 range, but still enables more data capabilities and functionality at the entry level. R&D engineers at

Qualcomm's Indian centers have made important contributions to developing this single-chip solution.[11]

## Single-Chip Digital TV

The single-chip phenomenon has now spread to a wide variety of product areas that use ICs. The basic idea of offering function-rich products at affordable price is perhaps the only strategy to be successful in emerging markets. For instance, by 2004, the first ever single-chip solution for a digital TV was expected to be offered worldwide to the entertainment electronics industry. It was developed by a small team of Indian engineers at the Bangalore-based India Design Center of the US-based analog device major, National Semiconductor. The product, a total 'solution-on-a-chip' (SOC), incorporates all the building blocks; the signal processing, graphics, audio, video and radio-frequency circuits necessary to build a state-of-the-art display monitor compatible with the emerging global digital TV standards. Such technology would serve the new 'convergence' market where TV and PC display functions are virtually interchangeable. It would significantly reduce the price of new generation digital TV sets suitable for the reception of 'combo' broadband video plus data signals through direct to home (DTH) satellites or cable.[12]

## Common People's Chip[13]—The Single-chip Solution

As an illustration of the innovations that have an origin in emerging economies and implications for other developing countries, the following examples would serve best. For instance, in an ultrasound machine, the machine transmits waves into the body of an individual; these hit the targeted tissue/body parts and bounce back. When they bounce back, they are picked up by sensors in the machine, which then calculate the distance the numerous different waves have traversed and, based on that, present an image of the tissue (e.g., the growth of a fetus over time). In this entire process, several elements are involved: (i) the low noise amplifier (LNA), which serves the purpose of amplifying the waves, but at the same time keeps its own noise level low; otherwise that sound could interfere with that of the wave signals; (ii) the voltage-controlled amplifier (VCA), which provides a second level of amplification to give the 'precise' voltage to the waves so that the waves remain strong enough to be read effectively by the sensors. Some waves travel a longer distance, and many of them become too weak before they reach the sensors. The VCA provides a boost to these waves, which are the 'real world' analog signals that then meet an analog-to-digital converter (ADC) so that they can be converted into binary language of (1s and 0s) the digital world, where the digital signals can be processed quickly by digital signal processors (DSPs) to get the images required.

Typically, the LNA and VCA used to be located on one chip and the ADC on another. TI India developed the pioneering process to integrate all of these processors into a single chip, without compromising the overall performance levels. This innovation brings several advantages. For instance, an ultrasound machine consists of many LNA/VCA and ADC chips. With the integration of several functions on a single chip, the space required, which used to be occupied by several chips with each performing a single function, becomes significantly less and thus enables the design of more portable machines, and because the signals have to travel less distance, the power required for the operation will be less.

Several semiconductor companies are making efforts to find similar solutions to bring the benefits of more advanced and modern health care, education, communications and even banking facilities to 'common Indians,' especially those residing in rural and remote locations. The effort is to bring greater functionality into a single chip in order to make the end product more affordable. These high-tech innovations have the potential to bring a lot of benefits to common people in developing countries. Such benefits include:

i. *Banking*: NXP Semiconductors and A Little World, providers of a mobile platform for 'inclusive banking,' introduced technology-enabled solutions to enhance micro-banking in villages in India, as a pilot project deployed by seven major banks in over 450 villages across four states in India. The solution is based on NXP's near field communication (NFC) technology, which is a short-range wireless connectivity technology that enables consumers to securely exchange and store various kinds of information, simply by bringing two devices close together. In this particular case, the two devices are an NFC-enabled mobile phone and an RFID (radio frequency identification) card. The mobile phone (with the bank personnel) executes the functions of a branch of the bank by storing the entire database of customers in the villages. It enables the banks to eliminate the cost and effort of setting up physical branches in rural areas, while providing full services for cash deposits and withdrawals, utility payments and money transfers. The smart card with a chip, which will be in the possession of the customer, stores the identity of the customer such as name, address, photograph, fingerprint templates and relevant details of the savings or loan accounts held by the issuing bank. With more than 40 percent of Indians lacking access to formal financial services, this technology helps in getting this segment into the banking fold.

ii. *Phones and computers*: semiconductor companies such as TI and NXP have developed a single-chip solution for the ultra-low-cost segment of the mobile handset market. This solution works by integrating the analog and digital base bands, radio frequency transceiver, power management and audio circuitry in a single IC. In 2008, Intel announced its Atom processor, a new range of low-power processors designed specifically for mobile Internet devices (MIDs), and a new class of simple and affordable Internet-centric computers arriving later this year. The Atom chip, according to Intel, measures less than 25 millimeters, making it the company's smallest and lowest power consuming processor yet. Intel's competitor, AMD, under its 50X15 initiative that seeks to enable affordable Internet access and low-power computing capability for 50 percent of the world's population by the year 2015, has introduced the Protos Desktop in alliance with Wipro (India). Protos, which is India's smallest fully functional desktop, caters to the needs of people who require basic computing and Internet. It consumes up to 25 percent less power when compared to a conventional desktop.

## 10.2 The World's Cheapest Car: Revamping Traditional Technologies for Emerging Economies

Unlike the previous example, this case is about using traditional technologies, automobile engineering, to develop 'Emerging Products' for 'Emerging Markets.' In a traditional technology sector that involves 'learning-by-doing' and requires accumulated knowledge, Tata Motors India, a company in an emerging economy, has set new standards in the car industry by developing a low-cost car without compromising functionalities. The most important feature of this innovation is its potential to promote 'entrepreneurship' across the countries in the South (the term 'South' refers to the developing world, sometimes called the Third World).

The concept of Nano originated with the idea to offer an affordable and safer mode of transport to people (families) who are currently using two-wheelers such as scooters and motorcycles, but without a significant increase in costs. Ratan Tata, the chairman of Tata Motors India, conceived it as a 'people's car' and offered to sell it at INR100,000 (US$2,000 to US$2,500, depending on the exchange rate. Tata Motors launched this ultra-low-cost car on January 10, 2008, at the Auto Expo 2008 in New Delhi. Judging by the extreme enthusiasm that greeted the launch, the Nano has exceeded industry expectations.

The Nano is a result of breakthroughs at many different dimensions of innovation, in price, in size, in distribution and in technology. By using lighter steel and a smaller engine and having longer-term sourcing agreements (technology alliances) with parts suppliers, Tata was able to keep the price of the Nano down. Tata has filed for 34 new patents on the Nano; most are in the engine. This is a very small number of patents compared to the international auto majors, who would file for thoUSnds of patents for a single innovation. The distribution model of the car is seen an innovation by itself, as the Nano uses modular design and manufacturing. Just like a bicycle, Nano is expected to be sold in kits that would be distributed and serviced by the 'entrepreneurs' who will assemble them for consumers. The Nano basic will be marketed at INR100,000 (US$2,000 to US$2,500), but there will be many variants of it, including an air-conditioned one, and the prices could go up to US$4,000, still less than the Maruti 800 (India), until now the world's cheapest car at US$4,800. The Nano will be customized for overseas markets and exported. Tata intends to export the car to emerging markets in Africa, Latin America and Asia, where it will be a natural fit. Typically, the auto industry creates one of the highest multiplier effects on the economy. The Nano, having created a new market segment, has already begun to build an industry around it. India's Apollo Tires has said it will start to make tires for small cars like the Nano (Kripalani, *Business Week*, January 10, 2008[14]).

## Technological Innovation[15]

i. *Chassis, suspension and brakes*: for a low-cost car, Nano is not a pure single structure construction, but has subframes, in the form of a couple of long members and cross-members for rigidity, which aid in the ride, handling and safety. The suspension systems are all independent (just as in other cars); the front suspension struts are supported by a lower A-arm for improved steering feel and directional control. The coil-sprung independent rear suspension in Nano consists of twin arms with lots of articulation. Nano uses a stiffer front suspension and wider tires at the rear, as well as measures like shifting the battery and fuel tank to under the front seats. Nano does not use expensive disc brakes, but relatively inexpensive drum brakes instead. Nano has a good amount of ground clearance of 180 millimeters, which permits going off-road or better handling on poor roads in developing countries.

ii. *Engine and gearbox*: the Nano's motor is an all-aluminum, 624-cubic centimeter, in-line, two-cylinder motor. It is kept so to keep costs down and, therefore, the valve gear is a simple two valves per cylinder, driven by a single overhead camshaft. The small engine is situated under the rear seat inside the rear axle line to facilitate better handling. The engine management system is supplied by Bosch (the German MNC) and this 'Value Motronic' version is essentially a low-cost version of Bosch's full-fledged Motronic System. The Value Motronic uses a simple engine control unit (ECU) with software that is especially tailored for this car. This customized setup allows Bosch to use comparatively basic electronic circuitry, which substantially reduces the number of sensors that relay information to the ECU. A typical Motronic System requires seven or eight sensors, but Nano's engine has only four basic ones. This system costs less than half of a normal system and yet meets the Bharat Stage III (Indian) emission norms. However, to meet Euro IV, the ECU may need to be upgraded. In terms of innovation, another big challenge with Nano was to control noise, vibration and harshness (NVH), both from the engine and the road, without costly soundproof materials. This was achieved by optimizing the sheet metal frequencies to control boom and vibration.

## Organization of Innovation[16]

The creation and design of the world's cheapest car is an excellent example of innovation and ingenuity, both inside and outside the organization. The Nano mission began back in 2003, when the chairman of Tata Motors India gave its engineers a challenge to build a 'people's car.' He set three requirements for the new vehicle: (1) It should be low-cost; (2) it should adhere to regulatory requirements; and (3) it should achieve performance targets such as fuel efficiency and acceleration capacity. The early designs developed were close to a scooter on four wheels, and they were quickly discarded. The chairman wanted a real car.

Tata Motors called a meeting of its top parts suppliers and, after showing them the discarded prototypes of the car, asked them to help. Auto parts manufacturers, both local and foreign, including Germany's Bosch, which makes the computer that is the heart of the car's engine, were skeptical. But Tata convinced them by pointing out that not only would their companies' specific developments for the Nano help to make history but they could also improve their respective companies' businesses. For instance, the Rane Group, which makes a rack and pinion steering system, focused its R&D on reducing the weight of the materials used, replacing the steel rod of the steering with a steel tube, leading to a major cost reduction. A typical product of this type is made of two pieces, but it was redesigned as one piece to save on machining and assembling costs. According to the Rane Group, the world has seen this sort of integration of two pieces into one, but for different applications and never for a new car and to reduce costs (a follow-on innovation driven by market forces).

Similarly, GKN Driveline India, a subsidiary of global auto parts leader GKN, designed the driveshaft––the component that transfers power from the engine to the wheel. Its team over a year developed 32 prototype variants to create the perfect driveshaft for the Nano. It also brought designers from the company's French and Italian units and designed the driveshaft to make it lighter and easier to manufacture. For the Nano's rear-wheel drive system, GKN designed a smaller diameter of shaft, which made it lighter and saved on material costs. Keeping the cost level has been the biggest challenge for Tata Motors, and it will continue to pose challenges in the future as well, particularly as the prices of raw materials like steel have more than doubled since the project was launched, and the company has to follow the new and stricter industry regulations (Kripalani, *Business Week*, May 9, 2008).

*A modular design revolution*: according to Hagel and Seely Brown (2008[17]) of Deloitte LLP's Center for Edge Innovation, Tata Motors did not draw a lot of attention to what is perhaps the most innovative aspect of the Nano, which is its 'modular design.' The Nano is constructed of parts and components that can be built and shipped separately to be assembled in a number of locations. The Nano is expected be sold in kits that would be distributed, assembled, and serviced by local entrepreneurs. Ratan Tata, in an interview with *The Times* of London said: "A bunch of entrepreneurs could establish an assembly operation and Tata Motors would train their people, would oversee their quality assurance and they would become satellite assembly operations for us. So we would create entrepreneurs across the country that would produce the car. We would produce the mass items and ship it to them as kits. That is my idea of dispersing wealth." In fact, even going beyond this, Tata plans to provide the tools for local mechanics to assemble the car in existing auto repair shops or even in new garages created to cater to remote rural customers. This is a breakthrough element of the Nano innovation. The Tata Motors/Nano approach is in contrast with the strategy of more established auto manufacturers for whom each new model represents an advance in tighter integration, with more and more of the functionality deeply embedded in electronics that truly feel like a 'black box' to the customer.

Recognizing the potential economic benefits that Tata's Nano could bring by transforming transportation systems, particularly in developing countries, already several governments in Africa and Latin America have approached Tata Motors to locate Nano operations in their countries, too. In countries where the public transport system is appalling and private transportation is limited to the affluent, the Nano could bring significant benefits to common people. Moreover, the Nano could promote entrepreneurship not only in terms of assembler, but also repair and service outlets in rural areas. The Nano could be used as taxis by individual entrepreneurs in places where currently three-wheelers, with questionable safety, are being used.

# 11 Summary and Conclusions

In recent years, MNCs have been conducting strategic innovation activities in emerging economies. Although, in the past, there were cases of MNCs conducting R&D in developing countries, such innovation was mainly related to adaptation of products and processes to the local conditions and/or at most product development for local markets (i.e., variants based on the parent's technology). It is only since the mid-1980s that MNCs have started carrying out strategic innovation, such as those relating to developing products for global markets or mission-oriented basic research for long-term corporate use in emerging economies, although the scale of such operations is still small. Mainly only the MNCs dealing with new science-based technologies (e.g., ICT, biotechnology and so forth.) have started locating strategic innovation activities in emerging economies.

The primary driving forces for such a move by MNCs are both technology-related, i.e., gaining access to R&D personnel; as well as cost-related, i.e., to leverage the low-cost advantages in emerging economies; and market-related, i.e., with the markets in emerging economies growing faster than those in the industrialized world. It has become imperative to locate innovation activities in these countries to better understand the needs and preferences of the consumers and to develop innovative products for such markets (e.g., emerging products for emerging markets). This is a new phenomenon and is significantly different from developing products for the local market (based on the parent's technology) in the earlier era. The present situation requires performance of more complex and advanced innovation activities, perhaps also not performed by the parent company itself until now. Another important driving force for locating R&D in emerging economies has been that the manufacturing facilities of most industrial customers of MNCs are located in emerging economies (e.g., China). They manufacture products for worldwide markets. In order to capture this intra-industry (or B2B) business, it becomes necessary to locate R&D centers in such locations to provide the customer with innovative and timely solutions.

However, it should be remembered that at the global level the proportion of R&D conducted in developing countries (including emerging economies) by MNCs is still only marginal. Over two-thirds of MNCs' R&D activities are located within the industrialized world. It is often difficult to get an exact estimate of the R&D performed by MNCs outside their home countries. At an average the internationalized corporate R&D ranges between 10 to 15 percent of total R&D conducted by MNCs, although the figure is rising steadily. The figure, however, is greater for MNCs based in small industrialized countries. Of the limited R&D conducted overseas, the share of developing countries would be only a small proportion, and this again depends on whether it is measured on the basis of R&D expenditures or R&D personnel or proportion of patents originating from innovation activities in developing countries. Similarly, the flexibility and the propensity for internationalization of R&D vary between different sectors, with the new science-based technologies scoring higher on both counts than the conventional technologies (Reddy 1997).

In addition, since the beginning of the new millennium (2000s), firms based in emerging economies have started performing R&D to develop products and services for the global markets (i.e., global innovation), putting them in direct competition with incumbent MNCs in the industrialized countries. In this effort, the emerging economy firms are being supported by their universities and national research institutes, which help the firms with innovation and technological activities (particularly in China).

This study, through empirical analysis (in-depth case studies), attempted to show that the characteristic features of innovation performed in some developing countries (which are called emerging economies) by both MNCs and local firms are changing significantly, making them attractive locations for more R&D-related FDI. This means that something uncommon or unforeseen is happening. What is it? Why is it happening? And what are its implications for the corporations, host and home countries (the actors) involved? Although when viewed from the perspective of all MNCs (or firms from emerging economies) as a group or all developing countries as a block, such activities are still marginal, when viewed from an individual actor's perspective such developments assume greater significance. It may be pointed out here that in the 1970s, internationalization of production also started as a marginal activity, with labor-intensive assembly activities relocated into low-cost countries, especially the newly industrializing economies (NIEs––Hong Kong, Singapore, South Korea and Taiwan). Starting with such low-tech activities of MNCs, the NIEs today have built up strong skills in production engineering and are now increasingly becoming locations for R&D activities. For instance, South Korea and Taiwan are today the foremost countries in the world that have micromachining capabilities (perhaps with the exception of Japan).

## 11.1 GLOBAL INNOVATION OF MNCS IN EMERGING ECONOMIES—DETERMINING FACTORS

### 11.1.1 Demand-side Factors

As analyzed in the theoretical framework (see Chapter 3, this volume), the internationalization of corporate R&D could be conceptualized as occurring in waves or phases. In an evolutionary fashion, MNCs tend to gain more confidence in the capabilities of their subsidiaries abroad and the NSI in host countries, increasing the level and complexity of the innovation being assigned to them. Until the 1970s, the MNCs that were internationalizing their business were mainly those dealing with conventional technologies (e.g., mechanical and electrical engineering, consumer goods and so on) which required adaptations to individual local market conditions. So in the initial phases, to carry out such adaptation work, TTUs were established in host countries abroad. By the mid-1970s, in order to increase the market share in host countries, a need for increased sensitivity to local conditions became apparent. Along with the expansion of production facilities, some localized innovation activities were established to develop products exclusively for local markets (ITUs) (but basically derived from the parent's technologies). However, most of such R&D was located within the industrialized host countries. Only a few large developing countries, such as India, were locations for even these limited functions.[1] A good example of such an ITU's innovation would be Unilever's (UK) subsidiary Hindustan Lever in India. Based on the detergent powder developed by the parent, the Indian affiliate developed a detergent cake for the Indian market. In India, where clothes are not washed in washing machines but in flowing water (either rivers or taps), powder was not a good choice. Hence, due to this variation in cultural habit, the cake had to be developed to gain a market share. It was considered to be an innovative product in India, with improved efficacy, compared to the earlier bar soap to wash clothes.

However, by the late 1970s, the industries based on new science-based technologies, especially those that were microelectronics-based, had begun to emerge rapidly, transforming the characteristic features of global competition by dramatically changing the industrial production system. This change in the techno-economic paradigm[2] has eroded the competitiveness of firms and countries that were leaders in conventional technologies and at the same time enabled some newcomers to take the lead (Ernst and O'Connor 1989). This volatile competitive situation was evidenced by the challenges posed to MNCs by the newly emerged high-technology firms in the electronics and biotechnology sectors.[3] For instance in the semiconductor business, during 1975–1985, USA-based MNCs dominated the market for dynamic random access memories (DRAMs). After the mid-1980s, Japanese MNCs overtook USA companies in global market share and were expected to maintain their lead for several decades. But another newcomer, Samsung of South Korea, entered the field and snatched the lead by accomplishing a phenomenal growth in a very short period. In 1989, Samsung was in ninth place in the global markets in memory chips, but by 1993 it had attained the number one position in the world (*Business Week* 1994, p. 23).

Furthermore, techno-economic and social developments in the 1980s have created a relatively more harmonized market in which consumer needs (at least some) worldwide could be met with standardized products. This compelled MNCs to adopt global strategies to remain competitive (Levitt 1983).

Due to the convergence of consumer needs and the rapid international diffusion of technologies, MNCs from the industrialized world could no longer depend on their home countries alone to provide the ideal conditions for innovation. New needs could emerge anywhere in the world, and the technological solutions to meet such needs could be located in another part of the world. These developments have increased the necessity for worldwide learning and the location of some strategic innovation activities away from home countries (Bartlett and Ghoshal 1991). As a result, in the 1980s, several MNCs located some strategic activities abroad. IBM's basic research center in Switzerland and global product development center in Germany illustrate this trend.

Furthermore, in order to reduce risks as well as development time and to obtain complementary knowledge and skills, firms started joining hands with earlier rivals in technological alliances. However, all such innovation-related activities were confined to the industrialized world. By the mid-1980s, the rapid pace of innovation and technological activities increased the demand for R&D personnel, surpassing the supply in the industrialized world. The competition for recruitment of scarce R&D personnel was also pushing up the costs. As a corollary, companies started searching globally, including new countries such as India, Israel, South Korea and Taiwan (perhaps based on their international publications or patent records) for locating their innovation activities.

As discussed in Chapters 1 and 2, the empirical evidence suggests that since around the mid-2000s, emerging economies have become more attractive locations for innovation-related activities than were the traditional leaders like the USA and the EU countries. This focus on emerging economies is now mainly driven by the need for R&D presence in rapidly growing markets (particularly in the light of continuing recession in the industrialized world) and the need to be in proximity to major business customers, who are largely located in the emerging economies.

### 11.1.2 Supply-side Factors

Complementing the demand-side factors that are compelling and/or persuading MNCs to locate R&D, supply-side factors in emerging economies are also favoring such a move. Some developing countries possessed supply-side factors. In their efforts to build up technological capacity for economic development, over the years many developing countries (e.g., the BRICS group) have built up large reserves of S&T personnel. However, until the early 1990s, such efforts, instead of resulting in rapid economic development, mostly resulted in increased unemployment among the educated or in brain drain. The twin reasons for such a situation have been: (a) mismatch between the requirements and human resources development (HRD) planning; (b) the low level and slow pace of industrialization. Even the limited industrialization in such countries mainly took place through transfer of ready-made technologies by MNCs (Reddy 1993).

In developing countries (particularly in the emerging economies) S&T manpower was lying dormant due to its underutilization by the indigenous industry. In most of these countries, either the industrialization did not take place at a corresponding level or the then existing industry, because of the low-emphasis on R&D, was not able to fully utilize the available manpower. These pools of S&T personnel were available for utilization by MNCs for their innovation activities at much lower-wages compared to their counterparts in industrialized countries.[4]

From the supply side, an added attraction for MNCs has been the interest among researchers from developing countries, who are educated and working in industrialized countries, to return to their native countries and work on challenging tasks for MNCs.[5] Many researchers from developing countries have attained reputations in their respective fields of study in industrialized countries. Earlier such people who were educated in industrialized countries chose to stay abroad, because of the lack of technologically challenging tasks in their developing home countries. Now with MNCs creating facilities similar to those available in industrialized countries and their home economies transforming positively, these researchers are showing greater interest in returning to their home countries, leading to a reverse brain drain. These expatriate researchers are familiar with the operations of MNCs and the systems in industrialized countries, as well as the operating conditions in their native countries.

As Fusfeld (1994) pointed out in the 1990s, the availability of educated, but underutilized personnel in developing countries representing a combination of talent and low-wages has an important implication for industrial research. These pools of scientists and engineers in non-OECD countries will continue to grow. There are three mechanisms by which these personnel will influence future industrial research: (1) MNCs from industrialized countries will locate more innovation activities in developing countries with large pools of scientists and engineers; (2) MNCs will subcontract specific R&D projects and related technical services to firms or research institutes or universities or government agencies in developing countries; and (3) entrepreneurial activity and industrial growth in developing countries will lead to the evolution of a base of industrial research in domestic firms, with increased absorption of domestic scientists and engineers.

### 11.1.3 Enabling Factors

In the early 1970s, one of the main reasons that MNCs did not locate strategic R&D abroad was the difficulty involved in coordinating and supervising such activities (Mansfield 1974). But by the mid-1970s, the improvements in ICT had vastly facilitated the scope for international sourcing of knowledge. The new technologies have become not only driving forces, but also enabling forces for the globalization of innovation. By the late 1970s, many MNCs dealing with new science-based technologies had established worldwide organization of R&D and international sourcing of S&T resources. ICT has enabled the geographical dispersal of corporate R&D worldwide as well as ensured the flow of technologies within the corporate group structures globally (OECD 1992). ICT, especially with the introduction of digital technology, enabled the exchange of detailed designs, drawings and specifications without time delays.

Another feature of new science-based technologies that enabled the globalization of R&D, particularly in industries such as pharmaceuticals, chemicals, microelectronics, biotechnology and new materials, has been their closeness to basic science. The increasing role of scientific knowledge in major technological developments is also increasing the number of disciplines relevant to innovation and thereby the necessity for companies to depend on external sources, particularly universities, for basic science-based knowledge inputs (Chesnais 1988a). Some developing countries, although not highly industrialized, have internationally reputed academic establishments. The proximity of new technologies to basic science is allowing MNCs to utilize the talents in such academic establishments in developing countries for their R&D requirements by sponsoring research, by subcontracting R&D or by research collaboration (Reddy 1993[6]).

Moreover, because of their basic science base, even theoretically trained personnel, with little or no industrial experience, can be utilized in innovation-related activities in new technologies. Such theoretically trained personnel are available in surplus in some developing countries, opening up opportunities for them to join the global R&D networks of MNCs. Unlike in conventional technologies, where 'learning by doing' plays the vital role in acquiring skills, the skills in new technologies can be acquired through formal training and education.

Another characteristic feature of new science-based technologies that has emerged in discussions with the MNCs' R&D has been that innovation process in new technologies is divisible into activities and/or subactivities, which can later be integrated to result in final innovation. For instance, in the initial phases of establishing Astra Research Center India (ARCI), the molecular biology portion of innovation was carried out at ARCI in India and the pharmacology and toxicology were carried out by Astra's R&D units in Sweden, with the final integration for product development taking place in Sweden (see Reddy 2000, for a complete case study of ARCI). It is this divisibility of innovation process that enables joint R&D projects and technology alliances, where each partner contributes the knowledge in which it has expertise. By implication, this also means that innovation activities can be divided into 'core' and 'non-core' or 'supplementary' activities. MNCs can save on costs by performing (or outsourcing) some of the non-core activities in emerging economies. At the same time, it also releases critical resources in home countries for concentration on core activities.

In the past, especially in conventional technologies, the economies of scale required for R&D were considered to be one of the main reasons for retaining substantial R&D in the home countries of MNCs. But in the new techno-economic paradigm the advantages of economies of scope have overcome the barriers of economies of scale. According to Mytelka (1993), contrary to earlier views, critical mass can now be achieved in terms of the size of the 'system' needed to acquire the knowledge rather than the size of the firm itself. This applies to all activities in the value chain from conception of an idea to marketing.

At the macro level, one of the important enabling factors for MNCs' R&D activities in emerging economies has been the changes in host government policies related to trade, FDI and particularly the intellectual property rights (IPRs) regime (see Chapter 2, this volume, for complete discussion).

However, in discussions with MNCs, the IPRs regime in the host country did not seem to be critical for locating or outsourcing innovation activities, as there are some ways to protect their intellectual property (IP). The reasons for this seem to be two-fold: (1) The entire innovation process for a product does not take place in one location. So each location only has the knowledge related to the activity handled by that unit, and such information without collaboration from units in other locations is not of much use for imitation. (2) In new technologies, the ability to copy and produce a product is not sufficient to be successful in business. The global marketing and distribution networks and the brand names, apart from technological edge, have become equally important for entry into global markets. And these advantages rest with the MNCs.

Another policy change in developing countries that has direct bearing on the location of MNCs' R&D activities has been the opening up of access to their national research institutes to foreign firms. Following a reduction in government financial support, research institutes are now motivated to earn a portion of their budgets from enterprises, including foreign-owned (Reddy 2000).

### 11.1.4 Internal Factors

To meet the challenges posed by the rapidly changing global business environment, MNCs have also rationalized their corporate structures, which in turn acted as an enabling factor for globalization. From the operational perspective of MNCs, the nature of demand and the increasing science base of new technologies are leading to homogenization of certain international markets and standardization of technologies for global markets. At the same time, they are generating wider variety and fragmentation in other markets (Granstrand et al. 1992). This necessitates changing the traditional headquarters-subsidiary relationships into a global intra-organizational network-based management structure. The creation, exploitation and dissemination of new technology in a global organization require simultaneous achievement of efficiency, local responsiveness, and worldwide learning and know-how transfer (Bartlett and Ghoshal 1991).

According to Porter (1986), MNCs have been compelled to shift from a multidomestic approach, where each subsidiary was confined to servicing a local market, to a global strategy, where subsidiaries are assigned a specialized role to play in the developments planned and organized from the center. This new role of subsidiaries may involve an increased emphasis on deriving distinctive new product variants as part of a regional or world product mandate, or if a unique 'global product' is envisaged, providing research input into its creation. Such rationalization has also become easier with the liberalization of economies worldwide and the establishment of the WTO.

## 11.2 GLOBAL R&D IN EMERGING ECONOMIES

The 'product life-cycle' theory suggested by Vernon (1966) has had a profound influence on the studies concerning the internationalization of production activities. However, in recent years, especially in the light of the globalization of business operations, including R&D, the relevance of the model to the new global environment is increasingly being questioned.

According to Cantwell (1995), the product life-cycle model was based on the hypothesis that innovation activities are almost always carried out in the home country of the MNC. The reasons for this have been: (1) economies of scale are important in R&D activities and therefore may need to be concentrated in a single center; (2) there are locational economies of integration involved in R&D, as the development of new products or processes requires close interaction between R&D, manufacturing and marketing; and (3) innovation is perceived as a demand-led process, where the special demands of sophisticated consumers and skill-intensive downstream facilities in the home countries are seen as providing stimulus for innovation.

Using the USA patent data for 100 years, which specifies the location of technological activity at the corporate level, Cantwell (1995) points out the weakness of the product life-cycle's hypothesis concerning the location of R&D activities. Based on the data, he argues that even historically the model was not correct. The USA electrical companies and European chemical companies had significantly internationalized their technological activity in the inter-war period. The data also indicate that, in recent years, the categories of industries internationalizing their technological activities have further broadened, including a wider range of companies.

Based on the results of subsequent studies, the product life-cycle theory was criticized on the grounds that the changes in the behavior of MNCs, due to internal pressures from well-established affiliates or external pressures from the host country governments, may lead to the compression of product cycle (Giddy 1978), giving scope for near-simultaneous occurrence of innovation in several major markets (Pearce 1989).

In a later paper Vernon (1979) conceded that there has been a considerable increase in the spread of the geographical network of MNCs' operations. As MNCs increasingly adopted a global approach, the spread of their operations increased, and the overall time lag between the introduction of a new product in the USA and its diffusion into other locations decreased dramatically. By the late 1970s, there had been a number of changes in Europe's macro environment, closing the gap between Europe and the USA.

In the present context, the product life-cycle theory is only relevant to the extent that the home countries of MNCs tend to be the location for the majority of innovation activities, as the largest proportion of R&D expenditures are incurred there. However, the changes in the global environment have made it possible for the product cycle to start anywhere in the world in the corporate system. As Bartlett and Ghoshal (1991) stated in the early 1990s, the latest fashion or huge market need could emerge in other countries and the technologies to meet such demands could be located in some other country. This implies that the initial phases of the product cycle can also be located in countries other than the home base (in the industrialized world). MNCs are pooling the resources available at the corporate level globally to find solutions. Efficient manufacturing subsidiaries may be converted into 'international production centers,' and the innovative R&D units of subsidiaries may be treated as 'worldwide centers of excellence' for a specific product or process development.

MNCs' strategic innovation activities in emerging economies negate the conventional views that developing countries have the capability to perform only low-tech activities. Instead, the trend suggests that even in developing countries (at least in some of them) there are segments that can perform high-tech activities given the resources. However, this does not mean that developing countries have achieved advanced technological capabilities on a par with the industrialized countries. It only means, just as Vernon observed the developments in Europe that negated his product cycle theory, that there have also been changes taking place in some developing countries that make them conducive for the location of activities related to the early phases of the product cycle.

The business environment for companies is increasingly being influenced by global developments, not only in terms of economic opportunities, but also in terms of technological developments. Whereas, traditionally, the technological and economic changes in the business environment took place in the USA, Europe and Japan, today some emerging economies such as Brazil, Russia, India, China and South Africa are playing a minor, but fast-growing role in such developments. They have emerged not only as large potential markets, but also as noticeable competitors and attractive locations for strategic innovation activities.

The liberalization of economies for trade and investments has played a major role in the entry of emerging economies into the global business environment. The new techno-economic paradigm, which gave raise to several science-based technologies, also played a critical role in the integration of new countries into the global business environment. Freeman and Perez (1988), in a historical analysis, showed how at the emergence of each new techno-economic paradigm new windows of opportunities were opened up for latecomers to industrialization and how the leading nations in an earlier paradigm were overtaken by the newcomers at the change of every techno-economic paradigm.

In the traditional technologies such as mechanical and electrical engineering, much of the learning and accumulation of knowledge took place through 'learning-by-doing' over long periods, as successful innovation and diffusion of these technologies required significant 'tacit knowledge,' Consequently, countries with vast industrial experience had a strong competitive advantage in these technologies. The entry-barriers were too high to latecomers. But in the new science-based technologies, much of the required knowledge is codified, hence the corporate world's growing emphasis on intellectual property rights (IPRs). The learning paradigm has started shifting from that of 'learning-by-doing' toward 'learning-by-training,' The science-based technologies, by lowering the entry barriers, opened up new opportunities to latecomers to compete in the global economy on an equal footing. The success of South Korea and Taiwan in the electronics industry is an evidence of this process. A similar process is underway in other technology sectors such as software, telecom, biotechnology and nano technology, opening up new opportunities to emerging economies that have a substantial number of trained scientists and engineers. Furthermore, even conventional technologies themselves integrate significant proportion of new technologies in their products (e.g., about 30 percent of automobile parts are composed of electronics).

At the moment the emerging economies do not pose a significant direct threat to the industrialized countries. But in the medium-term, with the existence of large domestic markets and the availability of low-cost resources, some companies located in emerging economies are likely to narrow the technological and economic gap with the MNCs. Instead of looking at the emerging economies as potential competitors, companies based in industrialized countries could focus on the potential opportunities that emerging economies can open up.

The business strategy of companies from the industrialized countries has traditionally been to focus on products (more advanced) and markets that provide higher profit margins with low sales volumes. Such a strategy arises from the small domestic market, which has an ability to pay higher prices. On the other hand, companies in the emerging economies follow a strategy of achieving high sales turnover, even with low profit margin. The consumers in emerging economies have lower purchasing power, and so the demand is more sensitive to price. Therefore, companies derive profit through higher sales volumes. Given the growing cost sensitivity, without compromising on functionality and quality, in the rapidly growing markets, the traditional business strategies of striving for high profit-margins on low volumes may need to be revised.

As Mathews (2006, p. 15) notes, the literature on international business/economics over the course of the past decade has been somewhat responsive to the new trends described above. It has now moved from viewing the MNC as an agent of internationalization to one where the MNC is seen as both initiator and beneficiary of globalization. Along with this shift in emphasis there has been a shift in understanding the rationale of multinationality and the means through which firms seek to obtain advantages from globalizing operations (Caves, 1982; Chi and McGuire, 1996). In the 1960s and 1970s, MNCs operated in a regime of import substitution and closed markets and therefore had to establish miniversions of themselves as more or less self-contained subsidiaries in each national market. In such a business environment, the theoretical explanations of the sources of multinational advantage focused on the MNC's ability to exploit its domestically derived advantages abroad (see also Chapter 3, this volume, particularly Hymer 1976 and Kindleberger 1969). But as globalization progressed, the source of multinational advantage is seen as arising not so much from the exploitation of existing advantages but from the tapping of resources that would otherwise not be available to a firm competing solely at home and exporting from the home base (Forsgren 1999). As the global economy becomes more and more closely interlinked, MNCs have been seeking new advantages by establishing global value chains, where product development, production and logistics are located around the world, in terms of cost considerations (e.g., labor-intensive operations in low-cost countries) or considerations of access to knowledge resources (e.g., R&D operations in knowledge-intensive regions) (Zander 1999).

# Notes

## NOTES TO CHAPTER 1

1. www.my-esm.com/showArticle?articleID=196702141 (downloaded on 6/20/2007).
2. www.businessweek.com/interactive_reports/innovative_companies/ (downloaded on 5/28/2008).
3. www.wipo.int/sme/en/case_studies/fk_biotec.htm (downloaded on 5/28/2008).

## NOTES TO CHAPTER 2

1. The emergence of these generic technologies is often attributed to the onset of a new techno-economic paradigm, in turn associated with long-wave theory and the rise of the fifth Kondratieff (Kondratieff 1935; Schumpeter 1939).
2. www.engineeringservicesoutsourcing.com (accessed 5/28/2008).
3. www.tcs.com.
4. According to Levitt (1983, 93), global standardization is not limited to raw materials and high-tech products, but even products such as Coca-Cola and Pepsi-Cola have successfully penetrated markets across 'multitudes of national, regional and ethnic taste buds trained to a variety of deeply ingrained local preferences of taste, flavor, consistency, effervescence, and aftertaste.'
5. Even prior to such need for deliberate efforts toward globalization of R&D, partly through mergers and acquisitions, companies have already started performing some R&D outside their home countries, but mainly in other industrialized countries.

## NOTES TO CHAPTER 3

1. According to Terpstra (1977, p. 26) "the last activity of the firm to be organized on an international basis—if it is at all—is R&D. Indeed some multinationals do not conduct any R&D outside their home country."
2. For example, IBM located a CTU in Haifa, Israel, to gain access to the advisory services of a professor, who declined to relocate to the US.
3. Pearce (1999), Dörrenbächer and Wortmann (1991), Håkanson (1992) and Granstrand et al. (1992).
4. This is also true in the R&D-intensive pharmaceutical sector, where 'me-too' products that followed have often surpassed the revenues generated

by the original product. For example, ranitidine (brand name, Zantac), an anti-ulcer drug by Glaxo, was a me-too drug of the original cimetidine by another company. But it earned more than US$2 billion for Glaxo and has been successful for several years now. Similarly, enalapril, an ACE inhibitor, and atenolol, a beta blocker, were also me-too drugs but became blockbusters (*Business India,* December 10–23, 2001, p. 58).

5. The advances in new technologies, such as ICT, are facilitating latecomers' access to basic science. Scientific knowledge is increasingly being stored and transmitted across nations in digital forms, giving greater access to basic science. For instance, through the Internet, scientists in Taiwan, India and South Africa today can run either individually or collaboratively the same computational models as scientists in the US or Europe (Friedman 2006).
6. The division of time periods should only be taken as approximate indications and not as precise cut-off dates.
7. Behrman and Fischer (1980).
8. See OECD (1988).
9. Mansfield et al. (1979).

## NOTES TO CHAPTER 4

1. *The Hindu*, May 23, 2006.
2. *Deccan Chronicle,* June 28, 2002.
3. Tata Consultancy Services, news release, June 7, 2004.
4. As cited in Etzkowitz et al. 2005.
5. As cited in Etzkowitz et al. 2005, p. 420.

## NOTES TO CHAPTER 5

1. "Indian Engineers Help Craft Futuristic Cellphone Chip," *The Hindu*, May 17, 2006. http://thehindu.com/2006/05/17/stories/2006051704851400.htm (downloaded 5/28/2008).
2. "MIDC Develops Communicator Mobile," *The Hindu*, May 18, 2006. http://www.thehindu.com/2006/05/18/stories/2006051802720500.htm (downloaded 5/28/2008).
3. "Intel Unveils Futuristic Chip,". *The Economic Times*, December, 17, 2009, p. 5.
4. "Chinese IT Firm Plans to Set Up R&D Base in India," *Times of India Online*, August 22, 2002.
5. The information relating to Motorola India in this book reflects the situation in the year 2007. As all companies do, Motorola India may have changed with the time and reconfigured its R&D activities.
6. "Motorola Labs Launched in India." http://mediacenter.motorola.com/content/detail.aspx?ReleaseID=9067&NewsAreaId=2 (downloaded on 6/20/2007 and 4/25/2010).
7. "India R&D Drives Motorola." http://mediacenter.motorola.com/content/detail.aspx?ReleaseID=8772&NewsAreaId=2 (downloaded on.6/20/2007 and 4/25/2010).

   "Motorola Launches New R&D Facility in Hyderabad." http://mediacenter.motorola.com/content/detail.aspx?ReleaseID=7952&NewsAreaId=2 (downloaded on 6/20/2007 and 4/25/2010).
8. "About Motorola India." http://www.motorola.com/content.jsp?globalObjectId=1794–3788 (downloaded on 6/20/2007).

"Motorola Establishes India as Headquarter for High Growth Markets." http://www.motorola.com/contentpf.jsp?globalObjectId=6988 (downloaded on 6/20/2007).

9. "Motorola signs Memorandum of Understanding with Indian Institute of Technology—Bangalore for Wireless Networking Solutions." http://mediacenter.motorola.com/content/detail.aspx?ReleaseID=7724&NewsAreaId=2 (downloaded on 6/20/2007 and 4/25/2010).
10. www.csir.res.in (downloaded 5/28/2008).
11. *The Hindu*, September 16, 2005, p. 13.
12. A paper based on this survey was earlier published as P. Reddy (1997).

## NOTES TO CHAPTER 6

1. Hariharan, 2005.
2. Wong, 2005.
3. Ho, 2005.

## NOTES TO CHAPTER 9

1. According to Granstrand et al. (1992), the availability of specialized biotech researchers is many times greater in India, with its conglomeration of knowledge activities in biotechnology and software, than in Sweden.
2. For example, the Netherlands-based AKZO Chemicals subcontracted R&D related to the development of a key ingredient for refining petroleum to the National Chemical Laboratories (NCL) in India. This product, 'Zeolite,' developed by NCL is being used by Akzo in its operations worldwide.
3. See also Westney (1988).
4. The types of R&D units are explained in Chapter 3, this volume.
5. See Science (1996).
6. See Business Line. (1996). "BE, IISc to Develop Silicon Technology." July 12. India.
7. See Science (1995b), p. 1419.
8. Dr. Sivaraman in an interview in January 2006 with the author of this book.
9. http://www.motorola.com/contentpf.jsp?globalObjectID=6988(downloaded on 6/20/2007).
10. R. A. Mashelkar, "The Search for Research. http://www.tata.com/scripts/print.asp (downloaded on 6/25/2008).
11. For instance, Chiron Vaccines of US established a 50:50 joint venture with India's Panacea Biotec for production and marketing a range of Chiron's products in the Indian market. Chiron may also use this joint venture to source its operations in adjacent regions and to carry out clinical trials for some of its products in India (Ernst & Young 2005, p. 75).
12. In 2004, there were some noted outlicensing successes for Indian companies. For instance, in the biotechnology segment, Molecular Connections licensed its proprietary knowledge base of 30,000 expert curated and annotated protein-protein interactions, NetPro, to the prestigious David Eisenberg Research Lab at the Institute for Genomics and Proteomics, UCLA. Ocimum Biosolutions has licensed its gene expression analysis program 'Genowiz' to two research organizations—Bioniche Therapeutics Research Centre of the US-based Bioniche Life Sciences Inc. and the University of Ottawa, Canada (Ernst & Young 2005, p. 75).
13. For instance, in Sweden, the protein research project, 'Human Proteome Resource (HPR),' involves mapping of all human proteins, in order to facilitate

development of antibodies that can cure diseases. By the beginning of 2007, the project had resulted in 1.2 million pictures. These pictures needed to be classified in terms of which organ the picture (or map) is showing, whether a particular protein is present, if yes, how much and of which cell type, etc. With the project generating almost 20,000 pictures a day, the team of 25 pathologists at the Uppsala University in Sweden was finding it difficult to cope with the workload. Therefore, the HPR research team opened a center in Mumbai, India, by recruiting 20 pathologists there (*NyTeknik* 2007).

14. For instance, in March 2006, Dr. Reddy's Laboratories of India acquired Betapharm Group, Germany's fourth-largest generics pharma company, €480 million deal for 100 percent of the equity ownership (*The Hindu*, 2006).
15. The British government would grant an amount ranging from 6.5 to £8 million over five years to the program. The Indian government would provide a matching grant (*The Hindu*, June 29, 2006).

## NOTES TO CHAPTER 10

1. http://www.redorbit.com/modules/news/tools.php?too=print&id=1325226 (downloaded 11/28/ 2008).
2. TCIL. (2007). "Pan-African e-Network: Heralding New Era in Providing Tele-education & Tele-medicine Services to African Countries." http://www.tcil-india.com (downloaded 5/28/2008).
3. This is also evident in the case of the growing number of students from other developing countries pursuing their higher studies in the BRICS group of countries.
4. http://www.ti.com/asia/docs/india/images/press_aug1005_toi.gif (downloaded 5/28/2008).
5. http://www.ti.com/asia/docs/india/images/press_aug1005_toi.gif (downloaded 5/28/2008).
6. "Texas Instruments Chairman Makes Live Phone Call from India to Europe on TI's Single-Chip Cell Phone Solution." August 8, 2005. http://www.ti.com/in/news_details_singlechip_milestone.htm (downloaded 5/28/2008).
7. The Hindu Business Line, August 9, 2005.
8. Techtree News Staff. "TI's 'eCosto' Single Chip Platform." November 21, 2006. http://www.techtree.com/techtree/jsp/article.jsp?print=1&article_id=77324&cat_id=580 (downloaded 5/28/2008).
9. *Esato News*. January 25, 2005. www.esato.com/news/article.php/id=415 (downloaded 5/28/2008).
10. http://findarticles.com/p/articles/mi_m0PIL/is_2007_Nov_12/ai_n21094558/print?tag=artBody;col1/ (downloaded 5/28/2008).
11. http://www.thehindubusinessonline.com/2006/02/21/stories/2006022102220400.htm/ (downloaded 5/28/2008).
12. *The Hindu*, April 27, 2003.
13. John, S., and Ghosh, D. "TNN, *The Times* of India." March 22, 2008.—http://timesofindia.indiatimes.com/articleshow/msid-2888664,prtpage-1.cms (downloaded 5/28/2008).
14. http://www.businessweek.com/print/globalbiz/content/jan2008/gb20080110_319276.htm (downloaded 5/28/2008).
15. Autocar India. (2008). "Nano-Mania!" Vol. 8, no. 6, pp.10–15.
16. http://www.businessweek.com/print/innovate/content/may2008/id2008059_312111.htm (downloaded 6/10/2008).

17. http://www.businessweek.com/print/innovate/content/feb2008/id20080227_377233.htm (downloaded 5/28/2008).

## NOTES TO CHAPTER 11

1. In countries with small markets, research teams were sent from headquarters on missions to provide technical support for adaptation, rather than establishing an R&D unit (Ronstadt 1997 and Behrman and Fischer 1980).
2. See Chapter 3 of this book, particularly Freeman and Perez 1988 and Perez and Soete 1988.
3. For example, Nokia of Finland has become the second-largest supplier of mobile telephones worldwide. Similarly, Samsung of South Korea became the first company in the world to develop a working prototype of the 256-megabit chip (*Business Week* 1994, p. 23).
4. Some developing countries, such as India and Brazil, are characterized by dual segments. One small segment is technologically highly developed and exhibits complementary characteristics to the systems in the industrialized world, and the other larger segment is highly underdeveloped and poor, making the whole country less developed. MNCs are attempting to utilize this advanced segment for their R&D.
5. Astra Research Centre India was in fact established mainly because of interest among the Indian researchers settled in the USA in returning to India. For related detailed discussion, see also *Science* (1993), pp. 346–367 and *Business Week* (1994), pp. 36–37.
6. The cases of AKZO Chemicals subcontracting R&D to National Chemical Laboratories, India, and the research collaboration between Glaxo and the Institute of Molecular and Cell Biology, Singapore, are good examples. Similarly even the MNCs based in developing countries are also entering into research collaboration with universities abroad. The collaboration between United Microelectronics Corp. of Taiwan and Fudan University of China in VLSI chip designing is a good example of that.

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# Bibliography


Alcácer, J. and Chung, W. (2007). "Location Strategies and Knowledge Spillovers." *Management Science* 53 (5): 760–776.

Amsden, A. H. and Tschang, F. T. (2003). "A New Approach to Assessing the Technological Complexity of Different Categories of R&D (with Examples from Singapore)." *Research Policy* 32: 553–572.

———, Tschang, T., and Goto, A. (2001). "Do Foreign Companies Conduct R&D in Developing Countries? A New Approach to Analyzing the Level of R&D, with an Analysis of Singapore." ADB Institute Working Paper 14. Tokyo: Asian Development Bank Institute, March.

Archibugi, D., Howells, J. and Michie, J. (1999a). "Innovation Systems and Policy in a Global Economy." In D. Archibugi, J. Howells and J. Michie, eds, *Innovation Policy in a Global Economy*, 1–18. Cambridge: Cambridge University Press.

———. (1999b). "Innovation Systems in a Global Economy." *Technology Analysis & Strategic Management* 11 (4): 527–539.

Arora, A., Arunachalam, V. S., Asundi, J. and Ronald, F. (2001). "The Indian Software Services Industry." *Research Policy* 30 (3): 1267–1287.

Arora, A. and Gambardella, A. (2004). "The Globalization of the Software Industry: Perspectives and Opportunities for Developed and Developing Countries." Working Paper 10538. Cambridge, Mass.: National Bureau of Economic Research, June.

Athreye, S. and Cantwell, J. (2007). "Creating Competition? Globalisation and the Emergence of New Technology Producers." *Research Policy* 36: 209–226.

Bartlett, C. A. and Ghoshal, S. (1991). *Managing across Borders: The Transnational Solution*. Boston: Harvard Business School Press.

Bas, C. L. and Sierra, C. (2002). "Location versus Home Country Advantages." In R&D Activities: Some Further Results on Multinationals' Locational Strategies," *Research Policy* 31: 589–609.

Behrman, J. N. and Fischer, W. A. (1980). *Overseas R&D Activities of Transnational Companies*. Cambridge, Mass.: Oelgeschlager, Gunn & Hain.

Bhattacharya, A. and Michael, D. C. (2008). "The BCG 50 Local Dynamos: How Dynamic RDE-Based Companies Are Mastering Their Home Markets—and What MNCs Need to Learn from Them." Boston: The Boston Consulting Group. March.

Birkinshaw, J. M. and Morrison, A. (1995). "Configurations of Strategy and Structure in Subsidiaries of Multinational Corporations." *Journal of International Business Studies* 26: 729–754.

Bonin, B. and Perron, B. (1986). "World Product Mandates and Firms Operating in Quebec." In H. Etemad and L. Séguin Dulude, eds, *Managing the Multinational Subsidiary*, 161–176. London: Croom Helm.

Borini, F. M., Oliveira Jr., M. M. and Guevara, A. J. H. (2005). "Determinant Factors of the Subsidiaries Roles in Emerging Economies." Paper presented at the Academy of Management Meeting, Honolulu, August 5–10.
Bowonder, B., Thomas, M. T., Rokkam, V. M. and Rokkam, A. (2003). "The Global Pharmaceutical Industry: Changing Competitive Landscape." *International Journal of Technology Management* 25 (3, 4): 201–226.
Brash, D. T. (1966). *American Investment in Australian Industry*. Canberra: Australian National University Press.
Breschi, S. and Lissoni, F. (2001). "Knowledge Spillovers and Local Innovation Systems: A Critical Survey." *Industrial and Corporate Change* 10 (4): 975–1005.
Brito Cruz, C. H. and de Mello, L. (2006). "Boosting Innovation Performance in Brazil." Economics Department Working Paper No. 532, ECO/WKP (20006)60. Paris: Organization for Economic Cooperation and Development (OECD), December 6th.
Brusoni, S., Principe, A. and Pavitt, K. (2001). "Knowledge Specialization and the Boundaries of the Firm: Why Do Firms Know More Than They Make?" *Administrative Science Quarterly* 46: 597–621.
Buderi, R. (2005). "Microsoft: Getting from 'R' to 'D." *Technology Review* 108 (3, March): 28–30.
Burstall, M. L., Dunning, J. H. and Lake, A. (1981). *Multinational Enterprises, Government and Technology: Pharmaceutical Industry*. Paris: Organization for Economic Cooperation and Development (OECD).
*Business Week*. (2008). "S&P/Business Week Global Innovation Index: The World's 50 Most Innovative Companies." May 1. http://bwnt.businessweek.com/interactive_reports/innovative_companies/ (downloaded on 5/14/2008 at 14.21).
———. (2003). "The Rise of India." December 8, 38–48.
———. (1999). "How Lenovo Lives Up to Its Name." February 5.
———. (1994). "21st Century Capitalism—Part II: Technology & Manufacturing, The New Global Workforce, The Emerging Middle Class, and Where Are We Going?" December 19, 20–68.
Cantwell, J. A. (1998). "The Globalization of Technology: What Remains of the Product-Cycle Model?" In A. Chandler, P. Hagstrom and O. Solvell, eds, *The Dynamic Firm*, 263–288. New York: Oxford University Press.
———. (1995). "The Globalisation of Technology: What Remains of the Product Cycle Model?" *Cambridge Journal of Economics* 19 (1): 155–174.
———. (1992). "The Internationalisation of Technological Activity and Its Implications for Competitiveness." In O. Granstrand, L. Håkanson and S. Sjölander, eds., *Technology Management and International Business: Internationalisation of R&D and Technology*, 75–95. Sussex, UK: John Wiley & Sons Ltd.
——— and Janne, O. (1999). "Technological Globalisation and Innovative Centres: The Role of Corporate Technological Leadership and Locational Hierarchy." *Research Policy* 28 (2–3): 119–144.
Carlson, B. and Stankiewicz, R. (1995). "On the Nature, Function and Composition of Technological Systems." In B. Carlsson, ed., *Technological Systems and Economic Performance: The Case of Factory Automation*, 21–56. Dordrecht: Kluwer.
Cassiolato, J. (2006). "The Brazilian Innovation System and the BRICS Project." Presentation. Rio de Janeiro: Economics Institute of Federal University of Rio de Janeiro.
———, Lastres, H. and Maciel, M., eds. (2003). *Systems of Innovation and Development: Evidences from Brazil*. Cheltenham, UK: Edward Elgar.
Casson, M. and Singh, S. (1993). "Corporate Research and Development Strategies: The Influence of Firm, Industry and Country Factors on the Decentralisation of R&D." *R&D Management* 23 (2): 91–107.

Castro, C. M. (1989). “What Is Happening in Brazilian Education?” In E. L. Bacha and H. S. Klein, eds., *Social Change in Brazil, 1945–1985: The Incomplete Transition*. Albuquerque: University of New Mexico Press.

Caves, R. E. (1982). *Multinational Enterprise and Economic Analysis*. Cambridge: Cambridge University Press.

———. (1971). ”International Corporation: The Industrial Economics of Foreign Investment.” *Economica* 38: 1–27.

Chandler, R. (1977). *The Visible Hand*. Cambridge, Mass.: Belknap Press.

Chen, S-H. (2004). “Taiwanese IT Firms’ Offshore R&D in China and the Connection with the Global Innovation Network.” *Research Policy* 33: 337–349.

Chesnais, F. (1988a). “Multinational Enterprises and the International Diffusion of Technology.” In G. Dosi, C. Freeman, R. Nelson, G. Silverberg and L. Soete, eds., *Technical Change and Economic Theory*, 496–527. London and New York: Printer Publishers.

———. (1988b). “Technical Cooperation Agreements between Firms,” *STI Review* 4: 51–119.

Chi, T. L. and McGuire, D. J. (1996). “Collaborative Ventures and Value of Learning: Integrating the Transaction Cost and Strategic Option Perspectives on the Choice of Market Entry Modes.” *Journal of International Business Studies* 27 (2): 285–307.

Clarke, P. (2006). “U.S. Turns to the Czech Republic for R&D.” *Electronics Supply & Manufacturing*. December 27, 2006. http://www.my-esm.com/showArticle?articleID=196702141 (downloaded on 5/8/2008).

Consoni, F. and Quadros, R. (2006). ‘From Adaptation to Complete Vehicle Design: A Case Study of Product Development Capabilities in a Carmaker in Brazil.” *Int. J. Technology Management* 36 (1/2/3): 91–107.

———. (2003). “Between Centralisation and Decentralisation of Product Development in Multinational Corporations: Recent Trajectories in Brazilian Subsidiaries of Car Assemblers.” In *XXVII EnANPAD*. Anais Eletrônicos. Atibaia: ANPAD.

Costa, I. (2005). “Notes on R&D and TNCs Affiliates in Brazil.” Paper presented at the Expert Group Meeting on the World Investment Report (WIR 2005), Geneva, UNCTAD, January 24–26.

——— and Queiroz, S. R .R. (2002) “Foreign Direct Investment and Technological Capabilities in Brazilian Industry.” *Research Policy* 31: 1431–1443.

Council on Higher Education. (2004). *South African Higher Education in the First Decade of Democracy*. Pretoria: Council on Higher Education, the Republic of South Africa.

Craemer, D. (1976). “Overseas Research and Development by United States Multinationals, 1966–1975: Estimates of Expenditures and a Statistical Profile.” New York: The Conference Board.

*Deccan Chronicle*. (2002). June 28.

Dehoff, K. and Sehgal, V. (2007). “Innovators without Borders: Features: Special Report.” *strategy+business* 44: 1–8. Booz Allen Hamilton Inc.

De Meyer, A. and Mizushima, A. (1989). “Global R&D Management.” *R&D Management* 19 (2): 135–146.

Dias, A. V. C. and Galina, S. V. R (2004). “Profit Strategies, Productive Models and the Global Organisation of Innovation Activities: A Comparison between the Automotive and the Telecommunication Industries in Brazil.” *Actes du GERPISA* 2004. Paris: 2nd GERPISA International Colloquium.

Dikshit, S. (2008). “India One of Our Prime Partners: Airbus.” *The Hindu*. May 29. http://www.thehindu.com/2008/05/29/stories/2008052961441200.htm (downloaded on 6/3/2008 at 17.45).

Doz, Y., Wilson, K., Veldhoen, S., Goldbrunner, T. and Altman, G. (2006). *Innovation: Is Global Way Forward? Survey Results*. A Joint Study by Booz Allen Hamilton and ISEAD.

Doz, Y. (1987). "International Industries: Fragmentation versus Globalization." In B. R. Guile and M. Brooks, eds., *Technology and Global Industry,* 96–118. Washington, D.C.: National Academy Press.

Drews, J. (2000). "Drug Discovery: A Historical Perspective." *Science* 287: 1960–1964.

DST. (2004). *Fruits of Freedom: South Africa's Achievements in Science and Technology during the First Decade of Democracy*. Pretoria: Department of Science and Technology (DST), the Republic of South Africa. ISBN: 1–920030–06–9.

———. (1994) *Research and Development Statistics, 1992–93*. New Delhi: Department of Science and Technology, Government of India.

Dunning, J. H. (1992). "Multinational Enterprises and the Globalisation of Innovatory Capacity." In O. Granstrand, L. Håkanson and S. Sjölander, eds., *Technology Management and International Business : Internationalisation of R&D and Technology,* 19–51. Sussex, UK: John Wiley & Sons Ltd.

———. (1977). "Trade, Location of Economic Activity and the Multinational Enterprise: A Search for an Eclectic Approach." In B. Ohlin, P.O. Hesselborn and P.M. Wijkman, eds., *The International Allocation of Economic Activity,* 395–418. London: Macmillan.

———. (1958). *American Investment in British Manufacturing Industry*. London: Allen and Unwin.

Dörrenbächer, C. and Wortmann, M. (1991). "The Internationalisation of Corporate Research and Development.c *Intereconomics* (May, June): 139–144.

Edquist, C. (2005). "Systems of Innovation: Perspectives and challenges." In *The Oxford Handbook of Innovation,* 181–208. Oxford: Oxford University Press.

———. (1997). "Systems of Innovation Approaches, Their Emergence and Characteristics." In C. Edquist, ed., *Systems of Innovation: Technologies, Institutions and Organizations,* 1–35. London: Pinter.

EIU. (2004). *Scattering the Seeds of Innovation: the Globalization of Research and Development*. London: The Economist Intelligence Unit (EIU).

Ernst, D. (2006). "Innovation Offshoring: Asia's Emerging Role in Global Innovation Networks." East-West Center Special Reports, No. 10, July.

———. (2005a) "Complexity and Internationalisation of Innovation: Why Is Chip Design Moving to Asia?" *International Journal of Innovation Management* 9 (1): 47–73.

———. (2005b). "Complexity and Internationalisation of Innovation: Why Is Chip Design Moving to Asia?" Presentation made at the Expert Group Meeting on the World Investment Report (WIR 2005), Geneva, UNCTAD, January 24–26.

——— and O'Connor, D. (1989). *Technology and Global Competition—The Challenge for Newly Industrialising Economies*. Development Centre Studies. Paris: Organization for Economic Cooperation and Development (OECD).

Ernst & Young. (2005). *Beyond Borders: Global Biotechnology Report*. A Report by the Ernst & Young Inc.

———. (2004). *Global Pharma Report*. A Report by the Ernst & Young Inc.

Etzkowitz, H.,, de Mello, J. M. C. and Almeida, M. (2005). "Towards 'Meta-innovation' in Brazil: The Evolution of the Incubator and the Emergence of a Triple Helix." *Research Policy* 34: 411–424.

Fagerberg, J. (1994). "Technology and International Differences in Growth Rates." *Journal of Economic Literature* 32 (3): 1147–1175.

Farrell, D., Laboissiere, M. A. and Rosenfeld, J. (2005). "Sizing the Emerging Global Labor Market." *The McKinsey Quarterly* No. 3.

*Financial Times*. (2005). June 9. As cited in UNCTAD 2005, 176.

Forbes, N. (2003). "Higher Education, Scientific Research and Industry: Reflections on Priorities for India." Working Paper No. 188. Stanford Center for International Development. Stanford: Stanford University, October.

Forsgren, M. (1999). "Some Critical Notes on Learning in the Uppsala Internationalization Process Model." Working Paper No. 99/23. Stockholm: Stockholm School of Economics, Institute for International Business.

Forster, C. J. (2006). *China's Secret Weapon? Science Policy and Global Power.* London: The Foreign Policy Centre, April.

Freeman, C. (1995). "The National System of Innovation in Historical Perspective.." *Cambridge Journal of Economics* 19 (5): 5–24.

———. (1987). *Technology Policy and Economic Performance: Lessons from Japan*. London: Frances Pinter.

——— and Perez, C. (1988). "Structural Crises of Adjustment: Business Cycles and Investment Behaviour." In G. Dosi, C. Freeman, R. Nelson, G. Silverberg and L. Soete, eds., *Technical Change and Economic Theory,* 38–66. London: Pinter Publishers.

Frew, S. E., Rezaie, R., Sammut, S. M., Ray, M., Daar, A. S. and Singer, P. A. (2007). "India's Health Biotech Sector at a Crossroads." *Nature Biotechnology* 25 (4): 403–417.

Friedman, T. L. (2006). *The World Is Flat: The Globalized World in the Twenty-first Century.* London: Penguin Books Ltd.

Frobel, F., Heinrichs, J. and Kreye, O. (1980). *The New International Division of Labour: Structural Unemployment in Industrialized Countries and Industrialization in Developing Countries.* Cambridge: Cambridge University Press.

Frost and Sullivan. (2004). *Outsourcing Technology in Asia: Analysis of the Changing Face of R&D*. San Antonio: Frost and Sullivan Company.

Frost, T. S., Birkinshaw, J. and Ensign, P. (2002). "Centers of Excellence in Multinational Corporations." *Strategic Management Journal* 23: 997–1018.

Furman, J. L. and Hayes, R. (2004). "Catching Up or Standing Still? National Innovative Productivity among 'Follower' Countries, 1978–1999." *Research Policy* 33: 1329–1354.

Furtado, J., Zanatta, M., Costa, I., Strachman, E. and Queiroz, S. (2003). "FDI and Technology Policies in Brazil." Paper presented at the Conference of the European Association of Evolutionary Political Economy (EAEPE), Maastricht, November 7–10.

Fusfeld, H. I. (1995). "New Global Sources of Industrial Research." *Technology in Society* 17 (3): 263–277.

———. 1994). *Industry's Future—Changing Patterns of Industrial Research.* Washington, D.C.: American Chemical Society.

Galina, S. V. R. and Bortoloti, L. (2004). "Subsidiaries Involvement in Technological Development of Telecommunication Industry: Results from S&T Indicators." *REAd*—Special Issue 42, 10 (6, December).

Galina, S. V. R. and Plonski, G. A. (2002). "Global Product Development in the Telecommunication Industry: An Analysis of the Brazilian Subsidiaries Involvement." Proceedings of the Ninth International Product Development Management Conference, European Institute for Advanced Studies in Management (EIASM), Sophia-Antipolis. France, May.

Gassman, O. and Han, Z. (2004). "Motivations and Barriers of Foreign R&D Activities in China." *R&D Management* 34 (4): 423–437.

Giddy, I. H. (1978). "The Demise of the Product Cycle Model in International Business Theory." *Columbia Journal of World Business* 13 (1): 90–97.

Giridharadas, A. (2007). "In India, Outsourcing Moves to the Top Floor." *International Herald Tribune*, Tuesday, April 3.

Gold, A. R., Leibowitz, G. and Perkins, A. (2001). "A Computer Lenovo in the Making." *McKinsey Quarterly* 3: 73–83.

Goldbrunner, T., Doz, Y., Wilson, K. and Veldhoen, S. (2006). *The Well-Designed Global R&D Network*. Resilience Report. *Strategy+business*. Booz Allen Hamilton Inc.

Goldman Sachs. (2007). *India's Rising Growth Potential*. Goldman Sachs Inc. January.

Gomroy, R. and Baumol, W. (2000). *Global Trade and Conflicting National Interests*. Cambridge, Mass.: MIT Press.

Granstrand, O., Håkanson, L. and Sjölander, S. (1993). "Internationalisation of R&D—A Survey of Some Recent Research." *Research Policy* 22: 413–430.

———. (1992). "Introduction and Overview." In O. Granstrand, L. Håkanson and S. Sjölander, eds., *Technology Management and International Business: Internationalisation of R&D and Technology,* 1–18. Sussex, UK: John Wiley & Sons.

Gupta, A. and Dutta, P. K. (2005). "Indian Innovation System: Perspective and Challenges." *Technology Exports*, 7 (4, April–June): 1–7.

Hagedoorn, J. and Schakenraad, J. (1989). "Strategic Partnering and Technological Cooperation." In B Dankbar, B. Groenewegen and H. Schenk, eds., *Perspectives in Industrial Economics,* 3–37. Dordrecht: Kulwer.

Hamel, G. (1991). "Competition for Competence and Inter-partner Learning within International Strategic Alliances." *Strategic Management Journal* 12: 83–103.

Hariharan, R. (2005). "Managing Nokia R&D in China." Presentation at the Conference on Global R&D in China, Nanjing, PRC, May 27–30.

Ho, J. (2005). "Lucent Bell Labs in China—An Account of Personal Experience.". Presentation at the Conference on Global R&D in China, Nanjing, PRC, May 27–30.

Hood, N. and Young, S. (1982). "US Multinational R&D: Corporate Strategies and Policy Implications for the UK." *Multinational Business* 2: 10–23.

Horst, H. T. (1978). *A Home Abroad: A Study of Domestic and Foreign Operation of the American Food Processing Industry.* Cambridge, Mass.: Ballinger Publishing Co.

Howells, J. and Neary, I. (1995). *Intervention and Technological Innovation: Government and the Pharmaceutical Industry in the UK*. Basingstoke, UK: Macmillan.

Howells, J. R. (1990). "The Internationalisation of R&D and the Development of Global Research Networks." *Regional Studies* 24 (6): 495–512.

Hu, M-C. and Mathews, J. A. (2008). "China's National Innovative Capacity." *Research Policy* 37 (5): 1465–1479.

Hymer, S. (1976). *International Operations of National Firms: A Study of Direct Foreign Investment*. Cambridge: MIT Press.

Håkanson, L. (1992). "Locational Determinants of Foreign R&D in Swedish Multinationals." In O. Granstrand, L. Håkanson and S. Sjölander, eds., *Technology Management and International Business: Internationalisation of R&D and Technology,* 97–115. Sussex, UK: John Wiley & Sons Ltd.

———. (1990). "International Decentralisation of R&D—The Organisational Challenges." In C. A. Bartlett, Y. Doz and G. Hedlund, eds., *Managing the Global Firm,* 257–277. London and New York: Routledge.

IBM. (2006). "IBM Annual Study: Jobs Created by Foreign Investment Grow More Than 20 Percent Worldwide." Armonk, New York: IBM's PLI-Global Location Strategies. IBM Press Room, September 18, 2007. http://www-03.ibm.com/press/us/en/pressrelease/22322.wss (downloaded on 5/8/2008 at 15.14).

IDB. (2006). "Enhancing Technological Innovation in Brazil." *IDB News*. Web Story, Inter-American Development Bank, July 21. http://www.iadb.org (downloaded on 6/25/2008 at 16.58).

Intel China Research Center. (2005). "Intel R&D in PRC: Strategic Implications for the Future." Presentation at the Conference on Global R&D in China, Nanjing, PRC, May 27–30.

Intel News Release. (2006). "Intel Establishes $50 Million Venture Capital Fund for Brazil." March 28. http://www.intel.com/pressroom/archive/releases/20060328corp.htm (downloaded on 6/25/2008 at 17.23).

ITRS. (2004). *International Technology Roadmap for Semiconductors, 2003 Edition*. Austin: Semiconductor Industry Association.

———. (2002). *International Technology Roadmap for Semiconductors, 2001 Edition*. Austin: Semiconductor Industry Association.

Kahn, M. (2006). "The South African National System of Innovation: From Constructed Crisis to Constructed Advantage?" *Science and Public Policy* 33 (2): 121–130.

Katrak, H. (2002). "Does Economic Liberalization Endanger Indigenous Technological Developments? An Analysis of the Indian Experience." *Research Policy* 31: 19–30.

Kindleberger, C. P. (1969). *American Business Abroad: Six Lectures on Direct Investment*. New Haven: Yale University Press.

King, D. A. (2004). "The Scientific Impact of Nations: What Different Countries Get for Their Research Spending." *Nature* 430 (July 15): 311–316.

Kogut, B. (1988). "Joint Ventures: Theoretical and Empirical Perspectives." *Strategic Management Journal* 9: 312–332.

Kondratieff, N. D. (1935). "The Long Waves in Economic Life." *Review of Economic Statistics* 17 (6): 105–115.

Kraemer, K. L. and Derick, J. (2001). "Creating a Computer Industry Giant: China's Industrial Policies and Outcomes in the 1990s." Working Paper. Irvine: Center for Research on Information Technology and Organization, University of California.

Krishna, V. V. (2001). "Reflections on the Changing Status of Academic Science in India." *International Social Science Journal* 168 (June): 231–246.

Kruss, G. (2008). "Balancing Old and New Organisational Forms: Changing Dynamics of Government, Industry and University Interaction in South Africa." *Technology Analysis & Strategic Management* 20 (6): 667–682.

Kuemmerle, W. (1997). "Building Effective R&D Capabilities Abroad." *Harvard Business Review* (March, April): 61–69.

Kumar, K. and McLeod, M.G., eds. (1981). *Multinationals from Developing Countries*. Lexington, Mass.: Lexington Books.

Kumar, N., and Aggarwal, A. (2005). "Liberalization, Outward Orientation and In-house R&D Activity of Multinational and Local Firms: A Quantitative Exploration for Indian Manufacturing," *Research Policy* 34: 441–460.

Kumar, N. and Joseph, K. J. (2004). "National Innovation Systems and India's IT Capability: Are There Any Lessons for ASEAN Newcomers?" RIS Discussion Paper RIS-DP No. 72/2004. New Delhi: Research and Information System for the Non-Aligned and Other Developing Countries (RIS).

Lall, S. (2000). "The Technological Structure and Performance of Developing Countries Manufactured Exports, 1985–1998." *Oxford Development Studies* 28 (3): 337–369.

———. (1983). *The New Multinationals: The Spread of Third World Enterprises*. Chichester, UK: Wiley.

———. (1979). "The International Allocation of Research Activity by US Multinationals." *Oxford Bulletin of Economics and Statistics* 41 (4): 313–331.

Landau, R. and Rosenberg, N. (1992). "Successful Commercialization in Chemical Process Industries." In N. Rosenberg, R. Landau and D. Mowery, eds., *Technology and the Wealth of Nations,* 73–120. Stanford: Stanford University Press.

Langlois, R. N. (2003). "The Vanishing Hand: The Changing Dynamics of Industrial Capitalism." *Industrial and Corporate Change* 12 (2): 351–385.

Leadbeater, C. and Wilsdon, J. (2007). *The Atlas of Ideas: How Asian Innovation Can Benefit Us All*. London: Demos.

Levitt. T (1983). "The Globalization of Markets." *Harvard Business Review* (May, June): 92–102.

Liebenau, J. (1984). "International R&D in Pharmaceutical Firms in the early Twentieth Century." *Business History* 26: 329–346.

Long, F. A. (1988). "Science, Technology and Industrial Development in India," *Technology In Society* 10: 395–416.

Long, G. (2005). "China's Policies on FDI: Review and Evaluation." In T. H. Moran, E. M. Graham and M. Bloomström, eds., *Does Foreign Direct Investment Promote Development?* 315–336. Washington, D.C.: Institute for International Economics.

Lorentzen, J. (2005). "The Absorptive Capacities of South African Automotive Component Suppliers." *World Development* 33 (7): 1153–1182.

Loural, C.A., Filho, R.A.Z., Bordeaux Rego, A.C.G. and de Oliveira, R.C. (2006). "Technological Development of Brazilian Telecommunications in the Past Decades." *Telematics and Informatics* 23: 294–315.

Lundvall, B-Å. (1992). "Introduction." In B-Å. Luvall, ed., *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning,* 1–20. London: Pinter.

———. (1988). "Innovation as an Interactive Process: From User-Producer Interaction to National Systems of Innovation." In G. Dosi, C. Freeman, R. Nelson, G. Silverberg and L. Soete, eds., *Technological Change and Economic Theory.* London: Pinter.

Maharajh, R. and Pogue, T. E. (2008). "South African Science, Technology and Innovation Scoreboard 2008." Pretoria, South Africa: COFISA and Institute for Economic Research on Innovation (IERI), November 14.

Mansfield, E. (1974). "Technology and Technical Changes." In J.H. Dunning, ed., *Economic Analysis and the Multinational Enterprise*, 147–183. London: George Allen and Unwin.

———, Teece, D. and Romeo, A. (1979). "Overseas Research and Development by US-Based Firms." *Economica* 46: 187–196.

Marais, H. C. (2000). *Perspectives on Science Policy in South Africa*. Pretoria, South Africa: Network Publishers.

Mashelkar, R. A. (2006). "Beyond Bangalore? The Changing Landscape of Indian Science and Innovation." Presentation, June 27. http://www.csir.res.in/External/Heads/aboutcsir/leaders/DG/Presentations/BeyondBangalore.pdf (downloaded on 5/8/2009 at 23.15).

Mathews, J. A. (2006). "Dragon Multinationals: New Players in 21st Century Globalization." *Asia Pacific Journal of Management* 23: 5–27.

———. 2003). "Competitive Dynamics and Economic Learning: An Extended Resource-Based View." *Industrial and Corporate Change* 12 (1): 115–145.

McKinsey Global Institute. (2005) *The Emerging Global Labor Market, Part II: The Supply of Offshore Talent in Services*. San Francisco: McKinsey & Company.

MCT. (2000). *Resultados da Lei 8248/91,* as cited in Galina and Bortoloti 2004.

Melin, L. (1992). "Internationalization as a Strategy Process." *Strategic Management Journal* 13 (2): 99–118.

Meyer-Stamer, J. (1995). "New Departures for Technology Policy in Brazil." *Science and Public Policy* 22 (5): 295–304.

Mitchell, G. (1990). "Research and Development for Services." *Research Technology Management* (November, December): 37–44.

MoC. (2005). *Report of the Foreign Trade Situation of China*. Beijing: Ministry of Commerce, People's Republic of China.

Morel, C.M., et al. (2007). "The Road to Recovery." *Nature* 449 (September 13): 180–182.

Morris, F. (2005). "Foreign Direct Investment, R&D, and Innovation: Concepts and Data." Background paper prepared for UNCTAD. Mimeo. Arlington, Va.: U.S. National Science Foundation, as cited in UNCTAD 2005.

Mowery, D.C. (1992). "International Collaborative Ventures and US Firms' Technology Strategies." In O. Granstrand, L. Håkanson and S. Sjölander, eds., *Technology Management and International Business: Internationalisation of R&D and Technology,* 209–249. Sussex, UK: John Wiley & Sons Ltd.

———. (1983). "The Relationship between Contractual and Intra-firm Forms of Industrial Research in American Manufacturing, 1900–1940." *Explorations in Economic History:* 351–374.

———, Oxley, J. E. and Silverman, B. S. (1998). "Technological Overlap and Interfirm Cooperation: Implications for the Resource-based View of the Firm." *Research Policy* 27: 507–523.

Mustar and Laredo. (2002), as cited in Etzkowitz et al. 2005.

Mytelka, L. K. (2000). "Local Systems of Innovation in a Globalized World Economy." *Industry and Innovation* 7 (1): 15–32.

———. 1993). "Rethinking Development: A Role for Innovation in the Other 'Two Thirds." *Futures* 25 (6): 694–712.

———. 1990). "New Modes of International Competition: The Case of Strategic Partnering in R&D." *Science and Public Policy* 17 (5): 296–302.

NACI. (2006a). "The South African National System of Innovation: Structures, Policies and Performance." Background Report to the OECD Country Review of South Africa's National System of Innovation. Pretoria: National Advisory Council on Innovation (NACI), July 21.

———. (2006b) *Innovation for a Better Future.* NACI Annual Report 2005/2006. Pretoria: National Advisory Council on Innovation (NACI).

Narula, R. (2003). *Globalization & Technology: Interdependence, Innovations Systems and Industrial Policy.* Cambridge, UK: Polity Press.

———. 2002). "Innovation Systems and 'Inertia' in R&D Location: Norwegian Firms and the Role of Systemic Lock-in." *Research Policy* 31: 795–816.

Nassif, A. (2007). "National Innovation System and Macroeconomic Policies: Brazil and India in Comparative Perspective." Discussion Paper No. 184, United Nations Conference on Trade and Development (UNCTAD). Geneva: United Nations, May, UNCTAD/OSG/DP/2007/3.

NASSCOM. (2006). National Association of Software and Services Companies. (www.nasscom.in) (downloaded 3/122007).

Nelson, R.R. (1993). "A Retrospective." In R. R. Nelson, ed., *National Innovation Systems: A Comparative Analysis*, 505–524. New York and Oxford: Oxford University Press.

———. 1988). "Institutions Supporting Technical Change in the United States." In G. Dosi, C., Freeman, R. Nelson, G. Silverberg and L. Soete, eds., *Technological Change and Economic Theory.* London: Pinter.

———, and Rosenberg, N. (1993). "Technical Innovation and National Systems." In R. R. Nelson, ed., *National Innovation Systems: A Comparative Analysis,* 3–22. New York and Oxford: Oxford University Press.

Niosi, J. (1999). "Introduction—The Internationalization of Industrial R&D: From Technology Transfer to the Learning Organization." *Research Policy* 28 (2, 3): 107–117.

Nobel, R. and Birkinshaw, J. (1998). "Innovation in Multinational Corporations: Control and Communication Patterns in International R&D Operations." *Strategic Management Journal* 19 (5): 479–496.

NRCSTD. (2003). *Report on China's S&T Development Research.* Beijing: National Research Center for Science and Technology Development.

NSB. (2008). *Science and Engineering Indicators: 2008.* National Science Board, NSB. Arlington, Va.: National Science Foundation.

NSF. (2007). *Asia's Rising Science and Technology Strength: Comparative Indicators for Asia, the European Union, and the United States*. Arlington, Va.: National Science Foundation, Division of Science Resources Statistics, May 2007, NSF 07–319.

*NyTeknik*. (2007). "Svenska proteinforskare måste få hjälp i Indien." Onsdag, mai 9 (in Swedish).

Odagiri, H. and Yasuda, H. (1996). "The Determinants of Overseas R&D by Japanese Firms: An Empirical Study at the Industry and Company Levels." *Research Policy* 25: 1059–1079.

OECD. (2006). *Evolution of Student Interest in Science and Technology Studies—Policy Report*. Paris: Global Science Forum, Organization for Economic Cooperation and Development.

———. (1992). *Technology and the Economy—The Key Relationships*. Paris: Organization for Economic Cooperation and Development.

———. (1988). *Science and Technology Policy Outlook, 1988*. Paris: Organization for Economic Cooperation and Development (OECD).

Patel, P. and Vega. M. (1999). "Patterns of Internationalisation of Corporate Technology: Location versus Home Country Advantages." *Research Policy* 28 (2, 3): 145–155.

PBQP. (1992). "Pesquisa qualidade e produtividade no meio empresarial." Brasilia, as cited in Meyer-Stamer 1995.

Pearce, R. D. (1999). "Decentralised R&D and Strategic Competitiveness: Globalised Approaches to Generation and Use of Technology in Multinational Enterprises (MNEs)." *Research Policy* 28 (2, 3): 151–178.

———. (1989). *The Internationalisation of Research and Development by Multinational Enterprises*. London: Macmillan.

Penner,-Hahn, J. and Shaver, J. M. (2005). "Does International Research and Development Increase Patent Output? An Analysis of Japanese Pharmaceutical Firms." *Strategic Management Journal* 26 (2): 121–140.

Penrose, E. (1995). *The Theory of the Growth of the Firm*. Oxford: Oxford University Press; first published in 1959.

Pereira, R. S. (1998). As cited in Etzkowitz et al., 2005.

Perez, C., and Soete, L. (1988). "Catching Up in Technology: Entry Barriers and Windows of Opportunity." In G. Dosi, C. Freeman, R. Nelson, G. Silverberg and L. Soete, eds., *Technical Change and Economic Theory,* 458–479. London and New York: Printer Publishers.

Petrella, R. (1992). "Internationalisation, Multinationalisation and Globalisation of R&D: Toward a New Division of Labour in Science and Technology?" *Knowledge and Policy* 5 (3): 3–25.

Polastro, B. S. and Tulcinsky, S. (2004). "India and China for Fine Chemicals." *Scrip Magazine* (October): 39–41.

Porter, M. E. (1990). "The Competitive Advantage of Nations." *Harvard Business Review* (March, April): 73–93.

———. (1986). "Introduction and Summary" and "Competition in Global Industries: A Conceptual Framework." In M. E. Porter, ed., *Competition in Global Industries,* 1–11, 15–60. Boston: Harvard Business School Press.

———. (1980). *Competitive Strategy—Techniques for Analyzing Industries and Competitors*. New York and London: The Free Press.

Poynter, T. A. and Rugman, A. M. (1982). "World Product Mandates: How Will Multinationals Respond?: *Business Quarterly* 47 (3): 54–61.

Queiroz, S., Zanatta, M. and Andrade, C. (2003). "Internationalization of MNCs' Technological Activities: What Role for Brazilian Subsidiaries?" Paper presented at SPRU Conference in honor of Keith Pavitt, Brighton, November 13–15.

Radyuhin, V. (2008). “IT Opportunities & Challenges in Russia.” *The Hindu*, January 19, 2008, p. OP-ED 11.

Reddy, A. S. P. (1993). “Emerging Patterns of Internationalisation of Corporate R&D: Opportunities for Developing Countries?” In C. Brundenius and B. Göransson, eds., *New Technologies and Global Restructuring—The Third World at a Crossroads*. London: Taylor Graham.

———, and Sigurdson, J. (1994). “Emerging Patterns of Globalisation of Corporate R&D and Scope for Innovation Capability Building in Developing Countries?’ *Science and Public Policy* 21 (5): 283–294.

Reddy, P. (2007). *Globalisation of the Biomedical Industry and the Biomedical Innovation System of India*. Stockholm: Center for Business and Policy Studies (Studieförbundet Näringsliv och Samhälle—SNS).

———. (2000). *Globalization of Corporate R&D: Implications for Innovation Systems in Host Countries*. London and New York: Routledge.

———. (1997). “New Trends in Globalization of Corporate R&D and Implications for Innovation Capability in Host Countries: A Survey from India.” *World Development* 25 (11): 1821–1837.

Ronstadt, R. (1977). *Research and Development Abroad by US Multinationals*. New York: Praeger Publishers.

Safarian, A. E. (1966). *Foreign Ownership of Canadian Industry*. Toronto: McGraw Hill of Canada.

Samuelson, P. A. (2004). “Where Ricardo and Smith Rebut and Confirm the Arguments of Mainstream Economists Supporting Globalisation.” *Journal of Economic Perspectives* 18 (3): 135–146.

Schoenberger, E. (1988). “Multinational Corporations and the New International Division of Labour: A Critical Appraisal.” *Inst. Reg. Sci. Rev.* 11: 105–119.

Schumpeter, J. A. (1939). *Business Cycles: A Theoretical, Historical, and Statistical Analysis of the Capitalist Process*. New York and London: McGraw-Hill.

Schwaag-Serger, S. (2006). “China: From Shop Floor to Knowledge Factory?” In M. Karlsson, ed., *The Internationalization of Corporate R&D: Leveraging the Changing Geography of Innovation*. Stockholm: ,The Swedish Institute for Growth Policy Studies (PS).

*Science*. (1996). “India—Industrial R&D Gets Boost Despite Lack of Patent Reform..” 271 (January 26): 442–443.

———. (1995a). “Science in China: A Great Leap Forward.” 270 (November 17): 1131–1154.

———. (1995b). “Joint Research—India Cracks Whip to End Addiction to State Funds.” 267 (March 10): 1419–1420.

———. (1993). “Science in Asia.” 262 (October 15): 345–381.

Sigurdson, J. (2005). *Technological Superpower China*. Cheltenham, UK and Northampton, Mass: Edward Elgar.

———. (1990). “The Internationalisation of R&D—An Interpretation of Forces and Responses.” In J. Sigurdson, ed., *Measuring The Dynamics of Technological Change*. London and New York: Printer Publishers.

Simon, D .F. (2005). “Hearing on China’s High Technology Development.” The US-China Economic and Security Review Commission, April, as cited in Forster 2006, p. 17.

Simpson, L. (2004). *Engineering Aspects of Offshore Outsourcing And Public Policy Investigation*. Washington D.C.: Washington Internships for Students of Engineering (WISE), August 6. http://www.wise-intern.org/journal/2004/WISE2004-LoriSimpsonFinalPaper.pdf (downloaded 3/12/2007).

Singh, A. (1995). “IITs Yesterday and Tomorrow.” *Economic and Political Weekly* 30 (38, September 23): 2389–2394.

Singh, J. (2008). "Distributed R&D, Cross-regional Knowledge Integration and Quality of Innovative Output." *Research Policy* 37: 77–96.

———. (2007). "Asymmetry of Knowledge Spillovers between MNCs and Host Country Firms." *Journal of International Business Studies* 38: 764–786.

Singh, N. (2003). "India's Information Technology Sector: What Contributes to Broader Economic Development?" Technical Paper No. 207, Development Center. Paris: OECD.

Srinivasan, T. N. (2001). "Integrating India with the World Economy: Progress, Problems and Prospects." Mimeo, Economic Growth Center, Yale University, as cited in Nassif 2007.

Stubenitsky, F. (1970). *American Direct Investment in the Netherlands Industry.* Rotterdam: Rotterdam University Press.

Sturgeon, T. (2002). "Modular Production Networks: A New American Model of Industrial Organization." *Industrial and Corporate Change* 11 (3): 451–496.

Suarez-Villa, L. (1990). "Invention, Inventive Learning, and Innovative Capacity." *Behavioral Science* 35 (4): 290–310.

Sun, Y. (2003). "Strategic or Tactical? Foreign Research and Development in Developing Countries, A Case Study of China." *Asian Geographer* 22 (1, 2): 143–167.

———, Du, D. and Huang, L. (2006). "Foreign R&D in Developing Countries: Empirical Evidence from Shanghai, China." *The China Review* 6 (1): 67–91.

TCIL. (2007). "Pan-African e-Network: Heralding New Era in Providing Tele-education & Tele-medicine Services to African Countries." http://www.tcil-india.com (downloaded 5/28/2008).

Teece, D. J. (1992). "Competition, Cooperation, and Innovation: Organizational Arrangements for Regimes of Rapid Technological Progress." *Journal of Economic Behaviour and Organization* 18: 1–25.

———. (1982). "Towards an Economic Theory of the Multiproduct Firm," *Journal of Economic Behaviour and Organization* 3: 39–63.

Terpstra, V. (1977). "International Product Policy: The Role of Foreign R&D." *Columbia Journal of World Business* 12: 24–32.

*The Economist*. (2008). "The Challengers." January 10. http://www.economist.com/displaystory.cfm?story_id=10496684 (downloaded 5/28/2008).

———. (1998). "The Alchemists: Survey of the Pharmaceutical Industry." February 21, 1–18.

*The Hindu*. (2006). "Dr. Reddy's Completes Acquisition of Betapharm." March 7.

———. (2005). "IISc Identifies Nine Projects with Boeing: Over 30 Faculty Members Involved." September 16, p. 13.

———. (2003). "Indian Engineers Develop Single-chip Digital TV." April 27. http://www.thehindu.com/2003/04/27/stories/2003042701471000.htm (downloaded on 6/25/2008 at 15.32).

*The Hindu Business Line*. (2005). "Texas Instruments Unveils Single-chip Mobile Solution." http://www.thehindubusinessline.com/2005/08/09/stories/2005080902580400.htm (downloaded on 6/25/2008 at 15.31).

The Innovation Hub (2009) Annual Report 2009.

The US Tariff Commission. (1973). *Implications of Multinational Firms for World Trade and Investment and for US Trade and Labor.* Washington, D.C.: Government Printing Office.

*The Wall Street Journal*. (1997). "China's Personal-Computer Industry Is Starting to Beat Out U.S. Companies." November 19.

TIFAC. (2006). *FDI in the R&D Sector.* New Delhi: The Technology Information, Forecasting & Assessment Council, Government of India.

UNCTAD. (2005). *World Investment Report, 2005: Transnational Corporations and the Internationalization of R&D*. United Nations Conference on Trade and Development. New York and Geneva: United Nations.

UNESCO. (2007). Institute for Statistics. Paris: United Nations Education, Social and Cultural Organisation, as cited in NSB 2008.

Vernon, R. (1979). "The Product Cycle Hypothesis in a New International Environment." *Oxford Bulletin of Economics and Statistics* 41 (4): 255–67.

———. (1974). "The Location of Industry." In J. H. Dunning, ed., *Economic Analysis and the Multinational Enterprise*, 89–114. London: Allen and Unwin.

———. (1966). "International Investment and International Trade in the Product Cycle." *Quarterly Journal of Economics* 88: 190–207.

Viotti, E. B. (2002). *Technol. Forecast. Soc.* 63: 653–680, as cited in Morel et al. 2007.

von Zedtwitz, M. (2004). "Managing Foreign R&D Laboratories in China." *R&D Management* 34 (4): 439–452.

Walsh, K. (2005). "Foreign R&D in China: Drivers, Dynamics, and New Directions." Presentation at the Conference on Global R&D in China, Nanjing, PRC, May 27–30.

———. (2003) *Foreign High-Tech R&D in China*. Washington, D.C.: The Henry L. Stimson Center.

Wang, H. (2005). "France Telecom's R&D in China." Presentation at the Conference on Global R&D in China, Nanjing, PRC, May 27–30.

Wei, X. and White, S. (2004). "Sequential Learning in a Chinese Spin-off: The Case of Lenovo Group." *R&D Management* 34 (4): 407–422.

Wells, L. T. (1983). *Third World Multinationals: The Rise of Foreign Investment from Developing Countries*. Cambridge: MIT Press.

Wen, Ke (2005). "Barriers for Foreign R&D in China." Presentation at the Conference on Global R&D in China, Nanjing, PRC, May 27–30.

Westney, D. E. (1988). "International and External Linkages in the MNC: The Case of R&D Subsidiaries in Japan." Working Paper Y No. 1973–88. Cambridge, Mass.: Sloan School of Management, MIT.

Wilson, D. and Purushothaman, R. (2003). *Dreaming with BRICs: The Path to 2050*. Global Economics Paper No. 99. October 1. Goldman Sachs Group Inc.

Wong, P. K. and Mathews, JA. (2004). "Editorial: Competitive Strategies of Asian High Tech Firms: The Challenge of Late-industrialisation." *International Journal of Technology Management* 29 (1/2): 1–5.

World Bank. (2008). *Unleashing India's Innovation,* ed. M. A. Dutz. Washington, D.C.: World Bank Group.

Wortmann, M. (1990). "Multinationals and the Internationalisation of R&D: New Developments in German Companies." *Research Policy* 19: 175–183.

Xielin, L. and White, S. (2001). "China's National Innovation System in Transition: An Activity-Based Analysis." National Science Foundation, Tokyo Regional Office, January.

Yeung, H. W. C., ed. (2000). *The Globalization of Business Firms from Emerging Economies*. Cheltenham, UK: Edward Elgar.

Yoshida, P. G. (2008). "India Emerging (Maybe) as Major R&D Center." *Research Technology Management* (March/April): 2–4.

Yuan, Z. (1995). "Reform and Restructuring of China's Science and Technology System." In D. F. Simon, ed., *The Emerging Technological Trajectory of the Pacific Rim,* 213–238. New York: M. E. Sharpe Inc.

Zander, I. (1999). "Whereto the Multinational? The Evolution of Technological Capabilities in the Multinational Network." *International Business Review* 8: 261–291.

Zanfei, A. (2000). "Transnational Firms and the Changing Organisation of Innovative Activities." *Cambridge Journal of Economics* 24: 515–542.

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