The main challenge facing the country will be to improve both the quality and quantity of S&T personnel. Fortunately, policy-makers are seized of this problem and have taken energetic steps to remedy the situation.

Sunil Mani

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INTRODUCTION

The impressive performance of India's economy since liberalization of the economy got under way in 1991 – and especially since 2005 – has been much talked about. Along with China, India has become one of the fastest-growing economies in the world, strong enough to withstand the brunt of the global recession since 2008. If growth in GDP dipped from 9.4% in 2007 to 5.7% in 2009, it was expected to climb back to 8.8% in 2010 (IMF, 2010). A number of studies have identified technological development as one of the drivers of India's strong economic growth. The country's science system has undergone perceptible changes over the past five years or so:

- Although India's R&D intensity increased only slightly between 2003 and 2007, from 0.80% to 0.88% of GDP, the share of the business enterprise sector in gross domestic expenditure on research and development (GERD) leapt from 18% to an estimated 28%. As the government share of GERD remained stable at 0.61% of GDP over the same period, the 10% rise in the GERD/GDP ratio can be attributed to the dynamism of the private sector;

- The state continues to accord great importance to public research and development (R&D) in certain high-tech areas, such as space, information technology (IT) and pharmaceuticals; moreover, public R&D itself has become more commercial and market-driven;

- The state has come to recognize the need to improve both the quantity and quality of scientific personnel by inaugurating a host of new tertiary institutions focusing on science and engineering education. This issue is discussed further on page 366;

- There has been a tremendous increase in the number of foreign R&D centres, which have grown from fewer than 100 in 2003 to about 750 by the end of 2009. Most of these R&D centres relate to information and communication technologies (ICTs) and the automotive and pharmaceutical industries;

- Indian companies have been investing abroad and acquiring important technology-based companies in medium-tech and high-tech sectors. Examples are Tata Steel's takeover of the British industrial giant Corus, Bharat Forge's takeover of forging companies in Germany, the UK and the USA, and Suzlon's takeover of wind turbine companies in Germany.

These five factors are slowly but steadily remodelling the science and technology (S&T) landscape in India. In the pages that follow, we shall survey developments since 2005 to the extent that data availability allows.

THE RISE OF INNOVATION IN INDIA

In recent years, there has been much discussion in the popular press about the rise of innovation in India. This has most likely been precipitated by the following factors:

- **India's rank in the Global Innovation Index[1] has improved.** According to EIU (2009), India's rank in the Economist Group's Global Innovation Index for 82 countries progressed from 58th place in 2006 to 56th in 2008, with a further progression predicted to 54th place by 2013. India has emerged as the fifth-largest economy in the world in purchasing power parity (PPP) dollars (World Bank, 2008). However, in relative terms, India's economy is just half the size of China's, which is growing at a faster rate: 8.7% in 2009 after progressing by 10% or more for six years in a row. India's GDP growth slipped back to 7% in 2007 and to less than 6% in 2009, after climbing from 5% in 2002 to a steady 9% in 2005–2007 (IMF, 2010).

- **There are many instances of innovation in the services sector, especially as concerns health care.** Currently, the services sector accounts for two-thirds of GDP in India (*see page* 324). Both the services and manufacturing sectors have been performing very well. For a very long time, Indian policy-makers avoided using the explicit term of 'innovation' in policy documents dealing with technological activities. The word 'innovation' appears in a policy document for the first time in 2008, in the draft National Innovation Act. This development reflects a broad sentiment in both policy and business circles that the country is becoming more innovative – or at least certain industries. In the manufacturing sector, the release of Tata's Nano brand in 2008 hailed the advent of 'the world's cheapest car', at US$ 2 200[2]. In the health sector, the MAC 400 machine produced by General Electric's

1. This index measures innovation performance in 82 countries, based on the number of patents awarded to inventors from different countries by patent offices in the USA, European Union and Japan. It also takes into account factors that help or hinder the ability to innovate, such as the GERD/GDP ratio and technical skills of the country's labour force. The index was created by the Economist Group, publisher of *The Economist* magazine.

A boy holds a phone to his mother's ear.

Photo: © UNESCO / Pankaj Arora

Table 1: Share of knowledge-intensive production in India's GDP, 2005–2009
In Rs millions, 2005 prices

	GDP	Knowledge-intensive manufacturing	Knowledge-intensive services	Knowledge-intensive production	Knowledge-intensive production (%)
2005	29 675 990	1 207 670	1 334 650	2 542 320	8.57
2006	32 491 300	1 454 220	1 651 780	3 106 000	9.56
2007	35 646 270	1 677 740	2 034 320	3 712 060	10.41
2008	38 934 570	1 822 770	2 483 210	4 305 980	11.06
2009	41 549 730	1 926 630	2 873 500	4 800 130	11.55

Note: Knowledge-intensive manufacturing refers to chemical and metal products and machinery, including electrical machinery and means of transport. Knowledge-intensive services refer to telecommunications and computer-related services plus R&D services. The data for 2006 exclude telecommunications, as the Central Statistics Organization did not report this information for this year.

Source: Indian Central Statistics Organization, 2010

John F. Welch Technology Centre in Bangalore records a patient's electrocardiogram; as it is portable, it can be used in rural areas to diagnose heart disease.

- **The knowledge-intensity of India's overall output has expanded.** Currently, about 14% of India's net domestic product[3] is composed of knowledge-intensive production (Table 1), much of it from the services sector. Also noteworthy is that growth in knowledge-intensive production surpasses that of the economy overall. Data show that the majority of new companies belong to knowledge-intensive sectors and that the number of knowledge-intensive enterprises has mushroomed over the past seven years or so. This trend is corroborated by the technology content of all industrial proposals implemented since the first economic reforms in 1991. Once again, with the exception of the textile industry and a few others, the majority of new proposals emanate from technology-oriented industries in areas such as chemicals, energy, electrical equipment and so on.

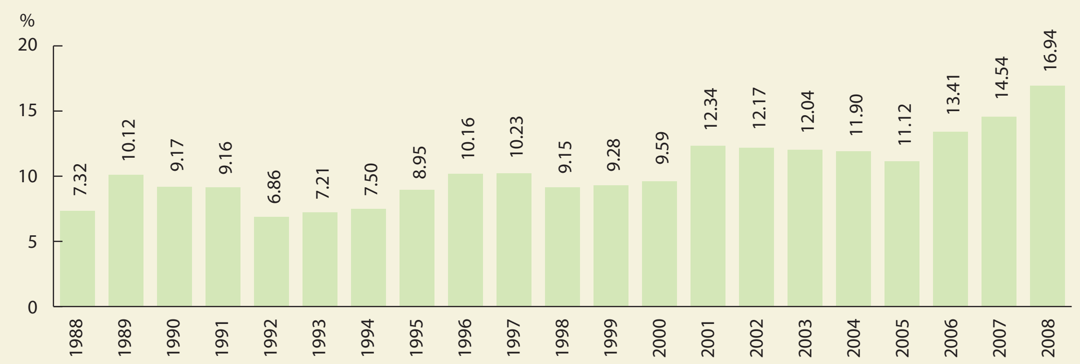
- **Foreign direct investment (FDI) from India has grown from just US$ 2 million in 1993 to about US$ 19 billion in 2009.** This includes some high-profile technology-based acquisitions abroad by Indian companies. However, information on the rate of survival of these ventures is unavailable. The amount of FDI flowing from India had always been insignificant until the trickle became a torrent from about 2005 onwards. Most of these investments have gone to technology-based ventures in the manufacturing sector of developed economies. According to Nayyar (2008), 'Indian firms could not have become international without the capacity and the ability to compete in the world market. The attributes of Indian firms, which created such capacities and abilities, are embedded in the past and have emerged over a much longer period of time'. According to *The Economist* (2009), the pursuit of technology is a powerful motive for foreign acquisitions. Before Tata Steel's purchase of Corus, Europe's second-largest steel producer with annual revenues of around £12 billion, the Indian steelmaker did not hold a single American patent. The takeover brought it over 80 patents, as well as almost 1 000 research staff. Thus, the growing number of foreign acquisitions of 'active targets', in technological jargon, has given Indian companies considerable access to the technological capacity of the acquired firms without their having to build this up assiduously from scratch. The same goes for mergers.

- **India has become more competitive in high-tech areas.** Although manufactured exports are still dominated by low-tech products, the share of high-tech products has doubled in the past 20 years (Figure 1). India has become the world's largest exporter of IT services since 2005 and exports of aerospace products

2. The Nano car was designed at Italy's Institute of Development in Automotive Engineering with component parts manufactured by an Indian subsidiary of the Germany company Bosch. Approximately two-thirds of the technology for Bosch products used in the Nano car is sourced from India. The initial production target is for 250 000 units per year.

3. Net domestic product is equivalent to gross domestic product minus depreciation.

Figure 1: High-tech content of India's manufactured exports, 1988–2008 (%)



Source: United Nations Comtrade database, applying the UNIDO (2009) definition of high-tech exports

have been increasing at a rate of 74% per year, compared to 15% for world exports of these products. India is acknowledged to have considerable technological capability in the design and manufacture of spacecraft and is now an acknowledged global leader in remote sensing (Box 1). According to Futron's 2009 ranking of ten entities in its Space Competitiveness Index[4], India ranks better than the Republic of Korea, Israel or Brazil. However, in India, the bulk of innovation in this area comes entirely from the government rather than from industry. By evoking the security angle, the government seems to have thwarted all attempts to create a sectoral system of innovation in the aerospace industry. This has prevented the country from emerging as a serious player in the civilian aerospace sector, despite possessing all the requisite ingredients. However, this situation is now set to change. Aerospace exports from India have increased manifold in recent years, even if these tend to be confined to aircraft parts or components. With approximately 300 small and medium-sized enterprises active in this area[5], India is slowly emerging as one of the few developing countries to have a high-tech industry of the calibre of its aerospace industry.

4. Futron Corporation in the USA offers a comparative assessment of ten leading players in space: Brazil, Canada, China, Europe, India, Israel, Japan, Korea (Rep.), Russia and the USA. The index assesses more than 50 individual metrics across three underlying dimensions of competitiveness: government, human capital and industry.

5. The Society of Indian Aerospace Technologies and Industries had over 300 members in 2009. Formed in 1991 and based in Bangalore, it brings together R&D, manufacturing and support services in aerospace. Members are drawn from both public- and private-sector industries and institutions dealing in one way or another with the aerospace industry.

A PROPITIOUS POLICY ENVIRONMENT

India has a long history of policies related to technology development, although no distinction was made initially between science and technology. The earliest attempt to support technical change in industry was the adoption of a Scientific Policy Resolution by Parliament in 1958. This policy laid the groundwork for training S&T personnel on a sufficient scale to satisfy the needs of the various economic sectors. This move was followed by a Technology Policy Statement in 1983, the main aim of which was to develop endogenous technology and ensure efficient absorption and adaptation of imported technology corresponding to national priorities and available resources.

In January 2003, the Prime Minister formally announced a new Science and Technology Policy, the main objective of which was to raise India's overall research intensity from 0.80% of GDP in 2003 to 2.0% of GDP by the end of the *Tenth Five-Year Plan* in 2007. Although this target has not been reached – the GDP/GERD ratio stood at 0.88% in 2007 – this policy contained four refreshingly new features:

- for the first time, a clear recognition of the extremely low density of scientists and engineers, even though a populous country like India counts a large number;
- an explicit statement on the need to manage brain drain;
- an emphasis on increasing the number of patents at home and abroad;

- an explicit mention of monitoring implementation of the policy, for instance stating that, 'effective, expeditious, transparent and science-based monitoring and reviewing mechanisms will be significantly strengthened and, if not available, will be put in place. It will be ensured that the scientific community is involved in, and responsible for, the smooth and speedy implementation'. This said, statistical indicators for measuring policy outcomes are still very rudimentary in India and what is meant by 'science-based monitoring' remains unclear. Another difficulty relates to the fact that the 11 strategies outlined in the policy document are extremely general. Much work needs to be done to give them a more concrete form. Only then will it be possible to evaluate whether or not the 2003 policy is a real improvement over its predecessor in 1983.

India's *Eleventh Five-year Plan* (2007–2012) contains provisions for a massive rise in the public outlay for S&T of 220% over the previous plan. It fixes eight primary objectives which confirm the growing emphasis on innovation:

- a national mechanism is to be set up to develop policies and provide orientations for basic research;
- the pool of S&T personnel is to be enlarged and infrastructure reinforced (*see below for details*); in parallel, efforts are to be made to attract and retain young people to careers in science;
- ten national flagship programmes are to be launched in areas ranging from the rural water supply, sanitation and health to telephony and education, with a direct bearing on India's technological competitiveness;
- globally competitive research facilities and centres of excellence are to be established (*see below*);
- an innovative spirit is to be kindled among scientists to encourage them to translate R&D leads into technologies that can be scaled up;
- new models of public–private partnership are to be developed in higher education, particularly as concerns university research and research in high-tech areas;
- ways and means are to be identified of catalysing industry–university collaboration;
- linkages with advanced countries are to be encouraged, including via participation in international megascience initiatives like the Large Hadron Collider at the European Organization for Nuclear Research (CERN), the International Thermonuclear Experimental Reactor project (ITER) [*see page* 158] or the rice genome sequencing project. The latter is based at the Indian Agricultural Research Institute and involves collaboration with Brazil, Japan, the Republic of Korea and the USA, among others.

A key element of the policy are the linkages the government is seeking to establish between innovation and development. This is exemplified in the implementation of the national flagship programmes for improving the quality of primary education through schemes like Sarva Sikhya Abhayan[6] and in the intention to develop the private sector's role in establishing research-based universities. The plan also stresses the oft-repeated maxim of improving university–industry ties.

As we near the end of the period covered by the plan, to what extent has the policy lived up to its promise? One major outcome of the S&T chapter within the *Eleventh Five-Year Plan* has been the initiation of a system-wide consultation of stakeholders on a draft National Innovation Act by the Department of Science and Technology within the Ministry of Science and Technology. The main objective of this Act is to facilitate public or private initiatives and public–private partnerships to build an innovation support system; develop a national integrated science and technology plan; and codify and consolidate the law of confidentiality to protect confidential information, trade secrets and innovation. The proposed Act focuses on increasing investment in R&D and enacting data confidentiality clauses to make India a preferred destination for research-oriented companies in sectors like IT, pharmaceuticals and engineering. However, the draft Act is yet to come before Parliament and, as such, remains of purely academic value for the moment.

Improving the quality and quantity of human resources in science and engineering is another area of great importance to the government. In higher education, the

6. This scheme strives to give all children eight years of primary schooling and bridge the gender gap in elementary education by 2010, via community ownership of the school system.

government is seeking to raise the gross enrollment ratio from 11% in 2007 to about 15% by 2012 and 21% by 2017. To achieve the target of 21 million students by 2012, compared to 14.8 million in 2007, enrollment in universities and colleges will need to grow by an annual rate of 8.9%. This does not seem unattainable, as tertiary enrollment grew by 15% between 2006 and 2007. One-quarter of the student body is now enrolled in S&T fields, according to the UNESCO Institute for Statistics.

To this end, the government has opted to establish 30 new central universities which will be owned and managed by the central government: 16 new universities for those 16 states which did not have a central university

Box 1: A space odyssey

India has had a very dynamic space programme since 1969 when the Indian Space Research Organization (ISRO) was founded with headquarters in Bangalore and facilities spread throughout the country. The size and importance of India's space programme can be gauged from the fact that it is second only to the USA in terms of the public budget committed to space research: approximately 0.10% of GDP. Space research alone accounts for about 12% of GERD in India.

The history of the space programme since 1969 falls into two phases. During the first phase (1970–1980), ISRO used experimental satellite programmes like Aryabhatta, Bhaskara, Rohini and Apple for experimental learning. During the second phase in the post-1980 period, ISRO introduced endogenous satellite and launch vehicle design programmes.

ISRO's activities cover four areas of space research:

- Earth observations and remote sensing;
- satellite communications and navigation;
- space science and environment: spacecrafts Chandarayan 1 and 2 were the first to confirm the presence of water at the poles on the Moon in September 2009;
- launch vehicles.

Of these four areas, India excels in remote sensing, where it is considered a world leader, and in the design and manufacture of satellites and launch vehicles.

One important innovation in the area of remote sensing has been the development and launch of the beta version of its web-based three-dimensional satellite imagery tool, Bhuvan, in August 2009. Bhuvan will offer imagery of Indian locations superior to that provided by other Virtual Globe software like Google Earth and Wiki Mapia, with spatial resolutions ranging from 10 m to 100 m. For the moment, Bhuvan is available only for the observation of Indian locations, although it is capable of offering images of the entire planet. It is claimed to possess a number of characteristics which give it an edge over its immediate competitor, Google Earth. This said, given the large number of technical glitches from which the software suffers, its actual diffusion rate has been limited. Nevertheless, Bhuvan brings a new arc to ISRO's bow by combining both astronautic and software capabilities.

Between its inception in 1975 and 2009, India's satellite launch programme sent 55 satellites into orbit, about half of them for Earth observation and the remainder for communication. ISRO has also developed the technological capability to design and manufacture both Polar Satellite Launch vehicles and Geostationary Satellite Launch Vehicles (GSLV), although it has a better record for the former. Recently, it has managed to design highly complex cryogenic engines for its GSLV, although the technology has yet to be perfected.

Two aspects of India's space programme are worth noting. Firstly, ISRO has institutionalized an excellent procedure for learning from past failures in technology development. Secondly, it has managed to use this high technology for the benefit of the civilian, through the establishment of Village Resource Centres. This concept integrates the capabilities of communications and Earth observation satellites to provide information emanating from space systems and other IT tools, in order to address the changing and critical needs of rural communities. One example is the EDUSAT programme, launched by the GSLV in September 2004. EDUSAT is India's first satellite devoted exclusively to educational services, providing one-way television broadcasts, interactive television and video and computer conferencing, among other services. Networks have been set up in at least 24 states and programmes reach more than 35 000 classrooms, including schools for the blind via a specialized network.

Source: Mani (2010c)

Box 2: The incredible feat of Indian pharma

The pharmaceutical industry is one of India's foremost science-based industries, with wide-ranging capabilities in the complex field of drug manufacture and technology. The country produces pharmaceutical formulations – the process of combining different chemical substances to produce a drug – and over 400 active chemicals for use in drug manufacture, known as Active Pharmaceutical Ingredients (APIs).

Industry turnover has grown from a modest US$ 300 million in 1980 to about US$ 19 billion in 2008. India now ranks third worldwide after the USA and Japan in terms of the volume of production, with a 10% share of the world market. In terms of the value of production, it ranks 14th for a 1.5% global share.

A kaleidoscope of foreign and Indian firms of varying sizes occupy the manufacturing landscape. In all, there are about 5 000 firms engaged in manufacturing pharmaceuticals in India, which employ directly about 340 000 individuals.

Much of industrial growth is fuelled by exports. Between 2003 and 2008, exports grew by an average rate of 22%. India currently exports drug intermediates, bulk drugs, APIs, finished dosage formulations, biopharmaceuticals and clinical services. The top five destinations in 2008 were, in descending order, the USA, Germany, Russia, the United Kingdom and China.

The industry has four key characteristics:

- it is dominated by formulations;
- it is very active in the global market for generics, supplying even developed countries;
- it enables India to be self-sufficient in most drugs, as witnessed by a growing positive trade balance;
- it is one of the most innovative industries in India, in terms of R&D and the number of patents granted, both in India and abroad.

This fourth characteristic may very well be the most important for India, accounting for one out of every four abbreviated new drug applications (generic product approvals) in 2007 and 2008. The Indian pharmaceutical industry also accounts for approximately 25% of the drug master files with the US Food and Drug Administration (USFDA). India has the highest number of USFDA-approved plants of any foreign country.

What explains the dynamic growth of Indian pharmaceuticals in the past few decades? According to one hypothesis, the 1970 Indian Patents Act allowed Indian pharmaceutical companies to come up with very cost-effective processes for imitating known products, by not recognizing product patents for pharmaceutical products. Favourable to intellectual property rights, this policy thus afforded the industry a long learning period through a process of reverse-engineering essentially. A second hypothesis is that the pharmaceutical industry benefited from the availability of highly trained personnel with a solid scientific background. In fact, for many years, the Indian higher education system was biased in favour of science to the detriment of engineering. As a science-based industry, pharmaceuticals are purported to have benefited from this apparent bias.

One spin-off of India's innovative capability in pharmaceuticals is that it has become a popular destination for clinical trials, contract manufacturing and R&D outsourcing. These capabilities hold great promise for the Indian pharmaceutical industry, as an estimated US$ 103 billion of generic products are at risk of losing patents by 2012. Furthermore, the global market for contract manufacturing of prescription drugs is estimated to grow from US$ 26 billion to US$ 44 billion by 2015 or so. According to experts, the country has 'good' to 'high' skills in preclinical trials and Phase I clinical trials and 'very high' skills in Phase II and Phase III clinical trials.

A very recent trend observed in India's pharmaceutical industry is the wave of cross-border mergers and acquisitions in which Indian companies have taken over foreign ones and foreign firms have in turn taken over Indian companies. The pharmaceutical industry has become one of India's most globalized industries. One of the most high-profile takeovers concerns Ranbaxy, India's largest pharmaceutical company and the country's biggest producer of generic drugs. In 2008, the Japanese pharmaceutical giant Daiichi Sankyo acquired a majority stake (35%) in Ranbaxy, at a cost of up to US$ 4.6 billion.

Source: Mani (2010c)

before and 14 world-class universities. The Ministry of Human Resource Development plans to set up these 14 'innovation universities' across the country from 2010 onwards to build 'disciplinary foci' and drive R&D. Each 'innovation university' is expected to focus on one area or problem of significance to India, such as urbanization, environmental sustainability and public health. Two private companies have announced plans to build world-class universities of their own, Reliance and Anil Agarwal. The latter has even donated US$ 1 billion to get the Vedanta University project off the drawing board.

In parallel, the government is in the process of doubling the number of Indian Institutes of Technology to 16 and establishing 10 new National Institutes of Technology, three Indian Institutes of Science Education and Research, and 20 Indian Institutes of Information Technology to improve engineering education. These new universities and institutes are at various stages of creation. In 2006, the ministry founded the Indian Institute for Science Education and Research and the National Institute of Science Education and Research. The Indian Institute of Space and Technology followed a year later.

In addition, in 2010, the government was in the process of adopting a policy permitting foreign universities to enter the higher education system in India by establishing their own campuses or joint ventures with existing universities and institutes.

All of these changes augur well for the further development of science and engineering education in India.

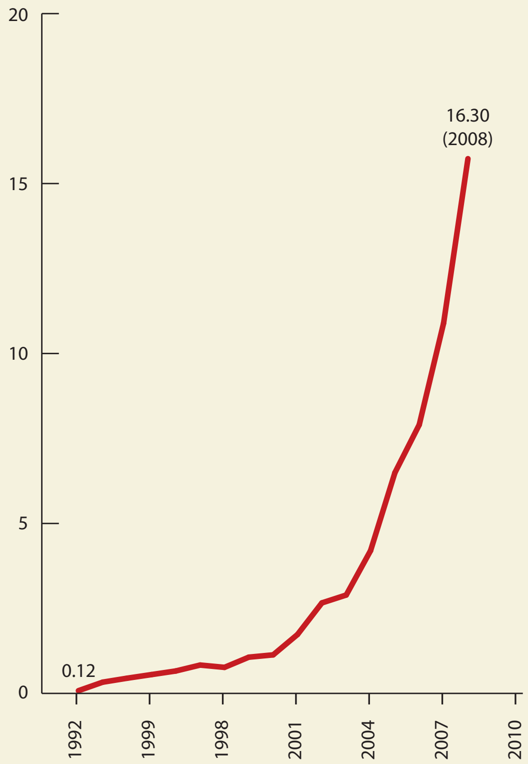
The impact of the Indian Patent Act

One important policy change in recent years has been the adoption of the Indian Patent Act, which took effect on 1 January 2005. This ordinance sought to bring the country into compliance with the Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS) of the World Trade Organization. The most distinguishing feature of this policy change is the recognition of both product and process patents, as opposed to solely process patents in the earlier Act of 1970. In bringing India into compliance with TRIPS, the intention was to restrict innovation in the pharmaceutical industry in particular, where the lack of product patents had allowed firms to reverse-engineer known products at little cost. This 35-year learning period seems to have given the pharmaceutical firms the time they needed to acquire the skills that are crucial to inventing new chemical entities (Box 2).

After the adoption of the Indian Patent Act, it was expected that R&D spending by the pharmaceutical industry would slump. This reasoning was based on the belief that much of Indian R&D in pharmaceuticals consisted of reverse-engineering. By requiring recognition of both product and process patents, it was thought that the amended act would effectively reduce the space for this type of R&D. However, it turns out that private pharmaceutical companies in India have actually been registering an increase in R&D investment since 2000 of almost 35% per year (Figure 2).

In fact, some of the provisions in the Indian Patent Act have protected Indian pharma, even if the ordinance imposes a 20-year protection period for product patents.

Figure 2: Average R&D expenditure per firm in India's pharmaceutical industry, 1992–2008
In Rs Crores



Source: Author's compilation based on Prowess Dataset

For example, there is a provision for granting compulsory licenses for the export of medicines to countries that have insufficient or no marketing capacity, to meet emergent public health situations, in accordance with the *Doha Declaration on TRIPS and Public Health*. This allows Indian companies to produce and export AIDS drugs to African and Southeast Asian countries. Another safeguard has been the introduction of a provision making patent rights for mailbox applications available only from the date of granting the patent rather than retrospectively from the date of publication. This provision has saved many Indian companies from being attacked for infringement of patent law by multinational companies that might otherwise have obtained patents for drugs already put on the market by Indian companies (UNESCO, 2005).

As for the impact of the Indian Patent Act on innovation in the agriculture, biotechnology and IT sectors this still requires in-depth analysis.

R&D INPUT

Complex trends in R&D expenditure

Both the nominal and real growth rates of GERD have declined in India since liberalization of the economy began in 1991. The country's overall research intensity has remained virtually constant at about 0.78% (Table 2). In China, on the other hand, the GERD/GDP ratio has more than doubled to 1.54% (*see page* 389).

Care must be exercised in interpreting these figures to mean that overall investment in R&D has declined, owing to the peculiarities of Indian research. Even now, the government accounts for over two-thirds of R&D performed in the country, although this share has declined over time. This trend has been accompanied by an increase in R&D investment by business enterprises, which now account for about 28% of GERD, compared to just 14% in 1991. In China, business enterprises have come to perform as much as 71%, with government research institutes accounting for only 19%. The growing share of R&D performed by the private sector is generally considered to be a desirable trend, as enterprises tend to transform the results of their research into products and processes more rapidly than the government sector.
As concerns the breakdown of GERD by type of research, the share devoted to basic research has increased quite substantially since 2003 (Figure 3).

Government expenditure on R&D in India tends to focus on nuclear energy, defence, space, health and agriculture (Figure 4). In the *Eleventh Five-Year Plan*, the public-sector outlay on S&T increased by a whopping 220% in nominal terms compared to actual expenditure on S&T in the *Tenth Plan*. The biggest beneficiary has been the Department of Atomic Energy, the budget of which nearly tripled from Rs 3 501 to Rs 11 000 Crores. Part of this amount will go towards funding India's participation in the ITER project, which India joined in 2005. The Council of Scientific and Industrial Research has also enjoyed a massive increase (from Rs 2 575 to Rs 9 000 Crores), as has the Department of Biotechnology (from Rs 1 450 to Rs 6 389 Crores). The rise in the public-sector plan outlay for renewable energy may have been less dramatic (from Rs 7 167 to Rs 10 460 Crores) but nevertheless represents a growth rate of about 46%.

The spillover of government research to civilian use is very limited in the Indian context, although conscious efforts have been made by the government recently to orient research more towards socio-economic goals. This is slowly beginning to produce results, especially in the area of space research with the development of environmental monitoring, satellite communications and so on.

One interesting result highlighted by the above analysis is that the higher education sector constitutes only a fraction of R&D performed in India, despite the fact that this sector encompasses the prestigious Indian Institute of Science dating back to 1909, the eight Indian Institutes of Technology and over 300 universities. In other words, the higher education sector in India is not a source of technology for industry. This may come as a surprise, as the Indian Institutes of Technology do collaborate with private industry. Unfortunately, however, cases of actual technology generation are few and far between, as much of R&D relates to basic research. Moreover, the institutes tend to be extremely teaching-intensive institutions. It is estimated that the entire higher education sector in India contributes no more than 5% of GERD. It does act as an important reservoir of skilled personnel, however, for the other actors in India's national innovation system.

Thus, the only sector performing more R&D than before is industry and the private sector in particular. Currently, private companies spend approximately four times more

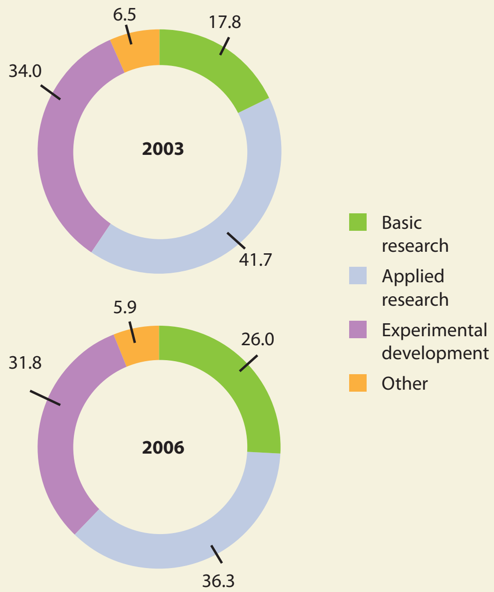
Table 2: Trends in GERD in India, 1992–2008

	GERD (current Rs millions)	Nominal growth rates (%)	GERD (constant 2 000 Rs millions)	Real growth rates (%)	GERD/ GDP ratio
1992	45 128	14	83 476	-0.16	0.76
1993	50 046	11	85 038	1.87	0.73
1994	60 730	21	93 824	10.33	0.77
1995	66 224	9	93 197	-0.67	0.72
1996	74 839	13	96 510	3.55	0.69
1997	89 136	19	106 647	10.50	0.71
1998	106 113	19	119 081	11.66	0.76
1999	124 732	18	129 542	8.78	0.77
2000	143 976	15	143 976	11.14	0.81
2001	161 988	13	156 879	8.96	0.84
2002	170 382	5	160 219	2.13	0.81
2003	180 002	6	163 037	1.76	0.80
2004	197 270	10	172 756	5.96	0.78
2005	216 396	10	179 600	3.96	0.75
2006	287 767	33	229 538	27.80	0.88
2007	329 416	14	248 954	8.46	0.87
2008	377 779	15	274 128	10.11	0.88

Note: The GERD/GDP ratio here differs from that in the Statistical Annex because the DST data are for the fiscal year from 1 April to 31 March, whereas UNESCO has allocated these to the previous year. The source of the GDP data used by UNESCO to calculate the GERD/GDP ratio is the World Bank's World Development Indicators, whereas the DST uses national data.

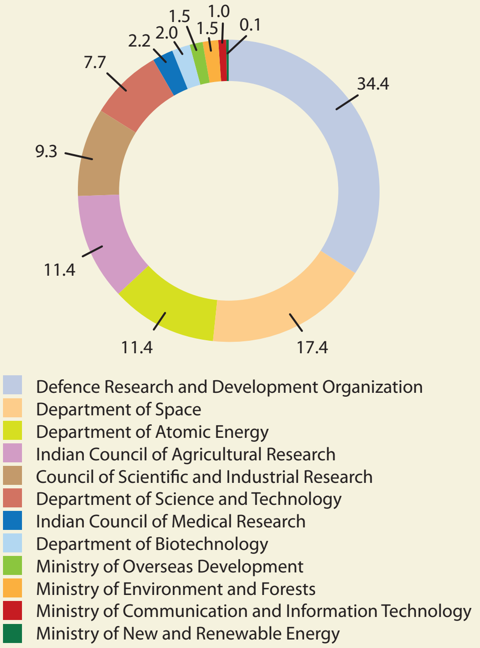
Source: Department of Science and Technology (2009) *R&D Statistics*

Figure 3: Distribution of GERD in India by type of research, 2003 and 2006 (%)



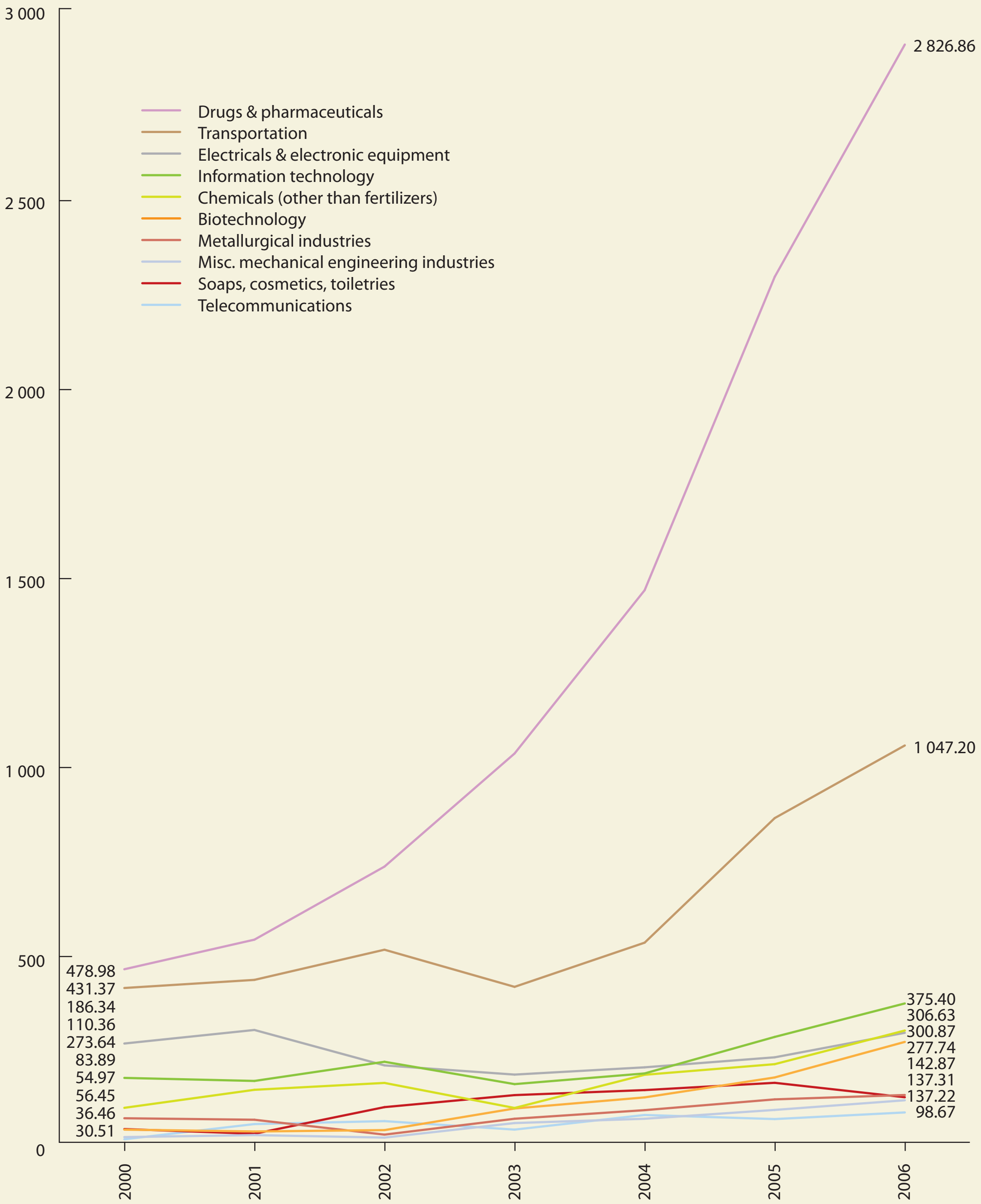
Source: Department of Science and Technology (2009) *R&D Statistics*

Figure 4: Government outlay for the major science agencies in India, 2006 (%)



Source: Department of Science and Technology (2009) *R&D Statistics*

Figure 5: Distribution of GERD in India by industrial sector, 2000–2006
In Rs millions at current prices



Source: Department of Science and Technology (2009) *R&D Statistics* than public enterprises on R&D and nearly three times more when compared to government research institutes. In other words, private enterprises in India are moving towards the core of India's innovation system.

The veracity of this trend is sometimes questioned on the grounds that business enterprises reporting R&D expenditure to the Department of Science and Technology may be tempted to exaggerate their R&D expenditure to gain tax incentives available in India to any business enterprise investing in R&D. These tax incentives are linked to the volume of R&D performed – hence the temptation to overstate it. However, this suspicion would appear to be unfounded if one compares R&D investment as reported by the Department of Science and Technology with the dataset available from the Centre for Monitoring the Indian Economy's Prowess for the period 1991–2003. This comparison shows that, although the level reported by the Department of Science and Technology is higher over most of the years under consideration than in the early 1990s, the difference has tended to decrease over time. Moreover, both series have followed a similar curve. The argument that the increase in R&D expenditure by private companies is a mere statistical artifice would thus appear to be false.

Four industries account for the lion's share of investment in R&D, with the pharmaceutical and automotive industries topping the list (Figure 5). In fact, it is sometimes claimed that India's national system of innovation is led by the pharmaceutical industry. It can therefore be safely concluded that, although GERD may not have risen, the pharmaceutical industry has been at the helm of an impressive rise in R&D expenditure by the private sector. Based on this one indicator, the more correct statement would be that there is insufficient evidence to show that the entire industrial sector in India has become more innovative since 1991 but sufficient evidence to posit that India's pharmaceutical industry *has* become more innovative. We shall confront this statement later with trends in the number of patent applications and grants in India (*see page* 375).

Scientists and engineers in short supply

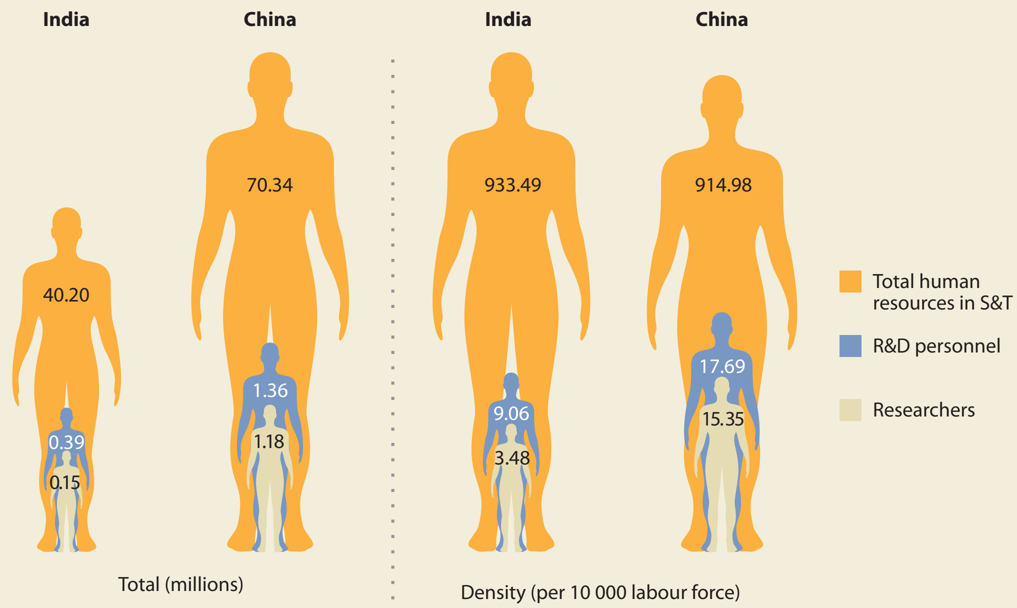
It is generally held that India has a copious supply of scientists and engineers, yet the actual density of personnel engaged in R&D and innovation is fairly modest, at just 137 per million population (*see page* 328).

The recent growth of knowledge-intensive industries is prompting many commentators to profess that India is becoming a knowledge economy. India's 'copious supply' of technically trained personnel is considered one of the key drivers of this growth. However, of late, industry has been complaining of serious shortages in technically trained personnel. For instance, a study by the Federation of Indian Chambers of Commerce and Industry (FICCI, 2007) has revealed that rapid industrial expansion in a globally integrated Indian economy has stimulated a huge demand for skilled personnel. However, the lack of quality higher education has become a hindrance to satisfying this demand. Based on a study conducted in 25 industrial sectors, the survey also revealed that there is currentlya 25% shortage of skilled personnel in the engineering sector. Figure 6 compares the present supply and density of scientists and engineers in India with the situation in China.

Two issues have an impact on the potential supply of scientists and engineers for domestic businesses in particular. The first is the long-standing issue of the migration of highly skilled personnel from India to the West primarily, with every indication that this brain drain has increased recently (Mani, 2009). According to some estimates, the emigration by highly skilled Indians as a share of those in tertiary education has increased from 2.6% in the 1990s to about 4.2% in the early 2000s. The second issue concerns the growing amount of FDI flowing into R&D. Foreign R&D centres are able to offer domestic researchers and R&D personnel better incentives, both pecuniary and otherwise, than domestic businesses. As a result, India's small stock of scientists and engineers may be lured to the foreign R&D centres, causing a 'crowding out' of sorts to take place. Lan and Liang (2006) have already observed this phenomenon in China. In addition to the supply question, doubts have been expressed as to the quality of education in science and engineering in India, although quality is often a difficult parameter to measure objectively.

The central government in particular has reacted by putting in place a number of measures which combine quantity and quality, not only in higher education but also in technical education. For details of these ambitious schemes, see page 366.

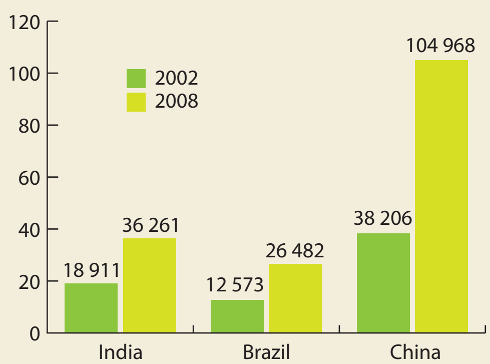
Figure 6: Stock of scientists and engineers engaged in R&D in India, 2005
China is given for comparison



Note: The definition of human resources in S&T is broad and covers 'people actually or potentially employed in occupations requiring at least a first university degree' in S&T, which includes all fields of science, technology and engineering. The term R&D personnel, as defined by the OECD *Frascati Manual* (2002), covers 'all persons employed directly on R&D', which includes those providing direct services such as R&D managers, administrators and clerical staff. The *Frascati Manual* defines researchers as 'professionals engaged in the conception or creation of new knowledge, products, processes, methods and systems and in the management of the projects concerned'.

Source: Computed from OECD (2008) *Reviews of Innovation Policy: China*; Department of Science and Technology (2009) *R&D Statistics;* NCAER (2005) *India Science Report, Science Education, Human Resources and Public Attitudes towards Science and Technology*

Figure 7: Total scientific publications in India, 2002 and 2008
Brazil and China are given for comparison



Source: Thomson Reuters' Science Citation Index Expanded, compiled for UNESCO by the Canadian Observatoire des sciences des techniques

R&D OUTPUT

A sharp rise in scientific publications

According to Thomson Reuters data, India's publication record shows a steep rise, especially since 2003 (Table 3 and Figure 7). If this growth rate is maintained, India's publication record will be on par with most G8 nations within 7–8 years. India could even overtake them between 2015 and 2020.

India's publications are evenly distributed between the physical and life sciences. The most recent data confirm earlier findings that India's strength truly lies in the basic sciences such as chemistry, physics, pharmacology and toxicology (Figure 8).

The USA continues to be India's top research partner but the level of international collaboration – defined as a fraction of GDP – is much lower for India than for other emerging

Table 3: India's scientific publication record, 1999–2008

	1999–2003		2004–2008	
	Count	Word share (%)	Count	Word share (%)
Chemistry	21 206	4.42	33 504	5.71
Agricultural sciences	4 303	5.91	5 634	5.65
Materials science	6 960	4.08	11 126	4.81
Pharmacology & toxicology	2 034	2.80	3 866	4.25
Plant & animal science	8 132	3.58	10 190	3.77
Physics	11 700	3.00	17 295	3.7
Engineering	8 101	2.69	14 103	3.57
Geosciences	2 839	2.64	4 266	3.13
Space science	1 322	2.44	1 665	2.79
Microbiology	1 078	1.62	2 273	2.79
Total for the top 10 fields	67 675		103 922	

Source: Thomson Reuters (2009) *Global Research Report: India*

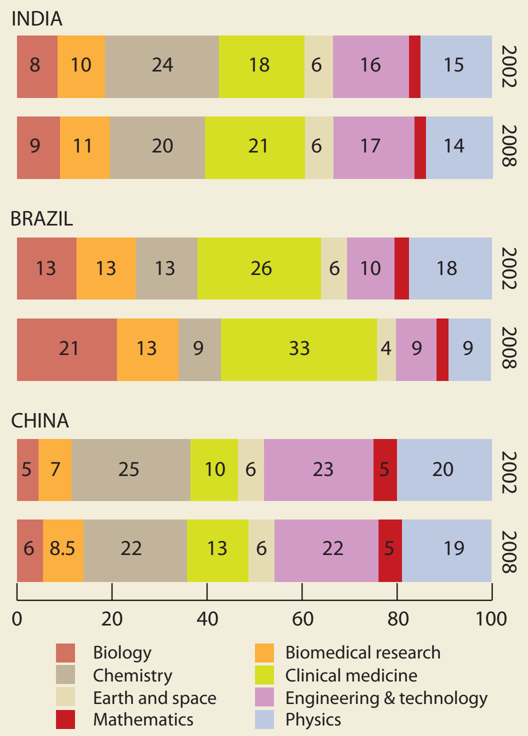
economies like Brazil. However, the period since 2004 has seen greater collaboration with Asian countries, notably Japan and the Republic of Korea. One important finding is the relatively sparse collaboration with European partners and especially the UK. This shortcoming is now being explicitly addressed by the European Union (EU) and British government through a host of new partnerships. The UK–India research partnership and recent initiatives under the EU's Seventh Framework Programme for Research and Technological Development (2007–2013) are two illustrations of research partnerships between India and the developed world in a host of S&T areas ranging from health to space and nanotechnology.

Foreign companies dominate patents

India has improved its patenting record in the USA, with an acceleration over the past decade. Most Indian patents are utility patents, defined as being those for new inventions (Figure 9). However, most of these patents are in chemistry-related areas and the great majority are being granted to foreign companies located in India, based on R&D projects they have carried out in India, in a growing trend (Mani, 2010*a*).

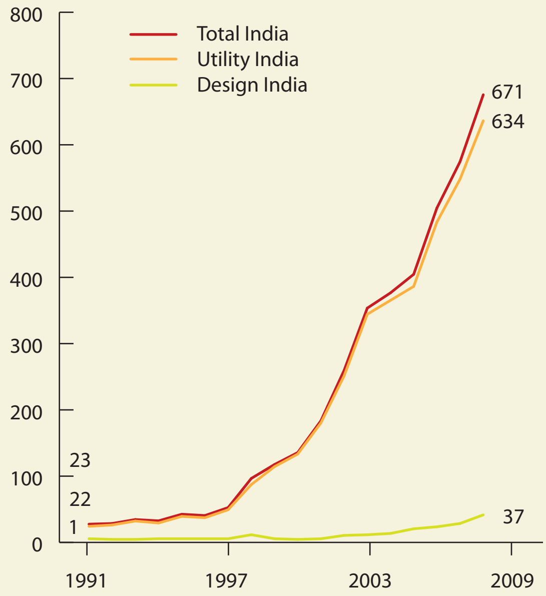
Similarly, the number of national patents granted by the India Patent Office has increased tremendously but over three-quarters are still being granted to foreign entities. Once again, most of these patents concern chemistry and pharmaceutical-related areas. Thus, although the TRIPS compliance of the Indian Patents Act appears to have had a positive effect on patenting by Indian inventors, most of the

Figure 8: Focus of Indian publications by major field of science, 2002 and 2008 (%)
Brazil and China are given for comparison



Source: Thomson Reuters' Science Citation Index Expanded, compiled for UNESCO by the Canadian Observatoire des sciences et des technologies

Figure 9: Trends in the number of patents granted to Indian inventors in the USA, 1991–2008



Source: Mani (2010*b*) *Have China and India become more innovative since the onset of reforms in the two countries?*

patents granted to Indian inventors both in India and abroad are going to foreign companies.

CONCLUSION

We have seen that economic growth has taken off in India, especially in the past five years. This performance has been very lopsided, however, tending to favour certain regions and income groups over others. In order to make economic growth more inclusive, the government has been placing greater emphasis on S&T, as witnessed by the massive increase in the budget allocation to S&T during the Eleventh Five-year Plan (2007–2012). It is also making an effort to orient innovation in the government sector more towards socio-economic goals.

The country has certainly made great strides in space research, life sciences and especially in biopharmaceuticals and information technology. Although domestic science continues to dominate, there is also a growing presence of foreign entities in India's technology system. The main challenge facing the country will be to improve both the quality and quantity of S&T personnel. Fortunately, policy-makers are seized of this problem and have taken energetic steps to remedy the situation. The future success of India's STI system will depend on how well they succeed.

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