India: The uneven innovator

Kirsten Bound

DEMOS

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Mapping the new geography of science

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1 Introduction
A brief history of India's future

'India's future "cannot be one that is half California and half sub-Saharan Africa".'

Amartya Sen, 93rd Indian Science Congress, Hyderabad, January 2006

Guru Ganesan brandishes a copy of the *San Jose Mercury News* with the headline: ‘The valley didn’t die, it moved to Bangalore’. Ganesan runs the Indian research centre of ARM, the UK designer of semi-conductors. This lab is a carbon copy of a sister facility in Austin, Texas, and does research of an identical quality, according to its managing director. Ganesan is one of the new generation of globally networked, technological elites who are driving India’s emergence as a source of innovation.

All around Bangalore, recently renamed Bengalooru by the government, ‘little Americas’ are springing up, as they are in other fast-growing cities such as Hyderabad and Pune. On some of these housing developments 80 per cent of the residents are Indians who have lived overseas, returning to take advantage of the opportunities opening up at home. Where Ganesan lives they even go trick-or-treating on Halloween.

Yet despite the media hyperbole, this at times chaotic south Indian city is a long way from becoming a Silicon Valley. The success of its software and service industries is still to make an impact on the lives of the majority: 390 million people in India live on less than $1 a day.[1] Predictions that India will become a twenty-first century knowledge superpower have to accommodate these contradictions.

8%

Economic growth has averaged around 8 per cent since 2003.[2]

The Indian economy is booming. Economic growth has averaged around 8 per cent since 2003.[2] According to Goldman Sachs, India has the potential to grow faster than China in the long term.[3] In just a few years India has been transformed from an aid recipient to a global competitor. ‘India everywhere’ was the slogan for the Davos World Economic Forum in 2006.

But these macroeconomic trends, including a threefold increase in R&D spending over the past decade,[4] do not convey the complex dynamics behind the rise of Indian science and innovation.

The impact of the R&D centres that have been set up by multinational companies is still unfolding, as is the contribution of the thousands of Indians returning from abroad. India does not conform to the state-led model of economic development of the East Asian tiger economies in the 1970s and 1980s. Modernisers in the Indian government want the state to become a catalyst for change. But others doubt whether the so-called ‘license state’, encrusted with layers of bureaucracy and regulation, is capable of playing such a dynamic role.

Above all, India’s rise as a source of innovation reveals its intense and sometimes troubled relationship with external ideas and influences. For much of the postwar era, India was a copier and adapter of technology developed in Europe and the US: foreign technology was a mark of prestige. That is why even now the taxis in New Delhi made by the Hindustan Motor Company are modelled on the ancient British Oxford. After independence in 1947, admiration for foreign technology co-existed with a period of science nationalism, in which the government launched a string of programmes to promote indigenous Indian science. During the 1980s and 1990s, Indian brainpower serviced the technology needs of foreign companies, health and education systems around the world, either by migrating to places such as Silicon Valley or directly from call centres in Bengalooru. The question now is how quickly India can evolve from being a technology server to an innovator and creator in its own right.

Keeping India in clear perspective is doubly difficult because we are not idle spectators in this story. Researchers were first dispatched to India by the British government in the eighteenth century to find out about innovations in steel, textiles and medicine. British attitudes towards India are inevitably inflected by our own history of colonialism and presumed superiority. This will be a liability if it breeds British complacency about India's potential.

Ancient excellence

India's potential as a centre for innovation is the product of earlier periods of scientific development that together will condition the path India takes into the future. For centuries, India was the world's largest economy, producing a third of global gross domestic product (GDP). Indians, like the Chinese, were an advanced civilisation when Europeans were still barbarians. From this perspective, we are not witnessing the emergence of India as a scientific power so much as its re-emergence.

2008

By 2008, India plans to have sent its unmanned Chandrayan 1 rocket on a mission to the moon.

Evidence of advanced technological culture comes from archaeology as well as scripture. The Harappans in 2500BCE had a sewage system at their city of Mohenjo-Daro and carefully laid out streets, indicating advanced notions of geometry. Ayurveda, the science of longevity, which still plays a significant role in Indian medicine, dates back to 800BCE. India developed the mathematical concept of zero in about CE600, as well as the decimal system. Even Pythagoras, in the sixth century BCE, is said to have learnt his basic geometry from the Sulva Sutras. By 200BCE, Indian scientists were the first in the world to be smelting iron with carbon to make steel.

Yet Indian science, with its deep intellectual roots, never translated into an industrial revolution like that in Europe in the late eighteenth and early nineteenth centuries, in which science, engineering and wealth were so powerfully combined. By 1850, when Britain's colonial dominance was reaching its peak in India, British technological capability was the envy of the world. Britain colonised India with soft power – science and engineering, ideas and language – as much as with war.

Dependence

'Modern science' was introduced to India under the shadow of colonialism.[5] The British founded the first Indian universities in the late nineteenth century and imposed English education and language, which was rapidly appropriated and propagated by the Indian elite. Scientists earned prestige by doing modern, western science. Yet colonial dominance was never complete. Hybrid approaches to science melded local and western knowledge. Ironically, the English language and western scientific knowledge, intended as tools of domination, have since become crucial to India's emergence as a source of global know-how. These colonial tools were not rejected when India gained independence, they were appropriated.

Independence

Science became a touchstone for national development following independence in 1947. Jawaharlal Nehru, India's first prime minister, declared that 'science alone… can solve the problems of hunger and poverty, of insanitation and illiteracy, of superstition and deadening customs'. Science became 'as important as the national flag'.[6] For Nehru, it was a route to self-sufficiency, industrialisation and national security. One of the legacies of Nehru's vision is the Council for Scientific and Industrial Research, a network of national laboratories designed to transform India's indigenous capacity for scientific excellence.

Nehru's vision of science modernising the nation stood in contrast to Gandhi's more diffuse, democratic and domesticated ideal of 'every man a scientist and every village a science academy'. This tension between science for national prestige and science for basic development remains acute today.

India's space programme, launched in 1963, is a prime example of how science can serve the needs of both modernisation and rural development. India launched its first space satellite in 1975. Its first home-grown rocket was launched five years later. By 2008, India plans to have sent its unmanned Chandrayan 1 rocket on a mission to the moon. But Indian space technology has also served rural development. Vikram Sarabhai, the programme's original architect, insisted it should also serve 'the common man', by using satellites to provide communication, meteorology and education across rural India.

Nuclear energy was another important focus of India's independent science. Only 11 days after Indian independence in August 1947, Dr Homi J Bhabha convinced the Atomic Energy Research Committee to set up a nuclear research programme. A year later, the Atomic Energy Commission was formed with Nehru's enthusiastic support.

The nuclear science that started in this period is still critical to India's position in the world. In 1998 India provoked international outcry by testing nuclear devices in Rajasthan, only 150km from the Pakistani border. But in 2006, US President George Bush signed an agreement on civil nuclear technology with India, which symbolised India's increasingly interdependent and strategic relationship with the US.

It was also under Nehru that the Indian Institutes of Technology (IITs), the icons of India's technological prowess, were inaugurated. The IITs were a symbol of independence; they marked a break from the universities of the British Raj. Yet they were modelled on the Massachusetts Institute of Technology and helped to sow the seeds for India's relationship with the US and the current period of scientific and technological interdependence.

" "

Policy-makers in India bemoaned the brain drain that sucked talent out of what was then regarded as a poor third-world country. But those brains were in fact being 'banked' overseas rather than lost altogether.

Interdependence

In the postcolonial era, science was seen principally as a national activity for national purposes. Now science is a global activity, dependent on international networks of knowledge-sharing in fields where science itself is increasingly complex, and research requires the combination of many disciplines. India's move towards global interdependence in science is the product of several factors.

India has been open for global business for less than two decades. Twenty years ago, only a few foreign companies were permitted to set up in India. These days Indians excel at networked and outsourced business models that are international in scope. New ventures created in Silicon Valley now depend on an Indian connection for technical support. Indian companies are applying the skills that they have built up in outsourcing basic business processes to new areas of innovation and research.

Underpinning this are flows of people, ideas and cultures. An influential slice of the 20 million Indians spread around the globe are scientists, technologists, engineers and entrepreneurs. In the 1970s, policy-makers in India bemoaned the brain drain that sucked talent out of what was then regarded as a poor third-world country. But those brains were in fact being 'banked' overseas rather than lost altogether. Now, many of the thousands of graduates who became successful in the US high-technology sector over the last two decades are returning to India for at least part of their time, bringing with them money, ideas, contacts and skills.

14%

Indians make up 14 per cent of the 3.1 million foreign-born S&E graduates in the US.[8]

During the Cold War, India led the 'non-aligned' movement and veered towards Moscow more than Washington. The watershed Indo–US agreement in 2006 demonstrated how Washington now sees India as an important counterweight to the rise of China. As C Raja Mohan put it in a recent edition of *Foreign Affairs:* 'India is emerging as the swing state in the global balance of power.'[7] Never before has India had such expansive relations with all the major powers.

The US is central to this network of relationships. Outsourcers in Bengalooru and elsewhere serve mainly US multinationals in computing and telecommunications. Young graduates from the IITs prefer to go to the likes of Stanford or MIT and on to the Valley to work. Indians make up 14 per cent of the 3.1 million foreign-born science and engineering graduates in the US; 300,000 of them have doctorates.[8]

What next?

Each stage of India's scientific development has drawn on what has gone before. The strengths and weaknesses of Indian science reflect that history. Colonial domination brought the English language which Indians now use with alacrity to trade, research, debate and invent all over the world. The IITs, which were set up as a mark of independence from Britain, have been a conduit for talented Indians to build new links with the US. Debates over what goals Indian science should serve continue to rage. Is science and innovation primarily about national prestige, servicing the needs of large US companies, or promoting more equitable social development? And will the current phase of interdependent innovation enable India to become a technology creator in its own right?

A note on methodology

The research for this report was carried out over 18 months by Demos, with the support of an expert steering group. The UK part of the project included a number of research seminars, one of which – Beyond Bangalore? The future of science and innovation in India – was part of a programme of events during the first Indo–UK Science and Innovation Council in June 2006.

Three months were spent doing fieldwork in India. Places visited include Bengalooru, Hyderabad, New Delhi, Mumbai, Kolkata, Pune and Varanasi. More than 120 interviewees, from venture capitalists to policy-makers to professors of quantum theory to priests, kindly gave up their time to contribute to the research through in-depth interviews and focus groups. A list of organisations interviewed is provided at the end of the pamphlet.

2 Mapping
More than the numbers game

Measuring Indian science and innovation is like standing in a fairground hall of mirrors. Seen from one vantage point India seems like a scientific powerhouse in the making; from another it looks feeble compared with the scale of the tasks it faces. CNR Rao, chair of the Scientific Advisory Council to the Prime Minister, likens the Indian approach to science and innovation to the preparations for an Indian wedding. There is quite often chaos. So many people appear to be in charge that no one is actually in control. Yet behind the scenes there is just enough coordination to make sure everything comes together at the last moment. In contrast to the orderly national innovation systems of countries such as Finland and South Korea, the Indian system looks ramshackle and improvised. But at its best it is capable of brilliance.

The statistics that tell India's story
Table 1 brings together some key scientific and social indicators for India.

Table 1 Key scientific and social indicators

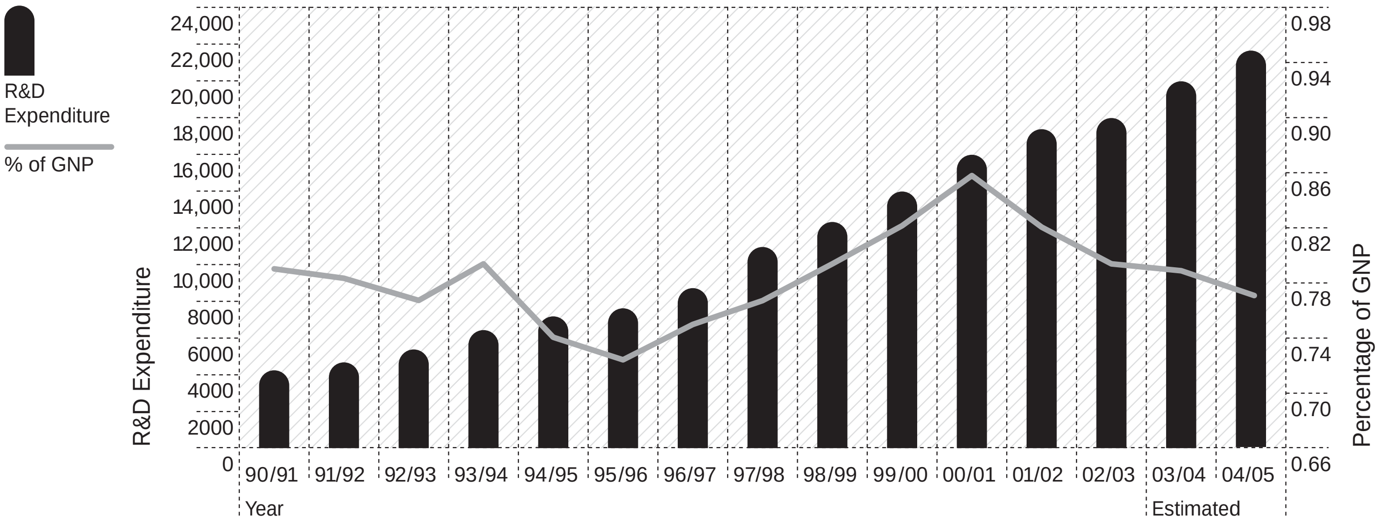
	Figure	Source
Inputs		
GDP growth rate	– 8.2%	Dahlman and Utz, World Bank, 2005
	– India has 17% of the world's population but only 2% of global GDP and only 1% of world trade	ITPS (Swedish Institute of Growth Studies), 2005
Percentage GDP on R&D	– 0.8% GDP	NSTMIS, Department of Science and Technology,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

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

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

	Figure	Source
Key social indicators		
Percentage of population with no schooling	– Decreased from 66.6% in 1980 to 43.9% in 2000	World Bank, 2001[14]
Percentage of population completing postsecondary education	– Risen from 0.7% to 2.2% of the population in the same period	World Bank, 2001
Literacy rate	– 58% men/31% women (1985) – 68% men/45% women (2000)	World Bank, 2006
Life expectancy at birth (years)	– 63.3	Human Development Index (HDI), 2003
Population living below $1 a day	– 34.7%	HDI, 2003
Population living below $2 a day	– 79.9%	HDI, 2003
Ratio of Indian population living below the poverty line	– 55% (1973/74) – 26% (1999/2000)	World Bank, 2006

Figure 1 R&D expenditure: less than 1 per cent of GDP, but rising



Source: National Science & Technology Management Information System (NSTMIS), *Research and Development Indicators*, Department of Science and Technology, Government of India, 2005.

Indian spending on R&D as a proportion of GDP now stands at just above 0.8 per cent GDP (figure 1 represents more conservative estimates). This is well below the US and Europe, and also South Korea and China. But it is now starting to rise. At a speech in October 2006, Prime Minister Manmohan Singh announced plans to increase R&D expenditure to 2 per cent of GDP in the next five years.

$4.5b

Government expenditure on science rose in 2005 by 24 per cent to reach $4.5 billion.

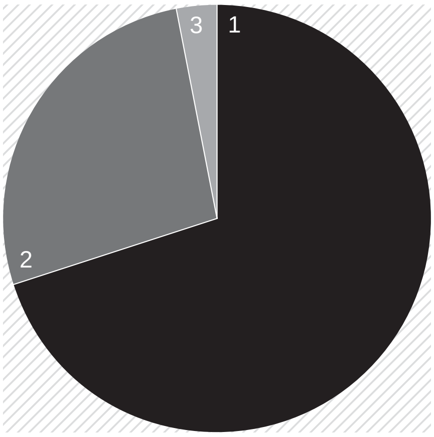
Seventy per cent of R&D spending in India is publicly funded, rising to 85 per cent if publicly owned enterprises are included in the figure (see figure 2). Government expenditure on science rose in 2005 by 24 per cent to reach $4.5 billion. As a result, few of the scientists we met complained of a shortage of funds. It was more common to hear reports of a system that was 'flushed with money'. Dr Bhattacharya, director of the Tata Institute for Fundamental Research in Mumbai, believes that the recent shake-up in the way science is funded in India has made a huge difference: 'Funding really isn't a problem now – any reasonable project will be funded here.'

Institutions of innovation

Indian policy-makers have high hopes that the creation of a $230 million 'National Science and Engineering Foundation' for fundamental research, modelled on America's National Science Foundation, will inject more dynamism into research. The new system, however, will overlay rather than replace the existing, complex arrangements. There are, for example, six bodies responsible for biotechnology funding.

Institutions created in the aftermath of independence still claim the lion's share of public science funding, largely directed towards projects in space, ocean development, atomic energy and defence. Defence absorbs around 60 per cent of government R&D spending, mostly for the almost 50-strong network of labs run by the Defence Research and Development Organisation (DRDO). In other mature innovation economies, notably the US, defence spending plays a significant role in funding research and innovation that eventually spreads more widely across society. But this diffusion depends on an ecology of institutional relationships that India does not necessarily yet have in place.[15]

Figure 2 Source of R&D funding



1	Central and state government
2	Enterprise (private and public)
3	Universities

Source: C Dahlman and A Utz, *India and the Knowledge Economy: Leveraging strengths and opportunities* (Washington, DC: World Bank, 2005).

Higher education

In developed economies, universities are vital sources of science, training the researchers who then work in industry, and forming hubs for clusters such as Silicon Valley. Yet India's universities do not play this role because education and research are separated. Universities teach and government laboratories do research.

The most notable exception, the postgraduate Indian Institute of Science (IISc) Bangalore (Bengalooru), is home to about 2000 postgraduate researchers. The IISc produces more scientific publications than any other Indian institute, as well as India's top-ranking science journal *Current Science*.

Indian Institute of Science Bangalore (Bengalooru)

JN Tata, the visionary industrialist, founded the IISc in 1909. The first Indian director, CV Raman, was appointed in 1934. The institute is neither a national laboratory nor a conventional university. Ranked as the top Indian university in 2005, the IISc is among the top 60 Asia–Pacific universities and one of the top 300 universities worldwide.[16] It was the breeding ground for other prominent institutions such as the National Centre for Biological Sciences and the Jawaharlal Nehru Centre for Advanced Scientific Research, which is presided over by India's top-ranking nanoscientist, Professor CNR Rao.

There are 95 other 'deemed universities',[17] a significant number of which fall under the aegis of the Council for Scientific and Industrial Research (CSIR). The rest of the higher education infrastructure consists of 229 universities and 13 Institutions of National Importance.

There are more than 400 government labs in India. The 38 CSIR labs awarded 350 PhDs and produced 2188 scientific papers in 2004/05, just under 20 per cent of India's total number of scientific publications. Yet the quality of CSIR labs is variable. Some, including the National Chemical Laboratory, the Centre for Cellular and Molecular Biology and the Institute of Chemical Technology, are ranked as excellent but others are regarded as 'white elephants' according to leading academics. Dr RA Mashelkar, director general of the CSIR for the last ten years, has received countless awards for his role in shaping Indian science policy, including two of the highest civilian honours from the president for his role in 'nation building'. During his tenure, CSIR has been transformed into a publicly funded institution guided for the first time by a corporate R&D business plan. It has also become a leading patenting organisation in the developing world, producing 555 patents between 2001 and 2005.[18]

As well as driving the connections between research and postgraduate teaching at CSIR laboratories, Dr Mashelkar has also been a leading proponent of a new set of institutions that will be known as the Indian Institutes of Scientific Education and Research (IISERs). The creation of these new institutions was confirmed by the Indian cabinet in 2006 and could have a dramatic effect on the flows of scientific knowledge. The first two IISERs will be created in Pune and Kolkata with more to follow. They will run a five-year science MSc and aim to produce more than 2000 PhDs a year. The aspiration is to create hybrid institutions with no silos between departments, capable of producing large numbers of graduates and postgraduates, who are well grounded in integrated science and also its application to business.

Beyond the Indian Institutes of Technology?

The IITs take centre stage in the story of India's technological rise. Books about the 'IIT phenomenon' pepper bookshop shelves, explaining how 'IITians', such as Arun Sarin, CEO of Vodafone, Vinod Khosla, co-founder of Sun-Microsystems, and Narayana Murthy, chairman of Indian software giant Infosys, are 're-shaping the world'.

99%

In 2006 about 300,000 students applied to an IIT, with most having spent three years preparing. Yet 99 per cent of these will be turned down.

Yet IITs are not prolific centres of research. They do not produce new inventions, and unlike MIT or Stanford, they do not excel in creating spin-off companies. IITs succeed because of the sheer quality of the undergraduates they produce. Only one in every hundred applicants is accepted (compared with one in six at Harvard) after taking allegedly the hardest entrance examination in the world. In a country of one billion people, 50 per cent of whom are under the age of 25, there are only 4000 new places each year at the seven IITs. This compares with the 4500 students accepted each year into a single dedicated science university like Imperial College London. In 2006 about 300,000 students applied to an IIT, with most having spent three years preparing. Yet 99 per cent of these will be turned down.

At the inauguration of the first IIT in Kharagpur, 100km west of Kolkata, in 1956, Nehru described it as a 'fine monument of India, representing India's urges, India's future in the making'. By 1961 there were five IITs, each created with substantial financial assistance from abroad. UK funders were instrumental in setting up IIT Delhi. An influx of Indian professors returning from the US and Europe meant IITs were international from the start. They were also granted autonomy from the rest of the educational bureaucracy, which meant they developed in a less hierarchical way.

Once accepted as members of this elite, students fight tooth and nail for every half mark, working cheek by jowl with their peers in hostels on campus. According to one IIT professor, the resulting environment is a 'knowledge powder keg'. Yet in some respects, IITs have contributed more to innovation in other countries than in India. An IIT is a departure lounge for the global knowledge economy. Until recently almost all IIT graduates went to elite institutions in the West for their postgraduate studies. But this is changing. According to Dr Mashelkar the number of IITians leaving India after their studies has dropped from 70 per cent to 30 per cent in recent years.

Just maintaining the quality of the seven IITs is a struggle. The director of IIT Delhi admits he is short of dozens of faculty members, with potential teachers drawn to jobs in the booming multinational sector. IITs will not expand into research and spin-off companies when they cannot recruit enough people to teach. As the head of research at an Indian pharmaceuticals company puts it: 'India really needs 70 IITs not seven.' Yet expanding the number of IITs would undermine the elite brand, which is why reforms are focused on upgrading the next level of national and regional technology institutes. As Dr Mashelkar puts it:

IITs take only 1 per cent of those that apply. Imagine what happens to the next 4 per cent of people, all really excellent students. Which institutes do they go to? Those are the ones we have to build up.

The IITs are beacons of Indian excellence. Yet their success comes from creaming off the elite of the education system, who have then tended to work and study abroad. The networks of IIT alumni threaded through the global high-technology sector are now playing a critical role in India's renaissance. Yet the bigger challenge is whether India can create a broader-based infrastructure for technological education. IITs may be a symbol of hope and achievement but they do not necessarily provide a model for India's future.

The impacts of Indian research

The 'hall of mirrors' effect can also be felt in assessments of India's scientific output. A study by Sir David King the UK's chief scientist, published in *Nature* in 2004,[19] assessed national research performance based on a range of criteria, including share of the top 1 per cent of highly cited publications. India came 22nd, with a total of 77,201 publications between 1997 and 2001, of which 205 were in the top 1 per cent of highly cited publications. This compares with 375 in the top 1 per cent for China and 4381 for the UK. India was at the bottom of the spectrum of King's sample when linking such citations to national wealth measured by GDP. These findings are hotly disputed in India. As Dr Mashelkar points out: 'Nothing looks big when you divide by a billion!' Mashelkar has turned King's paper on its head by examining the relationship between citations and GDP per capita. By this reckoning, India jumps to the top of the table.

Table 2 Scientific impact in relation to GDP per capita/year

Country	Scientific publications: SCI publications (1997–2001)	GDP per capita	SCI publications per GDP capita per year	Citations: SCI citations (1997–2001)	GDP per capita	SCI citations per GDP capita per year
India	77,201	487	32	188,481	487	77
China	115,339	989	23	341,519	989	69
US	1,265,808	36,006	7	10,850,549	36,006	60
Germany	318,286	24,051	3	2,500,035	24,051	19
UK	342,535	26,445	3	2,199,617	26,445	18
Japan	336,858	31,407	2	1,852,271	31,407	12
Canada	166,216	22,777	1	1,164,450	22,777	10
Italy	147,023	20,528	1	964,164	20,528	10
Korea, Rep.	55,739	10,006	1	192,346	10,006	4
France	232,058	240,461	0.2	1,513,090	240,461	1

SCI, Science Citation Index
Source: RA Mashelkar, director general, CSIR, presentation to Demos, 27 Jun 2006.

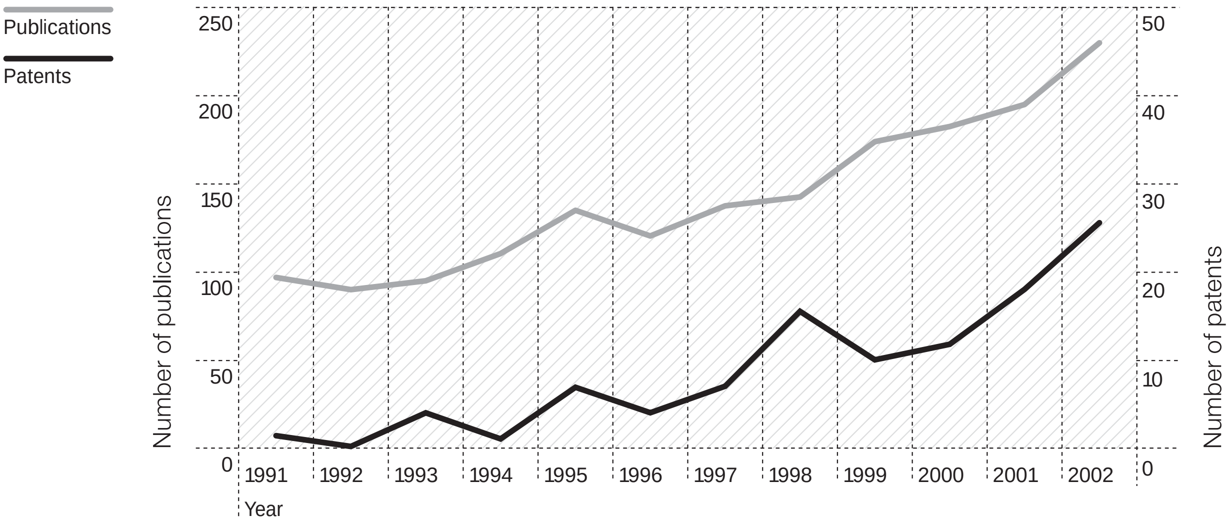
Yet both accounts are correct. Mashelkar's analysis tells us that India's science is successful for a country where most people are poor (see table 2). King's analysis tells us that, despite this, India still punches well below its potential weight.
The available data on publications reflects the different priorities of Indian science. In a country where food production is still a critical issue it should be no surprise that a 2004 study by Thomson ISI found that a majority of 86,440 scientific papers with at least one Indian author were in agricultural sciences.[20] Other areas of relative strength are physics, computer science, materials science, chemistry, engineering and mathematics.

But two emerging areas are particularly interesting as test cases for whether India can fulfil its ambition to become a global science leader: biotechnology and nanoscience.

— *Biotechnology: the 'best batsman' in India's team?*

In March 2005 Kapil Sibal, the Indian science minister, lauded biotechnology as the 'best batsman' in his team and argued that it would be India's 'next big success story' helping to create affordable health care and alleviate poverty. The Department of Biotechnology published a ten-year vision in 2001, which has encouraged a cascade of public investment in the sector, involving at least six other government departments. Funding has increased over the last decade from US$96 million in 1987/88 to $358 million in 2004/05,[21] with a growing share of funding earmarked for biopharmaceuticals rather than agribiotech. The growth in patents and citations shown in the graph in figure 3 is expected to continue.

Figure 3 Indian publications and USPTO patents in health biotechnology (1991–2002)



Source: US Patent and Trademark Office, cited in NK Kumar et al. 'Indian biotechnology: rapidly evolving and industry-led', *Nature Biotechnology* 22 (Suppl) (2004).

Yet biotechnology is at only the start of its trajectory in India, 'a 2–3-year-old baby' according to one pharmaceutical CEO. Scientists in the sector complain that biology research is underfunded. Visitors to the National Centre for Biological Sciences in Bengalooru would be forgiven for thinking otherwise. The director, Vijay Raghavan, claims: 'We don't base standards on benchmarking in India. We base standards on being world class.'

Infrastructure and regulations are being put in place to support a growing industry with international links.[22] In 2004/05, India's biotechnology revenues grew by 37 per cent to $1.1 billion (£600 million).[23] The National Biotechnology Development Strategy set a target for increasing that figure to $5 billion by 2010.[24] The strategy includes an open door for foreign direct investment that should make India more attractive for contract research, clinical trials and validation studies for multinationals. Raghavan claims India will be a leading player:

In 20 years global science will be driven by Indian scientists. There are new interfaces in science, with new rules, where new countries can contribute on an equal footing.

One of these 'new interfaces' among the many sub-fields of biotechnology is bioinformatics. In 2004, the Department of Biotechnology released a plan to turn India into 'a global hub for bioinformatics'. The Confederation of Indian Industry argues that this represents the biggest opportunity for the Indian IT industry since its huge volume of work on the millennium bug. As biotech becomes more dependent on computation, so India's position could strengthen.

Public–private partnerships, still rare in other sectors, are developing fast in bioinformatics. World-class facilities like The Centre for Genomic Application[25] supercomputer research centre in New Delhi should provide an open platform for research. The outlook is positive, but Professor Ashok Kolaskar, chair of the government's bioinformatics task force, has tempered his excitement:

In bioinformatics the country as a whole is moving towards its potential, but to be honest we are currently not even close. Being a democratic country, we have just spread ourselves too thin in the early stages. But in four to five years we will be getting extremely good results.

This may require more focus than is common in India's science strategies. But Kolaskar remains confident that India's bioinformatics industry will have a $2.5 billion turnover by 2010.

— *Nanoscience: can India catch up?*

India was a late starter in nanoscience and nanotechnology, and is still well behind the pack in terms of government investment, allocating $4 million for this field in 2002 compared with $200 million in the same period in China. So far around $24 million has been spent through the Nano Science and Technology Initiative launched in 2001. But in 2006, a national nanotech plan was launched that will invest $200 million over the next five years in areas such as nanotube solar power cells, diagnostic kits and drug delivery.[26]

India is less prolific than China and South Korea in almost all nanoscience disciplines. India's star nanoscientist, Professor CNR Rao, estimates that Indian researchers have published about 100 nanoscience papers in major journals, while Chinese researchers produce more than twice that number each year. This does not factor in the average impact factor of articles, which is likely to show India in more positive light.[27]

Nanotech exemplifies the weakness of an improvised innovation system. Coordination between institutions is limited though is increasing. The government prioritises the creation of nanotechnology enterprises but so far there is limited evidence of public–private collaboration.

Jayesh Bellare, a professor at IIT Mumbai, is one academic with a set of strong industrial connections. Bellare sits on the board of Yashnanotech, a company that collaborates closely with UK-based Cientifica, which in May 2005 announced a joint venture to 'turn India into a nanotechnology superpower', cooperating to provide services spanning the nanotechnology value chain.[28] Bellare points out that even when an area of science becomes a government priority India's innovation system can remain disjointed, limiting its impact:

There is no such thing as an innovation system in India. An innovation system means a chain linking all the way from idea to customer service: the early recognition of the idea, incubation, evaluation for commercialisation and commercialisation. There is no clear path in India – sure we have ideas, but then what do we do with them? There is a big gap in terms of translational research. At every part of the chain there is a hurdle. We need a proper innovation system!

The separation of education and research activities has been compounded by the lack of collaboration between different departments in universities and research institutes. Policy-makers are attempting to strengthen the links between research and commercialisation. When Dr Mashelkar took over CSIR in 1995, he vowed to turn it into CSIR *Inc.* Today, CSIR is the most prolific patenting organisation in the developing world (see table 3). Yet there is still a long way to go: CSIR employees were given the right to start their own companies only in 2005.

Table 3 Top five major PCT (Patent Cooperation Treaty) applicants from developing countries in 2002

Rank	Applicant	Country of residence	No. of applications (based on record copies)
1	CSIR	India	184
2	Samsung Electronics Co Ltd	Republic of Korea	184
3	Biowindow Gene Development Inc	China	136
4	LG Electronics Inc	Republic of Korea	125
5	Huawei Technologies Co Ltd	China	84

Source: World Intellectual Property Organization (WIPO), Geneva, cited in www.ias.ac.in/currsci/sep102003/570.pdf (accessed 25 Nov 2006).

Finding the path to commercialisation is not an easy task, even for renowned labs such as the Tata Institute for Fundamental Research (TIFR) in Mumbai. Dr Bhattacharya, the Institute's director, told us: 'Learning to commercialise is not an easy task for TIFR… There are just no intermediate mechanisms to take [our work] to market.' There are some signs of change. The week after our visit, Dr Bhattacharya was expecting his first-ever delegation of CEOs to visit the research institute, led by Intel. According to Bhattacharya: 'Science in India is finally getting connected up.'

3 People
India everywhere

The 15 largest Indian populations around the world outside India (India's population is 1.1 billion)

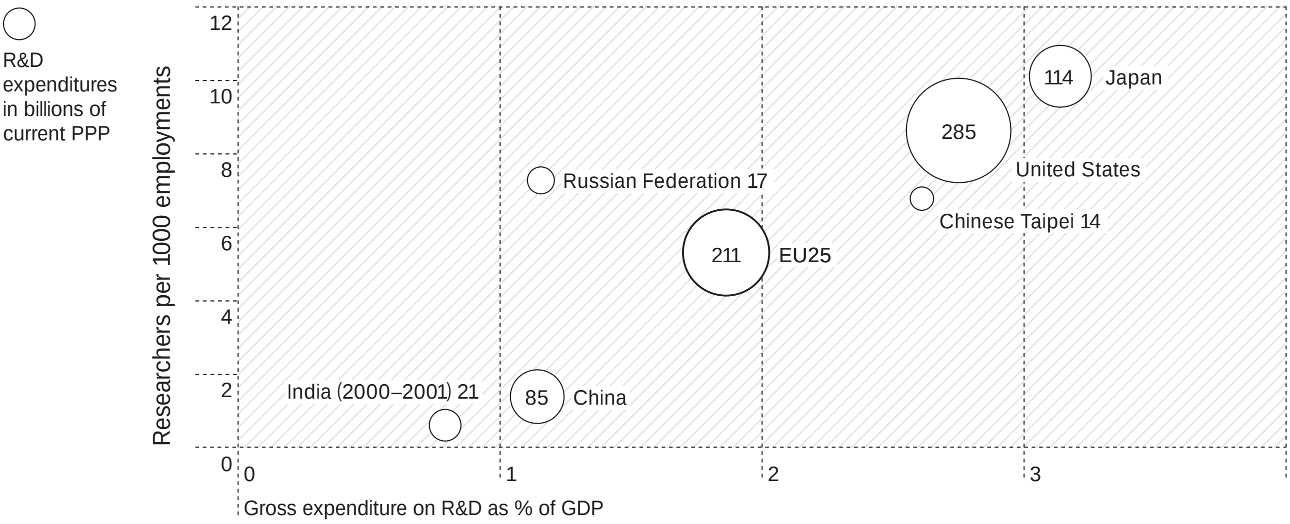
Source: Ministry of Overseas Indians Estimates (Persons of Indian Origin and Indian Citizens – MOI Estimates).
Data available at http://mola.gov.in/ (accessed 6 Dec 2006).

Indian science and innovation is not driven primarily by state initiatives, large companies or big publicly funded R&D programmes; the central players are people, the country's most abundant resource. India's capacity to compete as a knowledge economy depends on its flow of high-quality scientists and engineers – on retaining talent in India and attracting talent back from abroad – by creating an environment in which people can turn ideas into action. Having lots of bright people is not enough on its own – it depends what they can do with their ideas.

One of the reasons that India attracts so much attention in debates over global R&D is that it produces so many graduates. According to McKinsey, the management consultancy, the pool of young Indian university graduates (those with seven years or less of work experience) is about 14 million. That is 1.5 times the size of China's and almost twice that of the US. This reservoir of talent is topped up by 2.5 million new graduates in IT, engineering and life sciences each year, of which 650,000 are postgraduates[29] and between 4000 and 6000 are PhDs.[30] The WEF *Global Technology Report* placed India in pole position in terms of the availability of scientists and engineers in 2004.[31]

However, absolute figures reveal only part of the picture. In China, the number of scientists per unit of population has grown tenfold in the last decade. In India it has stagnated and is well below the corresponding percentage in more developed nations (see figure 4). And according to Indian scientists, especially in the public sector, the shortage of skilled workers remains the main constraint on Indian innovation.

Figure 4 Researchers per 1000 persons employed plotted against R&D expenditure



Note: The size of the bubble represents R&D expenditure in billions of current USD in purchasing power parities (PPP), based on data in constant 2000 prices. For researchers per 1000 persons employed: EU25, 2002; US, 1999; and India, 1998.
Source: OECD, Science, Technology and Industry Scoreboard 2005: Towards a knowledge-based economy; for statistics links see http://dx.doi.org/10.1787/083778005723 (accessed 29 Nov 2006).

Dr Bhattacharya, director of the Tata Institute for Fundamental Research in Mumbai, argues that 'the biggest bottleneck in Indian science is not money – it's a lack of people and a lack of ideas. The human resource crunch is the single biggest difficulty that India faces.'

One threat to publicly funded research is the success of the IT industry. Wages for recruits into the software industry have risen by between 11 per cent and 15 per cent a year since 2003, according to NASSCOM, India's software lobby.[32] Pay for those in senior managerial positions has risen by 30 per cent over the same period. Scientific institutions cannot compete, as academic salaries are tied to government pay scales. As a result much of the best talent is being recruited away from research and into IT.[33]

Furthermore, quantity does not always mean quality. According to Dr Mashelkar, only 10 per cent of India's 229 universities do what he would count as 'good-quality science'. One consultancy suggested that only 10–25 per cent of India's graduates are suitable for employment in multinational companies.[34]

The global Indians

Indian innovation is being driven not so much by the absolute numbers of graduates but by a particular group: transnational, Non Resident Indians (NRIs). NRI is the term used to describe permanent expatriates but also any Indian who has spent a significant amount of time living or working abroad. In recent years, it has become a form of social status, implying a certain level of economic success and cosmopolitanism. Even when NRIs return to India permanently they are often still described as NRIs or alternatively NRI returnees.

A 20-million strong Indian diaspora is scattered around the world. People of Indian origin constitute over 40 per cent of the population of Fiji, Mauritius, Trinidad, Guyana and Surinam and form considerable minority communities in the Gulf, Singapore, the United States, Great Britain and Canada. Around one-quarter of the diaspora live in Organisation for Economic Co-operation and Development (OECD) countries.

Of course, Indians have been mobile for centuries. The first big wave of emigration, from the mid-eighteenth century to the early to mid-nineteenth century, took thousands of labourers to the British, French and Dutch colonies. A significant proportion of the British Indian population have links to India that are a hundred years old. In the late nineteenth century and the early twentieth century artisans and traders spread to East Africa, Natal, Burma, Malay and Fiji. Following the Second World War, large numbers of educated Indians emigrated to developed nations. And from the 1970s, thousands of skilled and semi-skilled workers have gone to oil-rich countries in the Gulf. Indians are now the largest ethnic minority group in the UK, forming 22.7 per cent of the UK's 4.6 million ethnic minority population.[35]

NRIs were once regarded as deserters. But times have changed: the new global Indian identity, legends of success in Silicon Valley and a host of attractive new opportunities on home soil have turned this group into one of the main driving forces of the knowledge economy. They are providing the leadership and management skills, financial and risk capital that are giving momentum to Indian science and innovation.

Talent flows

Until recently almost all graduates with high grades would leave to study and work abroad, especially in the US. In the past decade, these flows have started to go both ways. India's economic and cultural liberalisation since the early 1990s has permitted new lifestyles and opportunities for work and travel, which have attracted talent back from overseas. The brain drain of previous decades has turned into an advantage as Indian ideas and culture have cross-pollinated with cultures overseas. India is no longer seen as a land of mysticism and poverty, but is now associated with a potent mix of East and West, Bollywood and Silicon Valley.

In 2001, 62,000 Indian students left to study overseas,[36] more than 75 per cent of them for the US. The difference is that now many are leaving with plans to return. Professor GD Yadav, of the University Institute of Chemical Technology in Mumbai, describes how his students are still going abroad:

The difference now is that they come back, or if they don't come back, they keep a close eye on what is going on here and maybe one day, a few years later we get a message asking if we want to collaborate.

The circulation of brainpower is reshaping the global knowledge economy making once peripheral zones, such as India, central to emerging innovation networks. AnnaLee Saxenian of the University of California at Berkeley has studied these talent flows extensively. She describes how 'engineers and entrepreneurs, aided by the lowered transaction costs associated with digitization, are transferring technical and institutional know-how between distant regional economies faster and more flexibly than most large corporations'. As a result countries like India are better connected to the core of technological activity:

The old pattern of one-way flows of technology and capital from the core to the periphery is being replaced by a far more complex and decentralised two-way flow of skill, capital and technology between differently specialised regional economies.[37]

Unlike China, Taiwan and Korea, where government policies are used to attract back returnees, in India the flows are organised bottom up, in response to emerging private sector and lifestyle opportunities. Colonial-era Indian science was embodied in the 'colonial scientist', invariably a redoubtable British engineer. Now Indian innovation is symbolised by the NRI – a mobile and entrepreneurial returnee with strong, transnational networks.

“ ”

Of all the India's national assets, it is the Non Resident Indian base that has a far greater value than anything else.
Ramalingu Raju, CEO
Satyam Computers

Returning to India in the 1970s was widely regarded as irrational, in part because living conditions were rudimentary. When Dr RA Mashelkar returned to India in the mid-1970s, the flat he shared with his wife had only a small kerosene camping stove. They waited two years to acquire a black and white TV and six years for a phone line.

The current generation does not have to make such sacrifices. Many aspire to live with a foot in two countries at the same time. Easier travel and communication combined with networks and associations of nationals living abroad have made it possible for global Indians to live in one country, while residing in another. As Professor Rajendra Lagu of IIT Mumbai says:

People look at Indians differently now. Customs officials used to look at me warily when I showed my passport. Now I'm waved through without a glance. A new Indian identity has taken the place of the old.

India's efforts to attract NRIs have been low key compared with China where the government has created knowledge parks and offered attractive incentives to returnees. But one contribution has been the creation of hybrid forms of citizenship. Until 2006, dual citizenship with India was impossible, with the problematic status of Person of Indian Origin the only alternative. In 2006, Prime Minister Manmohan Singh awarded the first-ever 'Overseas Citizen of India' card, to a female scientist, Nivruti Rai, one of the highest ranking IT professionals working at Intel in the US.

Yet far more important than overt government policy, it is the quality of life for professional middle classes in thriving Indian cities that appeals to NRIs. Huge billboards flank the roads that lead to technology parks, be they in Noida near New Delhi, Whitefields in Bengalooru or Hinjewadi in Kolkata. With watercolour paintings of exclusive apartment blocks, they entice prospective buyers with names like ‘Utopia village’ or ‘NRI lodge’. These compounds make it as easy as possible for NRIs to plug back into their country of origin. Shiny air-conditioned, glass-fronted shopping malls, complete with multiplex cinemas, provide NRIs with familiar shops, while the profusion of coffee-shop chains like Coffee Day and Barista are creating a café culture familiar to any Londoner. Cell phones have made the struggle to get a landline irrelevant.

For this younger, more entrepreneurial generation the US is the obvious place to go, just as Britain may have been for their parents or grandparents. Sridhar Iyengar, President of the Board of Trustees for The Indus Entrepreneurs (TiE), a leading diaspora organisation, says that the US is developing stronger connections to India than those between India and Britain because the social links are fresher. He explains: ‘Indians went to the UK to “serve”, they went to the US to learn.’ NRIs are critical to India’s interdependent approach to innovation in several ways.

— *Multinational company (MNC) pilots*
NRIs have piloted the creation of multinational R&D centres. A typical example is Naresh Gupta, an IIT graduate, who developed Adobe’s plans for the Noida R&D centre near New Delhi in 1997 after working in San Jose. MNC ‘pilots’ like Naresh Gupta and ARM’s Guru Ganesan say it takes an Indian to navigate and negotiate the vagaries of the Indian system.

Soon after setting up shop, Gupta’s team was given a problem that two groups in the US had failed to solve. They did it in less than a month. The Noida centre, complete with table football, table tennis, golf and basketball facilities, now employs more than 400 R&D staff.

— *Science leaders*
Most scientists in top jobs in the best institutes studied and worked abroad. Sabyasachi Bhattacharya, director of the prestigious Tata Institute for Fundamental Research in Mumbai, returned from the US in 2002 from the NEC Research Institute near Princeton. Ranjan Chackrabarti, vice president of Discovery Biology at Dr Reddy’s Labs (DRL), has worked for DRL since 1995, when he finished his postdoctoral studies in UMASS Medical Centre in Boston.

There are those who criticise the focus on NRIs. In an essay entitled ‘Requiem for a missing generation’, IISc director Professor Balaram argues that greater efforts should be devoted to bringing home-reared talent up to scratch.[38] Another eminent professor expressed fears that ‘it creates a hierarchy of science and innovation: talent raised in India is seen always as inferior to that from abroad’.

— *Micromultinationals*
A new breed of transnational entrepreneur is creating micromultinationals – start-ups such as July Systems, Infinera and InSilica with sales, marketing and brand based in the US but with a back office and technical support in India.

Rakesh Mathur is one example. Mathur moved to the US after graduating from IIT Mumbai. Since working for Intel, he has become a ‘serial entrepreneur’. His most successful venture, a comparison-shopping service called Junglee, was acquired by Amazon in 1998 for $241 million. Although he lives in Santa Clara in California, he visits India at least once a quarter. One of his recent ventures, Webaroo, a software service for mobile phones and laptops that lets you search the web offline, has an R&D base at his alma mater IIT Mumbai's incubator. Mathur explained: 'It's the cost and the leverage… If you raise $5 million you can make five times the mistakes.' For him, IITians are simply the only graduates that will do.

New players in a new innovation game

Global networks and flows of Indians are a crucial component of India's science and innovation story. They are taking advantage of globalisation at precisely the moment when they can have the biggest impact on India's economic dynamism. This shows just how important new and unusual combinations of cultural, technical and organisational knowledge can be during periods of rapid change.

India faces serious policy challenges: how can these flows be maintained and used productively without India becoming overly dependent on them, detracting from the need to develop home-grown talent? There is the danger of a hierarchy of innovators that may lead to divisions within the scientific community.

This also creates significant issues for the UK. Our links with India are strong but old. Among well over a million people of Indian origin in Britain there are huge opportunities to catalyse activity. But there is a danger of these opportunities withering through complacency. How can the UK improve its relationships with India through the diaspora, and reinvigorate a younger, more entrepreneurial set of connections?

4 Places
The changing landscape of Indian science

There will be no more expansion plans in Bangalore [Bengalooru]. The state is not attractive for investors any more… Infrastructure is a mess.
Jurgen Schubert, managing director Siemens India, 10 February 2006

Bengalooru has played the starring role in India's emerging knowledge economy. Home to more than 1000 technology firms, from two-person start-ups to multinationals, it has long been the cosmopolitan cradle of India's software success – about 300,000 of the city's seven million population are employed in IT.

Yet Bengalooru is now being challenged by other Indian cities. Thirty Indian cities have a population of more than a million and several, including Hyderabad, Mumbai, New Delhi and Chennai, are strengthening their position as hubs for R&D. This premier league is in turn being challenged by second-tier cities such as Pune and Ahmedabad. Bengalooru may have captured much of the attention to date but the geography of Indian science and innovation is about to become a lot more complex.

Bangalored out?

The one thing that everyone in Bangalore (Bengalooru) complains about is the traffic. The city's dilapidated infrastructure is creaking, with 900 vehicles added every day to its roads. Multinational companies (MNCs) echo Siemens' view that government must invest more in infrastructure to ensure Bengalooru keeps growing. One senior employee of GE told us:

There is little room for growth. MNCs are saying 'no more in Bangalore'. New set-ups will either have to be entirely self-contained or housed in the next set of towns.

There are prospects that things may improve. The international airport under construction at Devanahalli, 30km outside the city limits, is due to open in 2008, replacing the inadequate HAL airport, which was built for military use.

Sorting out these infrastructure problems will be critical, because Bengalooru is home to some of the crown jewels of Indian research: the Indian Institute of Science, whose leafy avenues and sandstone clock tower are more reminiscent of Cambridge than Calcutta, is the most prolific producer of scientific research papers in the country; institutes such as TIFR's National Centre for Biological Sciences and the Jawaharlal Nehru Centre for Advanced Scientific Research are among the best in India.

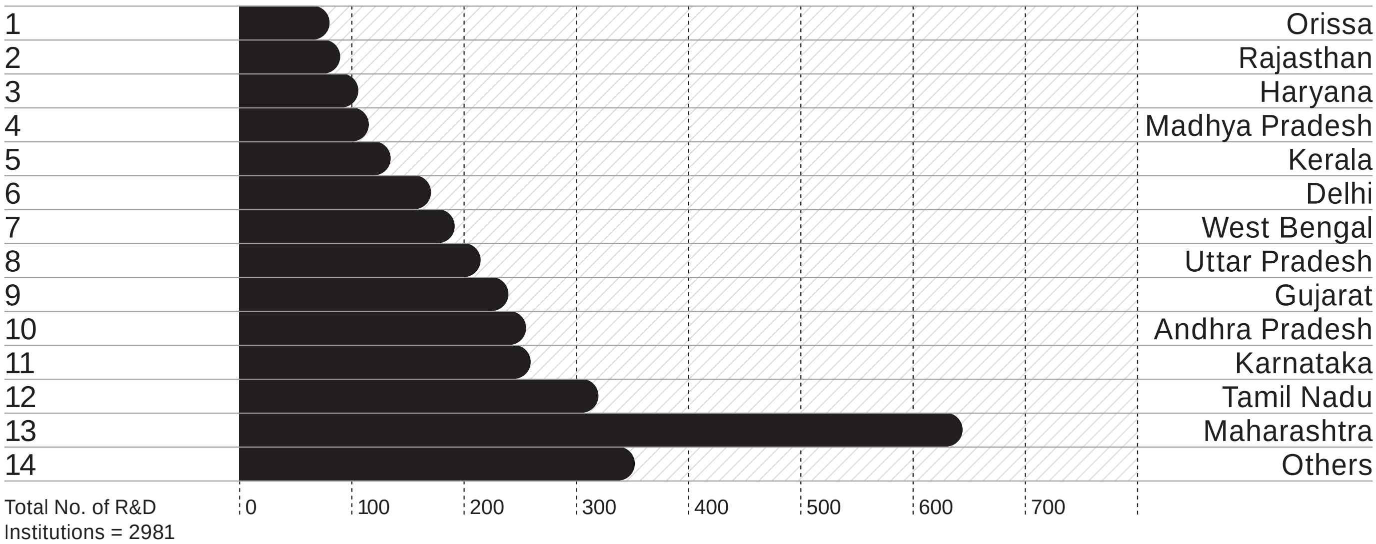
Bengalooru has the second largest concentration of venture capitalists after Mumbai. In a country of intense inter-city rivalry, New Delhiites may be unlikely to invest in the Mumbaikers, and Bengalooru has profited from its 'neutrality'. Its connections to other innovation hubs, in particular Silicon Valley, mean it is already an established node for international flows of people and ideas.

Bengalooru: software by any other name would smell as sweet

The accentuation of inequalities between the highly paid 'haves' in the IT industry and the 'have-nots' is fuelling a nationalist backlash against the city's links to the global economy. The most obvious expression of this is the decision to change the city's name to Bengalooru. Leading figures such as Infosys boss Nandan Nikelani fear this will damage the city's global brand. But name changes do not seem to have harmed Mumbai (Bombay) or Chennai (Madras). According to the *New York Times*, Bengalooru is a shortened version of 'Benda Kalooru', or 'city of cooked beans'.[39] The state government of Karnataka also recently decided to ban government primary schools from teaching in English in favour of the local language of Kannada to ensure its preservation.

Bengalooru may attract the headlines but R&D institutions are quite evenly dispersed, as figure 5 shows. Funding is concentrated in the states where the 'big five' cities of Mumbai, New Delhi, Chennai, Hyderabad and Bengalooru are found. Although state governments have little or no budget for science, they can create packages to attract R&D and they control state universities.

Figure 5 Distribution of R&D institutions among Indian states



Source: NSTMIS 2001 Research Handbook, Department of Science and Technology, Government of India.

— *New Delhi*
New Delhi has a large concentration of top educational institutions including 131 colleges (five medical colleges and eight engineering colleges including IIT Delhi), four universities, seven deemed universities and five CSIR labs. New Delhi's satellites towns, Gurgaon and Noida, have grown rapidly through outsourced IT services and call centres, and are now attracting corporate R&D centres.

— *Hyderabad*
There's a buzz about the future of Hyderabad, the capital of Andhra Pradesh, which is widely regarded as one of the most innovative states. Home to two federal, two state and two deemed universities, Hyderabad is home to a disproportionately large number of IT training institutes as well as top government institutes such as the Centre for Cellular and Molecular Biology, the Centre for DNA Fingerprinting and

Diagnostics and the Indian Institute of Chemical Technology. Andhra Pradesh has also started to win high-tech investment away from Karnataka.

Nicknamed ‘Cyberabad’ for its extensive IT population, Hyderabad also hosts the ‘Genome Valley’ biotech and pharmaceuticals cluster. One biotechnologist told us: ‘Hyderabad is likely to be a bigger success story than Bangalore [Bengalooru] – it is growing faster and is far more diverse.’ A third of investments made by the Technology Development Board, the government fund, have gone to Andhra Pradesh in recent years. According to one technology financier: ‘Andhra Pradesh simply has the most entrepreneurial culture in India.’

— *Mumbai*

Mumbai, the capital of the huge state of Maharashtra, is India’s most populous city, with 13 million people, and its financial hub. It is home to an IIT, the University of Mumbai (one of the world’s largest universities with 354 affiliated colleges and two postgraduate centres), and newly privatised dynamic institutions such as the University Institute of Chemical Technology. Mumbai’s diverse industrial foci include IT, pharmaceuticals and engineering. The availability of capital is a big draw for entrepreneurs. Entertainment, film and creative industries – led by the growing world audience for Bollywood – have helped to make Mumbai a global city.

— *Chennai*

Chennai, capital of Tamil Nadu, is home to a large number of multinational R&D centres in several software parks and two biotechnology parks, as well as a large share of India’s automotive industry, an IIT and several government labs.

Behind these established science centres a group of ambitious ‘second-tier cities’ is now emerging as possible new players in science and innovation.

The next tier

Ahmedabad is ranked fifth most attractive destination for IT services in India,[40] and has benefited from pro-industry Gujarat state policies, which are a big draw for NRI investment. Ahmedabad is home to pharma companies like Sun and Cadilla and the Indian Institute of Management.

Chandigargh, known as the ‘Silicon Valley of the North’, is well connected to New Delhi, and reputedly has the highest quality of life in India and an 82 per cent literacy rate (compared with a 64 per cent average).[41] Already home to infotech and software parks, Chandigargh will soon be the site of a prestigious centre for bionanotechnology.

— *Pune*

But one city stands out among these newly emerging hubs: Pune.

With a population of 3.4 million Pune is India’s seventh largest city and in 2006 earned third place in *Forbes* magazine’s list of the most promising locations for global business. During our research, at least 75 per cent of respondents mentioned Pune as one of the most interesting hotspots for innovation in India.

Pune University’s vice chancellor, Ashok Kolaskar, describes Pune as a ‘centre of gravity for change’, a base of revolutionary movements from the time of the Moghuls to the British. The forerunner of Pune University, Fergusson College, was the first in India to educate women. Today, Pune is cosmopolitan and open: the university hosts more than 6000 international students, mainly from oil-rich and developing countries, but also increasingly from the US and Europe. Many of the students live with local families, in a system uncommon elsewhere in India.

Pune hosts a concentration of scientific institutions: the National Chemical Laboratory; the Indian Institute of Tropical Meteorology; the Inter-University Centre for Astronomy and Astrophysics; the National Centre for Radio Astrophysics (which runs the Giant Metrewave Radio Telescope); the Centre for Development of Advanced Computing; and the Institute of Bioinformatics and Biotechnology. Pune has also tried to dissolve the dividing line between research and education: most of these research institutes are clustered on the university campus. It has recently been chosen as the site for one of the government's flagship Integrated Institutes of Scientific Education and Research. Pune also has access to engineering and finance, and Mumbai, the financial capital, is only a three-hour drive on the expressway.

No wonder Pune is frequently described as 'the Oxford of the East'. Sridhar Iyengar, of The Indus Entrepreneurs (TiE) network, has no doubt about Pune's prospects: 'Pune is the next Bangalore [Bengalooru]. It has a unique combination of traditional manufacturing with tech on side.'

— *Kolkata*

If Pune is a safe bet for future innovation, Kolkata in West Bengal is more of a wildcard. One interviewee told us that, until recently, Kolkata had been 'left for dead' in terms of innovation. But Kolkata is stirring. A senior GE employee revealed: 'I never thought it was possible, I thought [West Bengal] was a dustbin case. Suddenly it is starting to deliver.' Similarly, Chandar Sundaram, a senior executive at Microsoft, describes Kolkata as 'one of the next hot places for technology'.

Kolkata is India's third largest city after New Delhi and Mumbai, and was the capital of British India from 1772 to 1912. It remained prosperous until 1947. West Bengal was renowned as India's economic and intellectual leader for centuries, until, according to the Nobel Laureate VS Naipal, 'it discovered Marxism and like poor Russia in 1917, committed suicide'.[42] The Left Front coalition of Communist and Marxist parties has ruled West Bengal since 1977. Many people credit the changes in West Bengal to the current chief minister, Buddhadev Bhattacharjee, who has welcomed foreign investment. In September 2006, IBM, which employs 43,000 people in India, made Kolkata its second largest Indian centre after Bengalooru. And Kolkata could become particularly important for the UK: historic ties with the city may offer rich opportunities for collaboration.

Predicting the future hot spots of Indian science is no easy business. One clear dynamic to emerge in our study is the importance of city regions as the locus of innovation growth. Innovations tend to come from particular places and it is undoubtedly true that Bengalooru has put India on the map. The most innovative European nations, like Finland and Sweden, tend to operate at a relatively small scale. Similarly, US innovation strategies are often driven by state governments and regional specialisation. This raises important questions about the powers, resources and capabilities of regional government and networks, and the kinds of infrastructure and planning which will underpin successful innovation systems in the longer run. UK policy-makers and businesses need to understand a lot more about these dynamics in India.

5 Business
The entrepreneurial ecosystem

Until recently, India's private sector did very little R&D. In colonial times technology and know-how flowed into the country, promoting dependency and displacing indigenous innovation. Yet the closed and planned economy that followed was equally inimical to innovation. Companies were not allowed to have foreign operations. Tariffs made imports prohibitively expensive and lengthy approval processes made it difficult to buy new technology. There were few incentives for innovation; companies were prevented from expanding into markets reserved for competitors. Demand always exceeded supply, so marketing skills were unnecessary. Business was so wrapped up in red tape that the state was nicknamed 'the License Raj'.[44]

The economic reforms that began with liberalisation in 1991 may turn out to be as important for India's future as the political revolution of 1947.[45] A balance of payments crisis paved the way for then Prime Minister Rao to slash trade barriers, open up India for foreign investment and introduce privatisation. Many economic and social developments in India over the past two decades flow from these reforms.

Two decades on, some areas of Indian business are now investing in innovation: pharmaceuticals, automobile design and parts of the IT sector. Yet for many sectors, innovation is still an unfamiliar concept. A study by the Administrative Staff College of India found that 86 per cent of Indian companies spent nothing on R&D.[46] Even some of the modern corporate success stories – the IT outsourcers – spend surprisingly little on innovation.

Pharmaceuticals: a new model?

— The Indian pharmaceuticals market is valued at $8.2 billion: one-sixth of the global market.
— It is the fourth largest in terms of volume and the 13th largest by value.[47]
— It is growing at around 7.2 per cent per annum, primarily driven by exports.
— The industry's sales were about $4.6 billion in 2004, projected to rise to $8.3 billion by 2009, an increase of 80 per cent in five years.[48]
— India has 20 per cent of the global market in generic drugs.
— By 2010, the Indian industry aims to be 'innovation-led' with sales of $25 billion and a market capitalisation of $150 billion.[49]
— Leading Indian pharma companies are beginning to spend significant proportions of their sales revenues on R&D. Dr Reddy's Labs spent 15 per cent ($64 million) in 2004/05 (GSK spent 14.8 per cent of its sales in 2005 – $4 billion).
— Indian pharma companies are also producing more advanced drugs, for example to treat cardiovascular problems or disorders of the central nervous system.[50]

A growing number of Indian pharma companies are moving from making generic drugs or providing contract research services for western companies, to creating new drugs through their own research. Pharmaceutical R&D spending in India increased 300 per cent between 2000 and 2004 from two to eight billion Rupees.[51] Dr Mukherjee, chief scientist at New Delhi-based Dabur Pharmaceuticals, characterised their business plan as an attempt to move 'from a generics model to a leadership model'.

Indian companies have two distinct advantages. First, they can tap into large pools of researchers who are relatively cheap to employ by international standards. Second, they are drawing on their experience of outsourcing to develop global innovation networks that could be cheaper than the traditional pipeline models of established companies in Europe and the US.

Swati Piramal, director of strategy and communications for Nicholas Piramal Pharmaceuticals and the only woman on the prime minister's Scientific Advisory Council, is confident that: 'India will do things differently… At the beginning of my career all the talk was about reaching western standards, now it's about creating Indian standards.' Nicholas Piramal Pharmaceuticals' first global patent in 2001, for example, was for a product developed at a clinic in Canada, based on research done initially in Mumbai and then in the UK, US, Taiwan and China. Dr Reddy's Labs has one molecule at phase I trials in Belfast, and another at phase II in Canada.

Nicholas Piramal's relative inexperience in drug discovery may count against it. Yet the Indian entrants into research could also create cheaper, more networked approaches to innovation. Piramal's goal is to get a new drug to market at a cost of $50 million, one-twentieth of the cost of traditional approaches: 'It's a distant dream, but even if our estimates are out by 100 per cent that would still be a drug for only $100 million.' She claims they are on track to meet this target.

Indian IT: from 'coolies' to creatives?

- The 2002 NASSCOM–McKinsey report on IT in India predicted that software and services will contribute over 7.5 per cent of the overall GDP growth of India in 2008.[52]
- Software and IT-enabled services (ITES) exports from India grew from US$12.9 billion in the year 2003/04 to US$17.7 billion in 2004/05.
- The Indian software and ITES industry has grown at a compound annual growth rate of over 28 per cent over the past five years.
- The industry's contribution to the national GDP has risen from 1.2 per cent during the year 1999/2000 to a projected 4.8 per cent during 2005/06.
- IT exports are predicted to account for 35 per cent of the total exports from India in 2008, while the industry is expected to attract FDI of US$4–5 billion by this point.
- The total number of IT and ITES-BPO (business process outsourcing) professionals employed in India is estimated to have grown from 284,000 in 1999/2000 to 1,287,000 in 2005/06, growing by over 230,000 in the last year alone.[53]

The Indian IT industry is a somewhat ambiguous success story. India's 3000 IT companies, including those such as Wipro and Infosys, which have a global reach, account for 35 per cent of exports by value and 7.5 per cent of GDP growth. Yet the industry has grown up serving foreign multinationals, creating few of its own products, brands and relatively little intellectual property. Infosys spends only 1 per cent of its sales revenue on R&D.[54] The industry's critics argue this kind of dependence is a development trap. The most likely source of home-grown innovation is likely to come from the next generation of Indian IT companies. As we were told on several occasions: 'Just because you don't see it doesn't mean it isn't happening.'

Intellectual property

Inadequate intellectual property (IP) regulation is often cited as a barrier to closer collaboration with emerging science and innovation economies. But while India's hard infrastructure of roads and buildings may lag behind China, its soft infrastructure for innovation, including the IP regime, is developing fast. A recent *Wall Street Journal* article put it this way: 'India is rapidly evolving into Asia's innovation centre, leaving China in the dust. Its secret weapon? Intellectual property-rights protection.'[55]

Patenting in India picked up in the second half of the 1990s, following India's accession to the WTO in 1995 and alignment with the TRIPS intellectual property agreement. Indian patent law has been updated twice within the last decade, most recently in 2005, and a dedicated IP court is under discussion. The majority of patents in India are still filed by foreign multinational companies.

It is difficult to judge what impact these new regulations are having on patenting in India, still less on innovation. Dr Sridhar Mitta from e4e computing in Bengalooru told us: ‘IP development is happening at all levels in India… But unlike China, where everything is orchestrated by the government, in India it is uncontrolled, chaotic, invisible.’ India’s leading source of patents is the government’s Council for Scientific and Industrial Research but the pharmaceuticals sector is close behind (see table 4).

Table 4 Ranking of top five Indian players among the PCT rankings of developing countries in 2002

Rank	Indian applicant	No of applications (based on record copies)
1	CSIR	184
2	Ranbaxy Laboratories Ltd	56
3	Dr Reddy’s Laboratories Ltd	19
4	Orchid Chemicals and Pharmaceuticals Ltd	16
5	Biocon Ltd	10

Source: (WIPO), Geneva, cited in www.ias.ac.in/currsci/sep102003/570.pdf (accessed 25 Nov 2006).

Organisations that only a few years ago found the concept of intellectual property irrelevant now patent assiduously. Professor Yadav from the Mumbai University Institute of Chemical Technology admits that until a couple of years ago his institute rarely patented: ‘But all that has changed – now we patent rigorously.’ Incubators and even students are showing a growing interest in patenting their know-how, as Professor Jayesh Bellare, from the IIT in Mumbai, explains: ‘There is a new realisation of the importance of IP. Students now ask me religiously “should we patent before we publish?”’ Patent facilitation cells (offering support but not necessarily money) have been created in the IITs and other top institutes.

However, counterfeiting is still rife, especially in software and media products. Three-quarters of Indian software is pirated[56] and patenting is too expensive for most smaller companies. The implementation and policing of patent law leaves something to be desired. With the exception of Indian pioneers such as Sasken or Ittiam, few companies take advantage of the revenue-making possibilities created by intellectual property. Indeed a large proportion of India’s international patents come from multinational development centres and the pharmaceuticals sector.

Boost or barrier? The impact of multinational R&D centres

If you have travelled on an airplane with a screen mounted on the seat in front, you have probably used technology created by an Indian start-up, Ittiam.

Chosen as one of Red Herring’s top 100 Asian companies in 2005, Ittiam, short for ‘I think therefore I am’, designs software for portable devices like digital cameras and MP3 players. CEO Srini Rajan, who is every bit the American technology entrepreneur, had a long career with Texas Instruments, culminating in becoming managing director for its Indian subsidiary in 1995. He set up Ittiam with six Texas Instruments colleagues in 2001:

We wanted to do something that was beyond entrepreneurship. We thought that India needed to create giants of its own. That it needed companies with drive and passion, even nationalism.

Only one in every 500 applicants for a job at Ittiam makes the cut. The company presentation to new recruits focuses on its Indian roots. Rajan explained: ‘I make a lot out of the fact that we are Indian and we are going places.’ Investors on the other hand see a presentation that focuses only on Ittiam’s global position.

Ittiam could be among the first in a new wave of Indian entrepreneurial companies spun out of multinational R&D centres. Multinational R&D in India is growing rapidly, attracted by the skills of the workforce as much as low costs. Since Texas Instruments set up the first MNC R&D centre in 1985 the landscape of innovation in India has changed dramatically.

In 2006, India was host to about 150 multinational R&D centres, more than 100 of which were opened since 2002.[57] Foreign companies invested $1.1 billion in R&D in India between 1998 and 2003.[58] Large companies are increasingly adept at managing global innovation networks to draw on pools of relatively cheap but highly qualified brainpower. A recent survey by PricewaterhouseCoopers found that 35 per cent of multinational CEOs were likely to do business in India because of the available talent pool compared with 22 per cent for China and only 12 per cent for Russia.[59]

Multinational investment is an endorsement of India’s capacity for innovation, vital for a country keen to project itself internationally. Yet there is also a long-standing debate about how much it contributes to, or erodes, the host country’s knowledge base.

Critics argue that multinationals can be bad news for the Indian public sector. Government labs and academia cannot compete with the salaries offered. Academics complain that their best pupils are drawn to the lifestyle of working for a multinational, despite being overqualified for the tasks they are asked to undertake.

Some centres carry out ‘blue collar’ research, adapting research done overseas but not generating their own knowledge. Rather than adding to the local innovation system, these centres can be as disconnected locally as they are connected internationally. Professor P Balaram of the Indian Institute of Science Bangalore (Bengalooru) notes that:

These companies are only geographically located in Bangalore [Bengalooru], they contribute little to the science base here. In fact, as the R&D centres grow, interaction with science diminishes.

Academic studies show there is little knowledge spill-over to local firms when centres are poorly integrated into the local system.[60] However, supporters of multinational R&D point to longer-term benefits. Companies like Microsoft, HP and Phillips are retaining talent in India that would have left the country to find opportunities overseas. They help to attract back skilled NRIs who left because of the dearth of such opportunities in the past.

Over time, the balance of work is shifting from development to research. Texas Instruments, Oracle and Adobe have developed complete products in India and GE now conducts almost a full range of research at the John F Welch Technology Centre in Bengalooru. The UK company ARM does the same range of research in India as in Texas. Microsoft has 700 research staff in Bengalooru, making it the company’s third largest laboratory outside the US, after the UK and China.[61]

Multinational R&D centres will boost India’s capacity for home-grown innovation only if there are spill-overs into the local economy, with more people like Rajan starting companies like Ittiam. That in turn will depend on the climate for high-tech entrepreneurship.

At the moment, multinationals are disconnected from local innovation in part because often there is no local innovation system to connect to. Indeed some multinational centres may be helping to create such a system by contracting with universities to do research and spawning spin-off companies that may lead indigenous innovation. Professor Lagu, CEO of the SINE incubator at IIT Mumbai, says he receives at least one enquiry a week from a design team working for a multinational wishing to start their own venture. Some multinationals are encouraging these spin-outs themselves. Naresh Gupta, CEO of the Adobe Research Centre near New Delhi, supports employees wanting to build their own companies. His centre has so far spun out seven companies.

Growing pains

Failure is not an option for Bengalooru-based Qtech Nanosystems, which was founded by five young friends and first-time entrepreneurs who between them boast an impressive list of Indian and international degrees. They met in the coffee shop of the Indian Institute of Science Bangalore (Bengalooru) in December 2004 and by February 2005 they had created a company to take on the world’s best in nanomaterials, thanks in part to a professor at IIT Chennai turning a blind eye to Qtech’s CEO Alam continuing to use his labs after graduating.

The company’s makeshift HQ is in a residential street, just round the corner from a motorbike repair shop, with a cow grazing outside. Four worn out armchairs sit in one small room with a couple of PCs and a shelf of samples in the other. Qtech plans to design and patent nano products and processes, and then license them around the world.

Qtech’s dream is to create an Indian high-tech company in Bengalooru. They thought raising finance would be easy. They had two patents and knew they were ahead of their nearest competitors. They planned to keep their operations low cost, renting time and equipment from facilities already available in Bengalooru and using the cheapest possible office space. Their product is nanotalc, an ultrafine powder added to paint and plastics to improve their performance. Qtech’s process creates high-quality nanotalc in 45 minutes while that of their closest competitor takes three hours.

Qtech approached venture capitalists for $1 million to get the company through its first three years. But the venture capitalists they talked to weren’t interested in making investments of less than $3 million and they wanted the company to have a track record before they signed a cheque – difficult for a company less than 12 months old.

Frustrated by venture capitalists and exasperated by the government’s Technology Development Board, Qtech finally got backing through a CSIR scheme – the New Millennium Technology Leadership Initiative (NMTLI), which seeks to build Indian capabilities in frontier areas of science. They discovered this after spotting a tiny advert in the bottom corner of a newspaper page. As Alam put it: ‘It was luck that we spotted it. The advertisement appeared for just one day. It’s as if they don’t want people to know there is money available.’

Qtech’s experience illustrates just how hard it can be to commercialise emerging technologies in India. If NMTLI funding does not work out the Qtech team will have to go abroad to pursue their ambitions. An entrepreneurial ecosystem is crucial for innovation. For most of the twentieth century, innovation came mainly from R&D

done in large manufacturing companies. The rise of Silicon Valley ushered in a new model in which high-growth entrepreneurial start-ups exploited new technologies and ideas faster than big companies, especially when backed by venture capital funding. In a world of fast-expanding knowledge, smaller and more nimble companies often see opportunities before their larger competitors.

There are signs of change. Sridhar Mitta, a Silicon Valley old hand and managing director of Bengalooru-based technology incubator e4e, believes the entrepreneurial ambience of Silicon Valley is finally spreading to India: 'If entrepreneurship is really present, it infuses everything; it becomes a part of daily life.' Mitta visited a temple to ask for a blessing for a new venture from Ganesh, the elephant-headed Hindu God of success, a common practice in India. The Hindu priest offered his blessing, and then earnestly turned to ask the supplicant whether he had his funding in place. 'Because if not', he confided to Mitta, 'I know a great VC…'

The venture capital (VC) industry is still at an early stage, and regulations are holding growth back. But it is developing in pockets, with capital and skills from the US. The amount of venture capital available in India has doubled since 2000, and a large number of American VC firms now have permanent offices in the country. Nokia and Intel recently announced plans for India-focused VC funds worth $250 million. The IT companies that fuelled the rise of Bengalooru did not require and probably could not have raised venture capital. But the next generation will need a better climate for VC if they are to grow firms that create their own intellectual property.

Word is spreading fast that more capital is available, and NRIs and returnee Indians are making a beeline for it. The APIDC fund in Hyderabad, a joint venture between the Andhra Pradesh Industrial Development Corporation and Dynam Venture East of USA, is one such honeypot for entrepreneurs. More than 60 per cent of applications for this public–private partnership fund are from US-based NRIs. With an initial fund of $30 million it is India's only biotech-focused VC.

Overseas Indians in the US and Singapore are also behind a number of technology incubators. Incubators are a relatively new phenomenon in India and many are getting off to a slow start. Most activity in incubators appears IT-focused. Incubator managers insist their aim is to create companies that can exploit their own intellectual property rather than provide services.

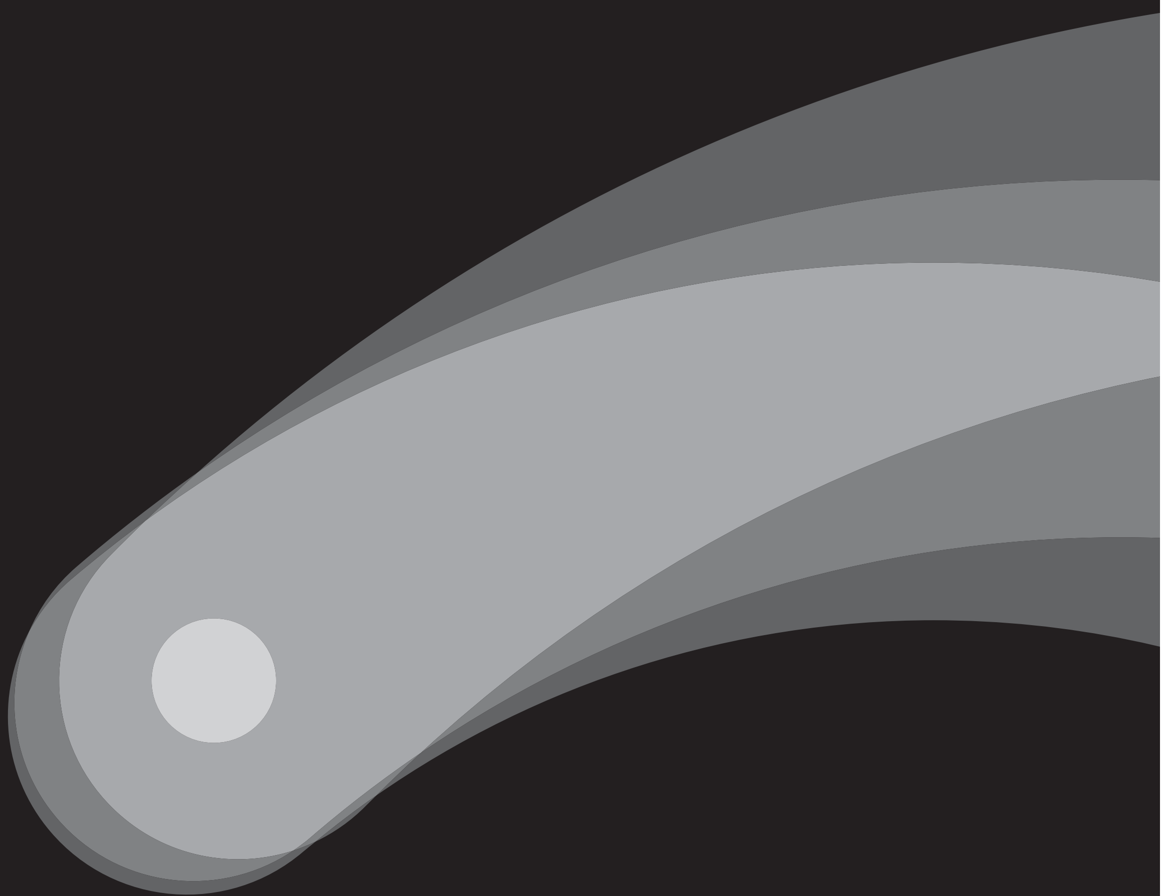
The shifting balance of R&D

Indian businesses are still learning what is involved in innovation, but important shifts are under way. Leading companies in sectors such as pharmaceuticals are moving to business models based on innovation, often exploiting global connections and flows of people. The climate and infrastructure for innovation is improving, with more venture capital and incubators. That change in climate is the result of factors such as WTO rules and the unfolding impact of liberalisation. Multinational investment in R&D is increasing, which in turn may start to spill over into the local economy. But many Indian firms, for so long recipients or at best copiers of western technology, are now in uncharted waters. This latest phase of Indian innovation has only just begun.

6 Culture
Science at the interchange

'There are many superlatives now written about India: the offshore IT centre of the world, the sixth nuclear weapons power and the second largest generator of science and engineering graduates… but there is one superlative which matters more than all of the others. That is India's values, and above all its position as the world's largest functioning democracy, and the most complex multi-racial and multi-religious society.'

Jack Straw, Hindustan Times India Leadership Summit, November 2006



It is trite to say India is rich in contradictions, that bullock carts and BMWs jostle for space on India's congested urban roads. If inequality and underdevelopment are India's chief challenges – 390 million people live on less than $1 a day – then India's cultural diversity and agility could be its chief asset.

Mihaly Csikszentmihalyi, the leading authority on cultures of innovation and originator of the idea of flow, argues that to understand creativity one must look where it happens.[62] In India scientific innovation takes place in an intense cultural interchange within Asia and with the West, between the past and the future (see figure 6).

Figure 6 The paradox of Indian science

India

BMW science	—	Bullock cart science
Bangalore (Bengalooru)	—	Bihar
Democracy and rule of law	—	Corruption (one-fifth of members of parliament arrested for crimes according to *Newsweek*)
45 million graduate population	—	500 million Indians depend on agriculture for survival
Modern, affluent and growing middle class	—	Ancient society
Conformity with global rules for the protection of intellectual property through WTO TRIPS	—	Traditional and ancient scientific knowledge such as ayurveda, requiring new concepts of knowledge ownership
Science as the answer to the development question	—	Importance of religion, astrology and superstition in daily life
Innovation increasingly important as a source of market differentiation and profit (from a low base)	—	Innovation, ingenuity and adaptiveness as a daily necessity for survival
English-speaking, western-educated scientific elite	—	Around 20 officially recognised languages spoken and numerous more dialects; multilingual capabilities as standard

Note: Bihar is among the least developed states of India and has a per capita income of $94 a year against India's average of $255. A total of 42.6 per cent live below the poverty line against India's average of 26.1 per cent.

The most striking feature of Indian culture is its complexity and heterogeneity.[63] Science has been enlisted as an ally by all those seeking to modernise India, from British colonial rulers through Congress to the BJP. India's recipe for modernity continues to blend science with religion, urban centres with rural village life. In some respects India is becoming more like Europe and the US with its urban shopping malls. But Indian scientific breakthroughs may come from the interaction of traditional with modern knowledge, for example between ayurveda and modern pharmaceuticals, or from attempts to use science to solve pressing development needs in India's 600,000 villages. India's potential should not be judged by how like Europe and the US it becomes but by its ability to create a distinctive mix of cultures and kinds of knowledge.

India's democratic dividend

At a November 2005 R&D conference, which aimed to showcase India as a 'world knowledge hub', Kapil Sibal, the science minister, claimed that India's ultimate advantage over China would be democracy: 'That's what will provide the freedom that we need to innovate…'

Indian democracy is chaotic and messy: stories of corruption and voter manipulation are rife. But science and democracy have had a long and intense interaction in India. Whether democracy Indian style is good for science – by providing the basis for the freedom of thought and speech critical to innovation – will be key to how India's development differs from China's. Democracy is crucial in deciding what kinds of science a society should do. Democratic debate about how the science is done and for what ends can build public legitimacy and confidence. But as the Asian tiger economies show, more authoritarian states with limited democracy – such as South Korea and Singapore – can mobilise vast resources for social transformation.

1.5m

India has around 1.5 million active non-governmental organisations.

In India, debates about the role of science in social development started with the Swadeshi (indigenous) movement of 1904. In the nationalist era the politics of knowledge provided a dividing line between rationalist modernisers such as Nehru who put great faith in the power of science and democratic traditionalists such as Gandhi who argued for bottom-up science for everyday needs. That tradition was reignited in the 1980s by the grassroots revolts following the Bhopal gas disaster of 1984 and the long fight against the Narmada dam.

Civil society movements play a critical role in these debates. India has around 1.5 million active non-governmental organisations (NGOs). These increasingly professionalised and specialised groups fill the gaps left by the state welfare, education and health services. The role of science in India's geopolitics – particularly the develoment of nuclear weapons – and the inequalities opened up by the knowledge economy are provoking a complex and active debate, in which, as one commentator puts it, 'the middle class dream of a second-rate America of supermarkets and science cities clashes with the tribal scream against large dams'.[64]

That debate is reflected in formal politics. In 2004, the incumbent nationalist BJP party, which had campaigned on the slogan 'India shining' to appeal to the emerging middle class, was surprisingly ousted by the centre-left Congress. The message was that growth and innovation in India had to deliver more for the rural poor.

India is one of the few countries of the world where poor voters could help to set the terms of the debate about science and development. When President Abdul Kalam addressed thousands of the nations farmers by satellite link at the first ‘virtual farmers’ congress’ as part of the 2006 Indian Science Congress, he spoke of what might be needed to resolve the dilemmas of doing world-class science in a largely poor and rural society. Can India play a role in global innovation networks, serving customers in Boston and Berlin, while also meeting the needs of rural India?

Science in Indian culture

Since independence, science has been enlisted in the cause of development. Nehru, India’s first prime minister in 1947 claimed that ‘science alone… Can solve problems of hunger and poverty, of insanitation and illiteracy, of superstition and deadening customs’.[65] The most recent statement of science policy issued in 2003 broadened the holistic aims of science, recognising ‘its central role in raising the quality of life of the people of the country, particularly of the disadvantaged sections of society’. Nehru’s principles of science for development echoed through speeches at the 2006 Science Congress in Hyderabad.

India’s space programme is one of the best examples of Indian inventiveness: doing science on a grand scale, but in a way that also serves the needs of rural villages. And all on a tiny budget by international standards: annual funding for its space programme is only Rs 27 billion (US$600 million) a year, 3 per cent of what NASA spends each year.[66] Since its creation in 1969, the Indian Space Research Organisation (ISRO) has had as a central mission: ‘to bring the benefits of high technology to the people, and particularly the poor people of India’. Aryabhata, the first Indian space satellite, was launched in 1975. A home-grown rocket launch followed in July 1980, while the first Indian cosmonaut spent eight days above a USSR space station in 1984.[67] India’s first moon mission, Chandrayan, is planned for 2008.

India’s space programme aims to deliver tangible social benefits. In September 2004, ISRO launched Edusat, the world’s first education satellite linking 5000 schools and colleges in five states. Plans have been drawn up to expand this into a nationwide space-based education service. Space science is also bridging some of the huge gaps in health care. The telemedicine programme, connecting specialist health care services to rural areas via satellite, started with a 2001 pilot and has now grown to link 50 remote hospitals to specialist centres in cardiology, neurology and organ transplants. Earth observation satellites have been used to combat deforestation, predict crop yields, trace water sources for irrigation and monitor desertification.

Debate over how Indian science could serve the nation continues to this day. Bengalooru’s software companies have put India on the map as an emerging centre for innovation, bringing new jobs and wealth. But for most people in India, innovation is more about the everyday improvisation required to get clean water, a roof over your head and a few vegetables at the market. In Europe and the US, innovation is mainly thought of as a tool of competition, to differentiate products in crowded markets. In India most innovation is about fashioning solutions to basic needs.

Dr Mashelkar, director general of CSIR, sums up what he sees as the essence of Indian innovation:

To understand Indian innovation, you have to understand the price–performance envelope. India is big – it’s not one size fits all. It’s not just about mass production, but production by the masses.

Innovation for India's low-income communities could in turn provide a basis for India's global competitiveness. In *The Fortune at the Bottom of the Pyramid*, management thinker CK Prahalad argues that multinational companies and indigenous Indians have failed to capture the 'market promise' of the 'aspiring poor'.[68] Four billion people in the world live 'at the bottom of the pyramid', earning less than $1500 a year. Creating products that are economically profitable, environmentally sustainable and culturally acceptable is an unexploited opportunity that could lead to radical innovations, which could in turn revolutionise more mature developed world markets.

Efforts to support this kind of innovation in India range from the high-end New Millennium Leadership in Technology Initiative, run by the CSIR, to the Honey Bee network, an NGO that disseminates inventions and helps to commercialise the best.

India's scientific culture

The ethics of science in India also reflects tensions between East and West, commerce and social purpose. Those tensions are embodied in the dual identities and loyalties of many western-trained Indian scientists. As one put it:

All of us have some element of dual identity. We are global citizens in terms of ethics and governance. We want to follow the best global standards. But when we step outside the lab we become part of wider Indian society, which is more chaotic and occasionally corrupt. It's not straightforward.

India's scientific institutions are not short on ethics committees. When asked how confident he was of India's ethical checks on science, one returnee from the US, Dr T Sridhar from Triesta Sciences, remarked: 'I'm not concerned about ethics in India, there are enough people thinking and worrying about that here.'

India has seen nothing on the scale of scandal of the Korean stem cell researcher Woo-Suk Hwang, but it has not entirely by-passed controversy. In 2005, an announcement by Dr Geeta Schroff, from New Delhi-based research lab Nu Tech Mediworld, claiming she had used embryonic stem cells to treat more than a hundred patients, was met with alarm. This produced consternation among the Indian scientific community, outraged that government watchdogs had failed to monitor the centre, and considerable scepticism among UK scientists who considered it 'highly improbable' that Schroff's claims were true.[69]

Dr Shashidara from the Centre for Cellular and Molecular Biology believes that the Hwang scandal may in the end benefit India by exposing it to more international scrutiny:

People can't quite believe we are doing this kind of work in India. There's a lack of confidence in our research system… [Hwang] may create some short-term turbulence, but in the long run may actually benefit India.

Guinea pig science

One area that highlights the problematic ethics of science in India is the growing market for clinical trials, which was valued at $30–35 million in 2002 and is expected to grow to between $250 million and $1.5 billion by 2010.[70]

In some ways, it is similar to software outsourcing but what is luring international drug companies is not the supply of engineering graduates but the availability of English-speaking doctors and the enormous number of potential patients (32 million diabetics alone[71]). Clinical trials account for about 40 per cent of drug development costs, and a trial in India can cost half that of more developed countries.[72]

In January 2006, the government took the controversial step of removing the legal constraint that drugs should be proven safe in their country of origin before they could be tested on Indians. India has opened the door to becoming ‘a guinea pig for the world’[73] with far-reaching ethical implications. A majority of patients involved in trials will be illiterate and deferential to authority figures such as doctors. Critics argue it is difficult to be sure whether properly informed consent has been given. Even when it is, there are still questions to resolve regarding the drugs’ relevance and affordability. Many drugs tested in India could never be affordable for the patients on whom they are tested, but eventually will be marketed in Europe and the US.

India has no formal regulations for clinical trials but the Indian Council for Medical Research published its Ethical Guidelines for Biomedical Research on Human Subjects in 2000. The Drugs Controller General of India polices and monitors trials but with just three medical staff. The boundaries between hospitals and drug companies is often blurred. Lack of formalised processes and delays is likely to leave the system open to corruption.[74]

Science cannot be detached from the context of its governance and ethics. As research spreads around the world, it will operate in more different cultural and ethical environments. This will require a constant renegotiation between global standards and local practice. India’s scientific culture is growing at the interchange between cultural norms. The challenge, offering exciting and unfamiliar possibilities for science, is how both the India of Bengalooru and the India of rural villages can shape the kind of science that is carried out and the contribution it will make to global innovation.

7 Collaboration
No such thing as a natural partner

In theory, the UK is in a strong position to collaborate with India – we share a language, a love of cricket and tea, historic institutional links, and family ties through over a million British Indians. Furthermore, a large percentage of the older generation of Indian scientists and leaders were trained in the UK education system. But will this remain the case in the future?

In practice, senior figures within Indian science fear that intellectual ties between the UK and India are withering. Historic links are at best irrelevant to many younger Indians who look to the US and elsewhere in Asia for collaborators. Britain can ill afford to be complacent about its relationships with India.

English has become a global language, spoken well by many more non-English people. Meanwhile India is spreading its wings. Science is increasingly interdependent, orchestrated through global research and innovation networks. Britain is rapidly becoming just one of India's many scientific partners.

Indian science reaches out

Indian scientists are collaborating far more internationally, with scientists in a much wider range of countries than even a decade ago, according to figures from the US National Science Foundation (see figures 7 and 8).

Figure 7 Number and distribution of India's internationally co-authored papers, comparing 1996 and 2003

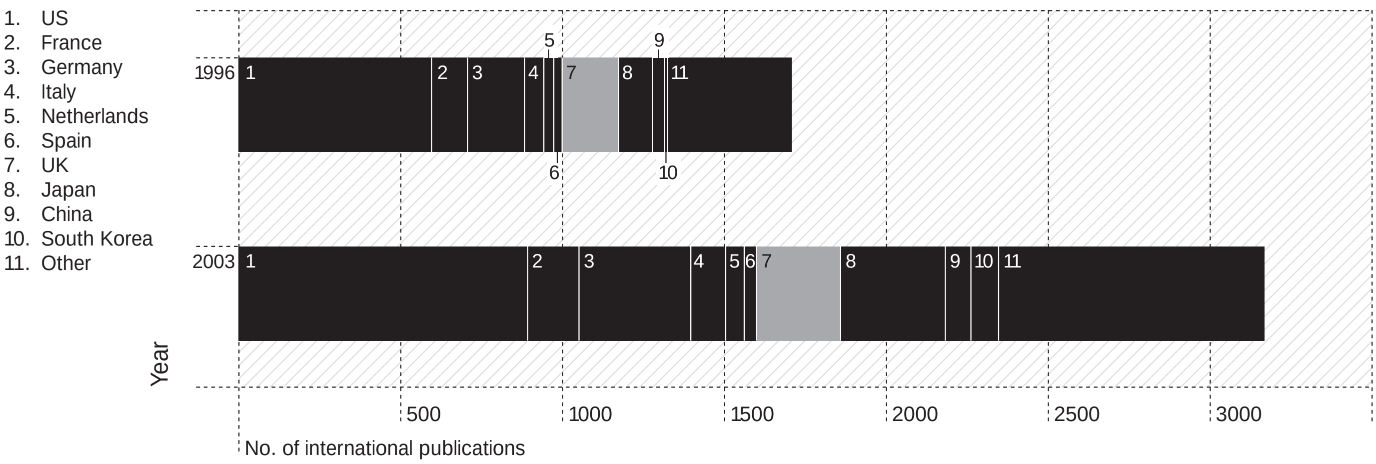
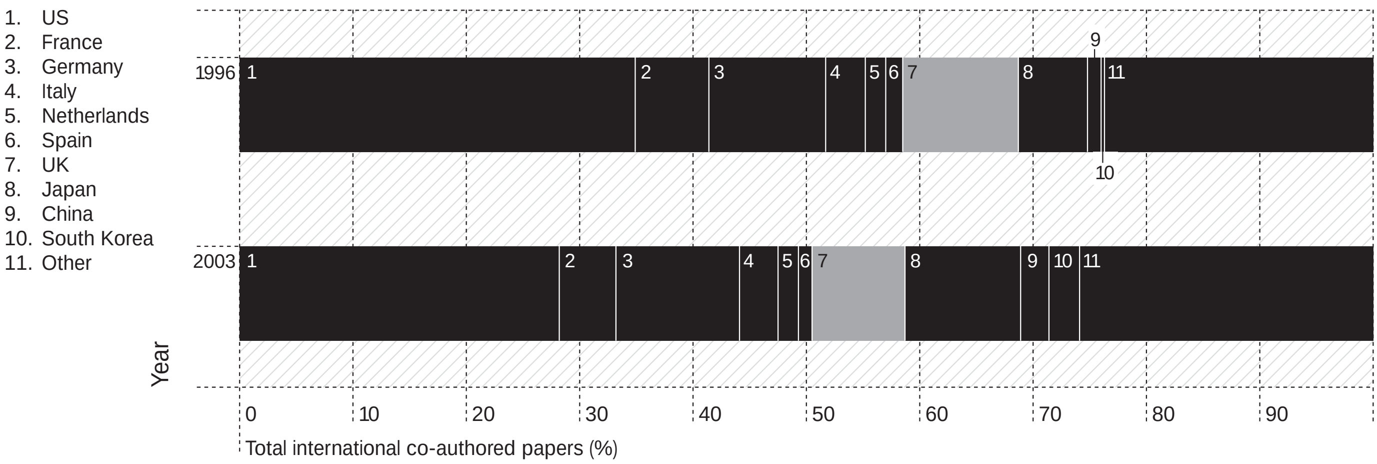


Figure 8 Relative change in proportion of India's internationally co-authored papers, comparing 1996 and 2003



Source (figures 7 & 8): Basic data from US National Science Foundation Science and Engineering Indicators 2006.

The UK is still a significant collaborator with India but its relative position is in a slow decline. Between 1996 and 2003, the UK's share of scientific co-authored papers fell from 10.2 per cent to 8.2 per cent. The US remained the main collaborator with India but its share also fell, from 34.9 per cent to 28.2 per cent. By contrast, the German position held up but the biggest rise was in publications co-authored with Japan, China and South Korea. Collaborations with China doubled from 1.2 per cent to 2.5 per cent, while collaboration with South Korea increased from 0.3 per cent to 2.7 per cent.

Indian scientists are becoming more hard-headed and outward-looking. Dr Sridhar from Bengalooru-based Triesta Sciences explains: 'To realise our aspirations we now recognise that we have to be part of the world network of science.' This view is echoed by Professor Rahul Pandit who runs the international relations cell of IISc Bangalore (Bengalooru): 'More and more scientists are coming round to the point of view that international collaboration is a duty rather than a pleasure.'

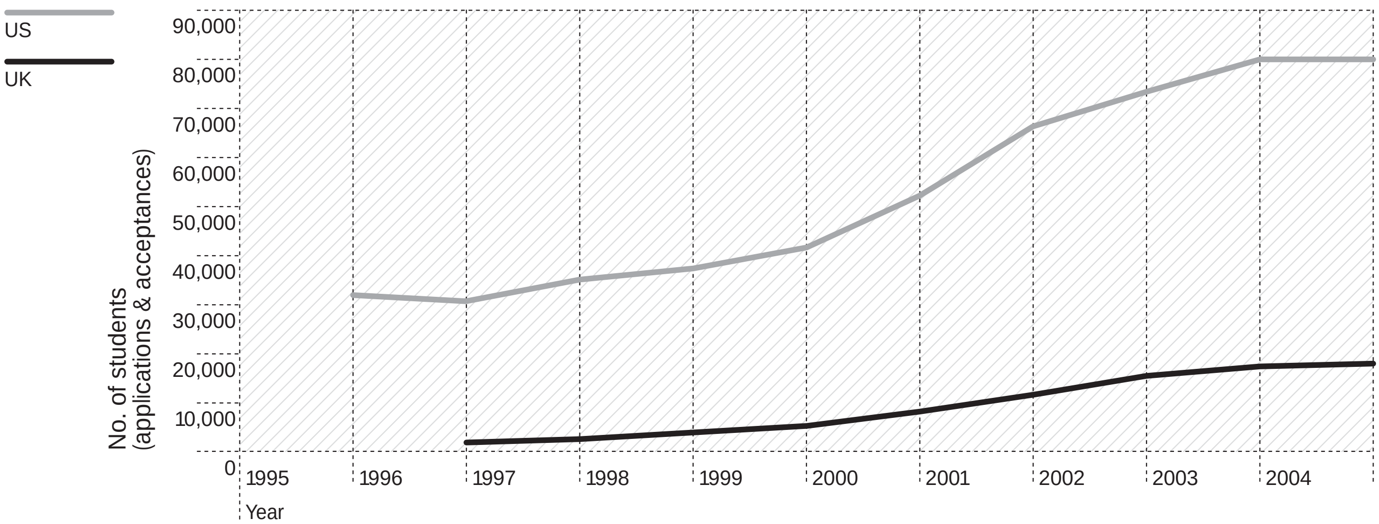
Yet it is still early days. Prior to India's economic liberalisation, international scientific collaboration was seen as shirking responsibility to one's home laboratory. The Indian system of promotion and reward does not encourage scientists to seek international collaboration, which as a result remains largely an elite activity, despite growing global connectivity. A study in the southern state of Kerala found internet access had little impact on scientific collaboration: fewer than one scientist in ten was engaged in international collaborative research.[75]

The best scientists working in the public and private sectors are becoming more collaborative with a wider range of countries. To explore what that means for the UK we need to look at people, business and institutional links.

People flows

Education is critical to collaboration. Where scientists study, the systems and people they become familiar with shape their attitudes towards collaboration later in their careers. The UK was a natural home for the older Indian elite, but the US has become the first port of call for an ambitious younger generation. There are still substantial numbers of Indian students travelling to study in the UK, but the gap between the UK and the US is growing sharply, as the graph in figure 9 shows.

Figure 9 Indian students in US and UK universities



Source: data drawn from the Higher Education Statistics Agency (HESA) and Universities and Colleges Admissions Service (UCAS) (UK) and Open Doors (US), all 2005.

Among our interviewees, America was frequently described as the ‘automatic choice’ for students wishing to study abroad. US universities are seen as the most prestigious and US business is seen to offer the greatest opportunities after university. IIT graduates who have emigrated to the US have a combined net worth of US$30 billion according to the *Taipei Times*.[76] Many of the students we spoke to saw the UK as at best a stepping-stone to the US. Indians want to live the American dream, or more accurately the Indian dream in America. The UK does not have the same kind of dream to offer.

With the exception of Oxford, Cambridge and Imperial College, the Indian scientists we spoke to regarded few UK universities as international leaders, with little to set them apart from their European competitors. A minority described the UK as the place to go to study the most difficult problems, what one professor called a ‘Nobel prize winning type of science’.

The University Institute of Chemical Technology in Mumbai provides a microcosm of these trends. Around half of the institute’s graduates go abroad even though it is one of India’s top research centres. Almost all of them have full scholarships to the US, and quite often offers from several US universities. As one of the institute’s faculty, Professor Yadav, told us: ‘It used to be like this with Cambridge, but now that is a distant memory.’

Many UK universities are marketing themselves aggressively in India to attract undergraduates but a few are then undermining the UK’s reputation by not providing teaching of sufficient quality or other forms of support. As one professor of entrepreneurship described:

There are a huge number of Indian students going to study ropey degrees in the UK. Very few Indian students study at the good universities – there are only a couple of hundred in Cambridge. It is a danger and must be recognised as a major threat to the reputation of UK education in India.

Research flows

Collaborations like that which Professor Home enjoys with his Belfast colleague are the glue that holds global science together. This is particularly true for the UK where collaboration is organised by scientists themselves, in a bottom-up way. As a result UK–India links are highly dispersed and often difficult to quantify. The UK needs to find a way to make more of the combined impact of its bottom-up approach.

The US is overwhelmingly the main focus of research collaboration, partly due to the frequency of scientific conferences in the US. One interviewee told us: ‘Collaborations with the UK are about friendship, collaborations with the US are about business.’

Britain is making some significant attempts to boost collaboration with India as table 5 shows.

Table 5 Examples of UK's collaborative efforts with India

Initiative	Description
Indo–UK Science and Innovation Council	Inaugurated in June 2006, this marks a desire to accelerate the tempo of collaboration. It is now the main bilateral platform at government level. The main themes of its agenda include climate change research, earth observation, energy security through innovation, bioscience, commercialisation of research, and sharing of best practice in research, innovation and technology transfer.[77]
OSI/Indian Department of Science and Technology Networking Scheme	This is run by the Royal Society on behalf of the UK Office of Science and Innovation. It provides grants for visits by individual scientists, workshops and the organisation of themed events with the aim of creating joint research projects. More than 70 applications have been approved in the last three years to fund collaborations in areas as diverse as chemistry, astronomy, engineering science, material science and mathematics. Over 80 institutions in India and the UK have benefited from the scheme.
UKIERI (UK–India Education and Research Initiative)	The major new addition to this portfolio is the UK–India Education and Research Initiative, a flagship programme to increase research and education links between the countries. UKIERI is affectionately known as 'Tony's ten million' thanks to the starting pot of funding Blair agreed with Indian prime minister Manmohan Singh in initial discussions in 2004 and 2005. After two years of bilateral discussion, the total has risen to £15 million from government (Department for Education and Skills (DfES), the Foreign and Commonwealth Office (FCO), the Office of Science and Innovation (OSI) and the British Council), £2 million from devolved administrations as well as £4 million in cash and in kind from private sector sponsors BP, BAE Systems, GlaxoSmithKline and Shell. As of the June 2006 Science and Innovation Council, negotiations with the Government of India (Department of Science and Technology and the Council for Scientific and Industrial Research) are under way for an additional contribution of £6–8 million. This brings the total fund to £25–28 million. The British Council is the main administrator of the funding. By 2011, UKIERI aims to meet the following minimum targets: – 50 new collaborative research projects, including five 'major' projects linking centres of excellence – 40 new UK award programmes delivered collaboratively in India with 2000 Indian students enrolled – 300 additional Indian research students, postdoctoral – 200 UK researchers worked in India and 200 UK undergraduate students supported for studies in India – 2000 Indian research students completed research degrees in the UK through collaborative delivery.
The British Council	The British Council funds exchanges with the aim of creating partnerships in science and technology between individuals and institutions. Current focal areas are biomedical sciences and genomics, climate change and environment, pure sciences in collaboration with the Royal Society and, most recently, nanotechnology.
FCO Science and Innovation Network	The recently enlarged UK Science and Innovation team in India promotes links between Britain and India, encouraging young scientists to study or work in Britain; working closely with the British Council and UK Trade and Investment (UKTI) to promote research collaborations and facilitate technology transfer. Their bases in India are in New Delhi and Bengalooru. Current focal projects include wireless networking and earth observation.
JETCO (UK/India Joint Economic Trade Committee)	Announced by Blair and Singh in 2004. Joint workshop to remove trade barriers. Achievements include involvement in quadrupling air services between UK and India over the last three years.
UK–India Roundtable	Established in April 2000, this group consists of 30 people drawn equally from India and the UK, including high commissioners. Its purpose is to reflect on the ways in which the bilateral relationship can be strengthened.
Indo–British Partnership Network	Originated in 1993 with the Indo–British Partnership Initiative set up by the then prime ministers. Incorporated as a company in 2005. Its principal mandate is to increase trade and investment between the two countries. It is co-chaired by Sunil Mittal and Karan Bilimoria.
The deal-maker	UKTI's Global Entrepreneurs Programme has created the deal-maker role – a serial entrepreneur charged with scouting talent, and linking up Indian life sciences and technology entrepreneurs with UK sources of funding. This activity is still at a very small scale in India, but is filling a private sector gap.

Of these various initiatives, the UK–India Education and Research Initiative is potentially the most significant. Not only does it combine education and research, but with around £25 million of funding from a combination of public and private sources, it has the potential to act across sectors, at the large scale required.

But the tensions surrounding its development exemplify the challenges of working across institutions. Creating a strategy that is acceptable to partners from the DfES, FCO, British Council, Office of Science and Innovation and several corporate partners has been a difficult process. The programme is now starting to emerge, with the major project proposals about to be announced two years after the initiative was first mooted by Prime Ministers Blair and Singh. Critics have suggested that the UK's initial consultations with Indian counterparts were ineffective, missing the opportunity for match funding from the start. With the Indian government keen to collaborate on equal terms, this was a complication that has only recently been addressed with a new, significant contribution from the Indian government. Yet despite these teething problems, UKIERI holds enormous promise and should be a central plank of more radical efforts to scale up collaboration.

Institutional ties

India's turbulent climate has a huge impact on the livelihood of its largely rural population. Around 700 million Indians depend on agriculture, and predicting the monsoon is critical to them. This challenge has provided the focus for one of the UK's most successful scientific collaborations with India, one which could provide a model for joint ventures in other fields, marrying theoretical modelling in the UK with local know-how in India.

700m

Around 700 million Indians depend on agriculture.

Indian meteorology dates back at least to the Upanashads in around 3000BCE, which discuss cloud formation, rain and seasonal cycles caused by the movement of the earth around the sun. Modern meteorology was institutionalised under colonial rule. The British East India Company established observatories in the late eighteenth century, while geologist Henry Francis Blanford founded the India Meteorological Department in 1875. As a result, despite a legacy of indigenous knowledge, Indian meteorology was rendered increasingly dependent on British expertise.

The Indian Institute of Tropical Meteorology (IITM), based in Pune, is one of India's most prestigious meteorological research centres, and is charged with predicting India's monsoon. This is impossible without state of the art climate-modelling tools, with the computational power to cope with the monsoon's unpredictability. Dr Rupa Kumar-Kolli, vice director of the IITM, says that he relies on a relationship with the Hadley Centre at Reading University to provide these tools.

The collaboration has become so valuable to both sides, says Kumar-Kolli, that even if they lost the funding for the links, they would still find a way to collaborate. His British counterpart Professor Julia Slingo, director of the Centre for Global Atmospheric Modelling at Reading University, agrees. Slingo has been collaborating with India for over 20 years and has witnessed a remarkable transformation in the quality of Indian climate science.

In the past, the IITM provided local data and interpretation while the Hadley Centre provided the theoretical model. Now the IITM is involved in the development of the model itself. It is becoming a collaboration between equals rather than a transfer of knowledge from the UK to India. According to Kumar-Kolli, the collaboration with the UK has also been instrumental in improving relations with neighbouring countries like Bhutan, Nepal and Pakistan: 'Seven or eight years ago I didn't know a single scientist elsewhere in south Asia – now I may even have too many contacts and enquiries to deal with!'

What started as a knowledge-transfer programme has become a partnership to create an Asian hub for climate science. Years of painstaking low-level collaboration are starting to bear fruit. Institution-to-institution collaboration can combine multiple sources of skill and ideas.

Learning from other institutional models

What does Britain have to learn from the approach of other countries that put more emphasis on building a physical and institutional infrastructure for collaboration? The French model of collaboration is popular among Indian academics and government scientists, principally due to a clear 50:50 system of funding, an equal peer review process, and the capacity to cut through red tape. Policy-makers like Professor V Rao Aiyagari of the Science and Engineering Research Council could not praise it too highly: 'It's a unique model and I really wish we could roll it out across the board.'

France and India

The French model of collaboration is more 'top-down' than most. It involves the establishment of joint centres for research where everything is split 50:50. Perhaps the most high profile of these is the Indo–French Centre for the Promotion of Advanced Research (CEFRIPA), which was set up in New Delhi in 1987 as an equally funded project between the Indian and French governments. It supports and finances joint research projects, bilateral workshops, seminars and exchange visits, bringing together scientists from the two countries. The current director is Professor Shiva Prasad.

The Centre has so far received 700 project proposals, of which 250 have been accepted. These projects have resulted in more than 1700 exchange visits, nearly 1200 research papers published in international journals and more than 100 PhD theses. Four patents have been granted from two of the projects. The projects have also offered more than a hundred postdoctoral positions in French institutions to young Indian researchers.

The French government established a series of longer-term collaborations in 2004. Of the ten laboratories announced, six were set up in Bengalooru, involving water science technology, organic chemistry, solid state chemistry, mathematics, bioinformatics and IT.[78]

India's Department of Science and Technology is in discussion with the US about some similar initiatives along the line of the French model. But the US has other unique aspects to its collaboration with India.

The United States and India

In 1987, the United States and India established a $110 million 'Rupee Fund' to promote and fund science and technology collaboration and educational and cultural exchanges. That fund continued until 1998. Negotiations about deeper collaboration broke down in 1993 over disagreements about the intellectual property regime in India.

The Indo–US Science and Technology Forum, established in 2000, explores and identifies fruitful areas of cooperation by sponsoring workshops, scientist exchanges and meetings.

The United States and India cont.

The two governments signed their most recent treaty – the Science and Technology Umbrella Agreement – in 2005. This is designed to accelerate cooperation between Indian and US scientists working in government agencies, private sector and academia and includes support for basic sciences, space, energy, nanotechnology, health and information technology. The agreement was touted by Secretary of State Condoleezza Rice as 'another dramatic illustration of the fast-growing bilateral relationship we are building between the United States and India'.[79]

Silicon Valley is the main channel for scientific and technological links between India and the US, closely followed by the Boston area. Networking among Indians living and working in the Valley is thought to be a strong factor behind their success. Indian professionals began utilising their networks in the 1990s through groups like The Indus Entrepreneurs (TiE). TiE has been an incredibly successful networking organisation, which has assisted the creation of businesses with market values of over $200 billion. Although founded in Silicon Valley, TiE has now spread across the world.

In October 2006 the US National Science Foundation (NSF) announced it would be placing personnel full time in the US Embassy in New Delhi. When the NSF established offices in Beijing it led to a huge increase in collaborations.

The challenge for the UK is how to adapt its bottom-up model, based on individual scientists choosing who to collaborate with, to a world in which more science will be done interdependently, and in which other countries are taking a more strategic approach to collaboration.

Turning talk and networking into action will be critical. Many Indian scientists we spoke to were critical of the UK for seeming to value dialogue over action in kick-starting new research collaborations. One scientist claimed that it took ten years after his first dialogue organised by the British Council on climate change before any real activity began to take place. Likewise, some scientists who took part in a recent India–UK workshop on stem cell research, organised by the Royal Society, are eager to start joint projects but feel unsure of what steps to take next.

Connecting business more directly into these largely public initiatives will also be critical. One indicator of growing business relationships is the physical flows of people. In 2004, there were just 16 flights a week between the UK and India. In 2006, there are more than 50. The UK has strong Indian business links, but largely in low-tech sectors: steel industry entrepreneurs such as Lakshmi Mittal and Lord Swaraj Paul. There are some signs of activity in more knowledge-intensive areas, for example Ranbaxy's relationship with GSK, which could form the basis of a new wave of innovation links between India and UK companies. But again most important relationships are with the US.

The UK needs to wake up to what India is becoming. If it fails to do this, it may sacrifice whatever historic cultural advantage it had with India. Ironically, countries that lack the UK's past colonial ties with India are perhaps quicker to see how rapidly it is changing. Our historic links may blind us into a kind of postcolonial short-sightedness.

8 Prognosis
Interdependent innovation

‘The Indian influence across much of Asia has been one of culture, language, religion, ideas and values, not of bloody conquest. We have always been respected for our traditional export, knowledge! Does that not also make India a “global superpower”, though not in the traditional sense! Can this not be the power we seek in the next century?’

Manmohan Singh, Hindustan Times India Leadership Summit, November 2006

Alpesh Patel is a talent scout. As one of eight 'dealmakers' commissioned by UKTI's Global Entrepreneur Programme, he scours India for budding innovators to match with UK investors. Patel has learned that to find the best ideas he needs to venture off the beaten track. One excursion took him to a hidden corner of the University of Hyderabad, where an Ivy League-trained professor had developed some promising IP. But what startled Patel was the setting in which the discovery had been made: protruding through the window of the dusty laboratory was a large tree, its growth a force of nature that the university had been unwilling or unable to tame.

Indian science is not straightforward. It's a complex mix of factors and forces that can create unexpected results and confound easy clichés. Something significant is stirring in India, and science and innovation is crucial to it. But India's rising is uneven, its trajectory uncertain.

So many Indias co-exist, and all are moving at different speeds. Not long ago India was a backward, low-growth economy and aid recipient. Now it is more open and dynamic, both culturally and commercially. The buzz around science is part of that.

Yet underdevelopment still casts a long shadow. Large parts of the country remain impoverished. Indians are more used to juggling these contradictions than western observers. As Sridhar Mitta, managing director of e4e Systems in Bengalooru, puts it:

Westerners always want to simplify things into black and white – but everything can survive at the same time in India. It is a big place and everything has its own role.

India's growth is being fuelled by the size and reach of its young population: a rapidly increasing graduate base, a newly confident global culture and strong flows of people back from the US and Europe. But its institutions, both public and private, were largely designed for a time before India was open to such dynamic forces, and the task of modernising them has only just begun. Political, religious and class-based divisions make that challenge even harder.

India seems like an emerging giant, and even a threat, if one just focuses superficially on the large numbers of scientists and engineers it is producing. But once the variable quality of its education system and the shortages of top talent are taken into account, India's knowledge base looks distinctly fragile.

Before we consider how these dynamics might play out in India's future, it would be helpful to review the argument so far.

We saw in chapter 1 how the interweaving of ancient scientific excellence, colonial dependence and post-independence nationalism has contributed to the complex, globally connected environment for science and innovation in India today.

In chapter 2, we mapped the main elements of science and innovation in India. We showed that systematic links between education, research and commercial activity are sparse, but increasing, as organisations like CSIR pioneer a more integrated approach. The quality of university education is hugely variable, ranging from excellent to inadequate. Elite institutions like the Indian Institutes of Technology cannot provide all the answers.

In chapter 3, we argued that a key determinant of India's ability to compete in the knowledge economy will be its returning diaspora, bringing with it leadership skills and creativity. In the long run, what will matter more is whether these skills filter through the wider scientific and business community.

Chapter 4 described the growth of science and innovation activity in India's second-tier cities, and argued that this might create opportunities for the UK. We then turned in chapter 5 to look at the role of business, and saw how the impetus for private R&D in India is changing. From the biggest pharmaceutical companies to the smallest start-ups, companies are finding new ways to benefit from global networks of R&D.

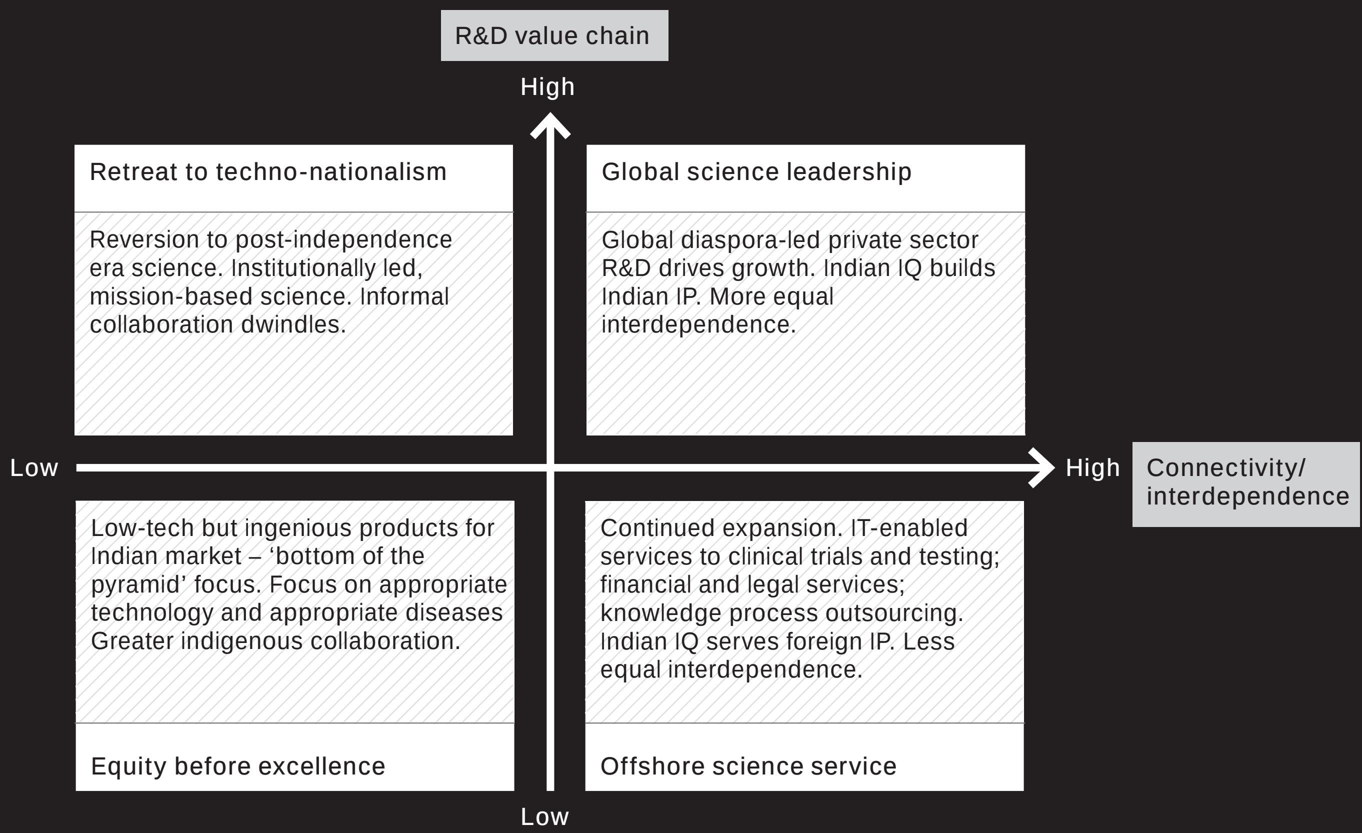
In chapter 6, we described the tension between the need to meet India's basic needs and the desire to undertake world-class science and innovation. We argued that this tension could ultimately be productive if it creates hybrid forms of science, which draw on the best of Indian and international approaches.

Finally, in chapter 7, we argued that the UK cannot afford to be complacent as India emerges as a significant player in the new geography of science and innovation. We run the risk of squandering a historic opportunity to contribute to India's scientific future. Britain needs a new special relationship with India for a new era of networked science and innovation.

Future directions for Indian science

With so many variables at play, Indian science and technology could develop in several directions, perhaps simultaneously. The matrix in figure 10 describes four possible trajectories, based on two dimensions of change: first, the value or creativity of the R&D undertaken and, second, the level of interdependence or connectivity. These scenarios are not predictions, but simply provide entry points into thinking about the future paths that India may take.

Figure 10 Possible futures for science and innovation in India



— *Scenario 1: Equity before excellence*
India is not a global science power. The inadequacies of the Indian science and innovation system – bureaucracy, disjointedness and weak infrastructure – mean that public science underperforms. Economic growth slows and talent flows reverse: returnees start going back to the US. At the same time, the failure of science and innovation to benefit the rural poor foments a political backlash, leading to the election of a populist government focused on intermediate technologies and 'bottom of the pyramid' innovations for rural India. Advances in malaria control, water management and climate prediction are among the early benefits of this new focus.

The politics of this scenario – innovation India vs agricultural India – are plausible and to some extent already visible. Innovation is widely seen as benefiting an elite rather than the nation as a whole. Much therefore depends on sustaining the fundamentals of Indian growth. As long as India prospers, it will attract people back from the US, and its demographic and educational prospects are essentially strong. At the same time, the fruits of this growth must be seen to be distributed more fairly.

— *Scenario 2: Retreat into techno-nationalism*
Geopolitical instability in east Asia fuels the emergence of ultranationalist politics and a re-orientation of Indian science towards military competition with Pakistan and China. Science becomes a tool for projecting India's power in Asia, signalling the renewed primacy of post-independent traditions in Indian science, such as space and nuclear programmes. The focus of these programmes is more about international prestige than development. Constituencies and institutions which favour national science in India gain sway. The first indication of this is when Indian scientists withdraw from international benchmarking efforts and rely on parallel national frameworks.

Given how much India has invested in interdependence economically and politically, the overall likelihood of this scenario is quite low. India's reliance on flows of people and money from abroad give it a major stake in multilateralism and mutuality. But this does not preclude the possibility of techno-nationalism in a few specific areas, most notably the military.

— *Scenario 3: Offshore science service*
More innovation by large companies is outsourced to India as part of global innovation networks. Indian IQ works in India but does not yield much Indian IP, which continues to be controlled by western companies. This scenario is interdependent, but it is unequal. It is a process driven by multinationals that become increasingly adept at managing global processes of innovation. In university and public sector R&D, the same model may apply. European and US partners could do the theory and modelling, while India does the development and 'blue collar' research. Elements of this scenario already exist, and it is likely to form part – if not all – of whatever the future unfolds.

— *Scenario 4: India as global science and innovation leader*
India increasingly masters its management of interdependent relationships. It is eminently capable of leading global innovation networks, or acting as an equal partner within them. India starts to create new standards and platforms which means it is not just servicing global innovation networks, but actively leading them. Crucial to this is the improving quality of fundamental research and capacity for innovation in Indian clusters and companies. India, or at least a growing part of it, will increasingly be on equal terms with Silicon Valley, Boston, Munich and Cambridge. This scenario is eminently plausible. But there is still a long way to go.

India: a science power, but not as we know it

During the Cold War, science had a particular national significance – linked to the arms race, defence technology and the 'national interest'. Today, the complexity of scientific problems, specialisation of scientists, expense of equipment and ease of communication have all contributed to the rise of international collaboration. World-class science is as much about participation in global networks as it is about a world-class 'national' system.[80]

Power is no longer a once and for all acquisition. Rather than embarking on a quest to become a superpower, India is learning to exploit soft, transactional forms of power to its advantage. Khilnani describes India as a 'bridging power', a country that exploits its capacity to be the 'essential connective tissue' to its advantage.[81] India's future strength in science and innovation will come from its ability to utilise the power of its networks: to combine the sheer numbers of its technical workforce with the dynamism of its entrepreneurial diaspora, to mix ancient and modern knowledge.

India is both an economic powerhouse and a country crippled by budgetary deficit; it faces huge development challenges even as parts of the country integrate into the global knowledge economy. India is not trying to beat the West at its game, but instead create its own. Its emergence as a science power is easy to caricature but harder to characterise. We ignore how India is changing the world at our peril.

Throughout the report we have examined the dynamics that are shaping India's scientific future. The likelihood of each of the above scenarios depends on India's response to them. We end by revisiting the dynamics discussed in this report in the condensed form of a set of strengths and weaknesses, and finally by offering a set of recommendations for UK policy-makers.

Strengths

— *The democratic dividend*
India is the world's largest democracy. This brings constraints in terms of directing research and resources, but India's democratic status remains a source of strength, not weakness, in three main respects. First, democracy is part of India's soft power. It makes India an attractive partner rather than a competitive threat. India's relationship with the US hinges on its status as a democracy able to act as a 'counterpoint to China'. Second, India has a vibrant civil society. Its huge NGO sector and long tradition of public debate performs a crucial scrutinising function and sets a public interest test for science and innovation. Third, democracy helps to sustain creativity and innovation. The relationship between democracy, innovation and economic growth is not straightforward or linear. Nevertheless, in the long term, a democratic climate and the social values that underpin it provide the freedom to innovate and think creatively on which scientific success depends.

— *India's talent ocean*
India's talent pool is boosted by around 2.5 million graduates in science, IT and engineering every year. At the top end of the education market, graduates from the Indian Institutes of Technology are sought after worldwide. India's population is growing younger, and will overtake China as the world's most populous country by 2040. The size of this talent ocean is a familiar part of the Indian success story. But we still have little concept of the scientific potential that might be created simply by virtue of scale. The current configuration of scientific research and innovation activities in Europe and the US, and the business models that underpin them, reflect certain historic realities about cost and the availability of human capital. The rise of India does not so much threaten western dominance of those activities as make possible entirely new ways of organising science, and on a totally different scale.

— *Discount discoveries*
There are now around 150 multinational R&D centres in India benefiting from the comparative low costs of research in India. Drugs trials can be undertaken at only 60 per cent of the cost in Europe. This brings advantages of speed to Indian science, and the ability to run more trials or design more prototypes for every research dollar that is being spent. Innovation is simply cheaper in India.

— *The sun never sets on 'India'*
The Indian diaspora is a worldwide network of over 20 million people. A significant proportion of these are highly skilled professionals and scientists, many of whom are now returning to the country to provide leadership and management experience. They are creating waves in the upper echelons of Indian science that are now beginning to spread throughout the system. What is important in this story is not just the reversal of brain drain to brain gain, but the constant and multiple connectivity that is driving Indian capacity for innovation and entrepreneurship. This is significant not only as a source of scientific influence, but also political and economic power.

— *Much more than Bengalooru: multiple R&D hotspots*
Indian success in science and technology was in the past limited to a select few cities. But established R&D locations such as Bengalooru are now facing significant challenges from 'second-tier cities' such as Pune and Ahmedabad. This is beginning to create healthy inter-state competition for a piece of India's knowledge economy action. New institutions such as the Indian Institutes for Education and Research could provide a crucial new source of multidisciplinary excellence in these emerging cities.

— *The software story: a powerful role model*
The story of software success in India is now well known. It has revolutionised opinions and images of India in Europe and the US. More importantly, it has changed India's own view of its potential. The folklore that surrounds Indian success in Silicon Valley and the profile of Bengalooru in the global media is driving Indian self-confidence in science. If the country can do it in IT, then why not in other fields like biotechnology? This confidence has also played a fundamental role in enticing multinational R&D centres and Non Resident Indians to invest in India.
IT is only the end of the beginning of India's story in the knowledge economy. India's investment in new models of networked innovation and outsourcing is likely to reap results elsewhere.

— *New dynamism in the private sector*
Private sector innovation is a crucial part of any knowledge economy. Before 1991, India was a closed environment where innovation was seen as unnecessary. But the Indian private sector is now coming alive. Faced with increased global competition, certain sectors are beginning to undergo an innovation overhaul. Particularly interesting is the pharmaceutical sector, which has seen a 400 per cent rise in R&D in the past four years. This trend has accelerated since compliance with WTO regulations since 2005. The capacity to comply with intellectual property regulations increases the attractiveness of India as a site for FDI and reduces anxiety in collaborative relationships.

— *Multiplying linkages*
India is open to creating as many strategic alliances as possible, not only with the US and Europe but also with China, Australia, Japan and other Asian nations. The crucial test for India will be whether it can get as good at building domestic innovation linkages as international ones. It also has the potential to combine traditional knowledge (eg ayurveda) with modern techniques in new and surprising ways.

Weaknesses

— *Disjointed innovation*
In India, research and education have been separated historically, limiting connectedness between the creation of ideas and their dissemination. Innovation often happens despite formal cooordination mechanisms rather than because of them. India has a fairly poor track record in commercialising ideas, due to the absence of well-understood pathways to take ideas from the lab to the market.

— *A follower but not a leader*
It is difficult to say with certainty that India will be the place where big discoveries will come from because, so far, there's little precedent for it. India is getting better at incremental innovation, but its strengths in outsourcing and 'service science' provide no guarantee of building the capacity to be a genuine science pioneer. In spite of India's meteoric rise it is still vulnerable to being marginalised in global innovation networks.

— *Testing times: the variation in educational quality*
Looking below the top-line statistics reveals a system of higher education that is hugely variable in quality. The IISc Bangalore (Bengalooru) and the 'deemed universities' of CSIR labs may meet global requirements, but many universities have an inadequate infrastructure for science teaching and research. It can be difficult for potential collaborators to judge the quality of Indian universities and pick appropriate partners. University lecturers' wages are tightly regulated, making it hard to incentivise and reward research. There is also still a long way to go to bring basic education up to scratch. World Bank data shows that the literacy rate has risen from 58 per cent to 68 per cent since 1985 for men, while for women it has risen from around a third to just under half. India faces huge challenges in terms of equity as well as excellence.[82]

— *License Raj lives on? The curse of red tape*
Cumbersome regulations still surround new businesses, and the World Bank's list of countries where it is easy to do business ranks India at a miserable 134th, below the West Bank, Syria and Gabon. Regulations surrounding science are sometimes contradictory. The bureaucracy that tightly controls wage scales also makes procurement of new equipment in universities a great challenge. One of India's advantages is its rule of law and independent judiciary. But India's systems of governance also face significant challenges. The World Bank rates India low in its rankings for successfully tackling corruption.[83] India also topped the latest 'Business Bribe Payers Index' released by Transparency International, the anti-corruption NGO.[84]

— *Still a tough deal for entrepreneurs*
The climate for entrepreneurs in India is now more positive, particularly since the success of Indian entrepreneurs in Silicon Valley. As the venture capital industry grows, experienced innovators are benefiting. But first-time entrepreneurs still get a hard deal. Gaining approval for loans can be difficult and a new wave of technology incubators are only now getting started.

— *Walking the tightrope of stability*
India's demographic boom is a strength, but it also presents huge governance challenges. India is home to 40 per cent of the world's poor. This creates an intense pressure to create jobs. The threat posed is exacerbated by the mix of religious communities represented in India, and the regional disparities between rich states like Karnataka and Kerala and poor states such as Bihar. The conflict between India and Pakistan over the disputed territory of Kashmir has made this one of the most

heavily militarised zones in the world. Tribal wars between local tribes and Maoist Rebel Naxalites plague the central state of Chattisgargh. Some have said that it is pure magic that holds India together.

— *Built to last? Infrastructure ills*
More people means more pressure on India's creaking infrastructure. Millions of people do not have access to adequate sanitation systems. In science hubs like Bengalooru, road systems are at breaking point. With the government failing to act fast enough, the private sector is taking the strain, but the government needs to provide faster answers to these long-term problems.

— *What you see isn't what you get*
Contradictions come as standard in India. Statistics are often unreliable and hard to fathom. But chaotic systems produce results. Ideas can be found in the most surprising places. Visitors are shocked to find venture capitalists working from offices next to slums, or interesting IP created in a lab with a tree growing through the window. This is one reason why so many multinational R&D managers are returnee Indians – they are more able to understand how India works.

Lessons for UK policy-makers

1

Unleash mass collaboration
A clear imperative to emerge from this study is the need to scale up levels of collaboration and the skills and capabilities needed to coordinate it. New initiatives such as UKIERI are a positive development, which could supplement and enhance the UK's 'bottom-up' approach to science partnerships. The UK and India should continue to experiment with different collaborative models, drawing lessons from the more strategic approaches taken by France and Germany. The UK should also learn from the US model of venture capital partnerships with Indian institutions and regional governments. The UK currently has one 'talent scout' in the form of the Global Entrepreneurs Programme deal-maker – a good idea on far too small a scale.

2

Be a magnet for talent
Although the UK is home to a large Indian diaspora, the links that this brings are mature and not as productive or creative as they could be. The UK must learn how to tap into these networks to support collaboration. New links should be activated, and stories of Indian success in the UK promoted. Indian researchers based in the UK should be provided with more support to collaborate in India. Universities also need to present a more coordinated approach to India that is about long-term research partnerships as well as prospecting for students. As a starting point, the UK and India could host a university summit to share knowledge and inform collective strategies. Investment in scholarships to the UK should be increased, and top universities in particular should step up their efforts to attract Indian students in order to multiply the number of future Indian science leaders that have close links with the UK. The new scholarship scheme recently announced by the Royal Society is a step in the right direction. It should be developed with Indian and Chinese researchers in mind.

3

Get our story straight
Conservative leader David Cameron suggested during a recent visit to New Delhi that Britain and India should forge 'a new special relationship'. This relationship needs to be built not only on culture and history but on a shared understanding of how science can help to meet the most pressing global challenges. There is a need to improve the UK's visibility and promote its distinctive advantages as a collaborator. Crucial to this will be better promotion of the UK's scientific infrastructure, such as the Rutherford Appleton Laboratory and Diamond synchrotron. This is not just

about promoting collaboration at the facility to facility level, but collaboration with UK academic users of these facilities and the installation of instruments for exclusive bilateral research. Some facilities are increasingly costing more than national budgets can afford. Collaboration in building new facilities may be particularly important to the future of some UK science strands. The OSI should assemble a scientific ‘Doomsday Book’, cataloguing the UK’s science assets as part of a marketing strategy to encourage Indian scientists to work with the UK. The UK must also shed its reputation for ‘talk and no action’: too many networking efforts lack a clear sense of purpose. We need a more hard-headed and rigorous evaluation of what has and hasn’t worked, and a greater willingness to back small-scale projects and experiments. Above all, the UK needs to turn more of the ceremonial networking it does so well into genuine collaboration, no matter how small scale at first.

4

Build the knowledge banks

Despite our strong historic links, knowledge about how Indian science and innovation is changing is surprisingly limited in the UK. The knowledge gained from numerous scoping trips and networking activities is not collected centrally, so effort is duplicated, and wheels are endlessly reinvented. As more places in India become centres of innovation, the UK should look beyond the obvious and familiar locations. Pune and Kolkata should be significant targets for UK efforts. The Foreign and Commonwealth Office is ideally positioned to gather information through its science and innovation network, but these specialists need more time ‘pounding the pavements’, creating links with Indian organisations, and less time organising scoping visits for UK visitors. Other European countries combine their fact-finding trips to India into larger, less frequent delegations of 50 or 100 people. This can generate more interest from prospective collaborators, and greater recognition from the Indian government, so is a model that the UK should consider adopting.

5

Lead global science towards global goals

Collaborations will be more productive if they can help to address India’s most pressing development needs, or tackle global issues like climate change. To this end, the UK should strengthen its science links not only with traditional institutions, but also with the powerful NGO community in India. As CK Prahalad has demonstrated in the context of corporate strategy, a focus on the market ‘at the bottom of the pyramid’ can create new opportunities for innovation. There is exciting scope to apply this model to science and technology, and make it the focus of a fresh round of India–UK collaborations.

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Kirsten Bound
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India: The uneven innovator

Indian science confounds easy clichés. Many Indias co-exist, all moving at different speeds. World-class science exists alongside grinding poverty. But India's uneven innovation brings significant strengths as well as weaknesses. Flows of people, ideas and culture, both within India and across its global diaspora, are generating new businesses, new opportunities and a growing sense of national confidence. Understanding the future of science and innovation in India is not simply a matter of benchmarking its success against that of Europe or the US. Instead it depends on recognising how India can pioneer an interdependent model of knowledge creation, drawing on its distinctive cultural and historical resources.

The UK risks squandering a historic opportunity to be part of this future: India's emerging strengths as a global centre of innovation require a new approach to collaboration.

This pamphlet forms part of The Atlas of Ideas, an 18-month study of science and innovation in Asia, with a focus on opportunities for collaboration with the UK and Europe. The project is funded by the UK government and a consortium of public and private sector partners.

The second phase of The Atlas of Ideas begins in April 2007. As well as deepening our analysis of innovation in Asia, this will explore countries including South Africa and Brazil, and examine cross-cutting themes such as scientific diasporas, low-carbon innovation and science in the Islamic world. To find out more, or to download the other project reports, visit www.atlasofideas.org

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