Nesta...

OUR FRUGAL FUTURE: LESSONS FROM INDIA'S INNOVATION SYSTEM

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FOREWORD

There are many exciting aspects to working in India. One of these is that the UK Government's gaze is firmly fixed on India as a priority for international partnerships, particularly with regards to research and innovation. The benefits are numerous: researchers and businesses gain access to complementary knowledge, new technologies, facilities and new markets; taking products and services overseas can drive innovative new solutions with the potential to solve issues that affect the world.

To realise the UK's ambition to build a stronger bilateral relationship with India in this area, the UK's policymakers, businesses and universities need a deeper understanding of India's policy, people, private sectors and growing hot spots. A consequence of the diversity and rate of development of India's research and innovation ecosystem is that an overall understanding is difficult and time consuming to achieve. The answer was to follow up and update the well-received 2007 report by the think tank Demos, *India: The Uneven Innovator.*

Locating, distilling and analysing information about a nation – especially one as big and diverse as India - is never easy but the writers of this report have done the hard work for you. It is based on data collected in 20011–2012 and was written by Nesta, an independent innovation foundation in the UK, with the assistance of, and in partnership with, the UK Foreign and Commonwealth Office (FCO) through the Science and Innovation Network (SIN) in India, Research Councils UK (RCUK) India and UK–India Education and Research Initiative (UKIERI). The report is based on over 130 interviews and extensive desk research and includes the findings of three pieces of commissioned work detailed in the Executive Summary.

The report tackles broad issues. One such issue, which is central to its conclusions, is India's potential as a laboratory for frugal innovations and the knock-on effect this could have not just on Indian or UK societies but on the global community. It also comprehensively covers and analyses the changing strengths of India's research and innovation ecosystem. All of which is relevant to both UK and Indian policymakers, innovative companies and universities as well as a wider international audience.

The report culminates in recommendations for practical solutions on how we can enhance the UK-India relationship. The debate on this all important question starts here.

Sir James Bevan KCMG, British High Commissioner to India

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In India and the UK, we are very grateful to the 130 interviewees who generously gave their time, expertise and insights for the project. They are all named in the Appendix. Of course, not all of the interesting or valuable contributions could make it into this final text. Thanks to Brune Poirson and Nicholas Miailhe for their hospitality in Delhi and willingness to help, and to Sukhman Randhawa of the Office of Adviser to the Prime Minister, Public Information Infrastructure and Innovations. Thomson Reuters, NISTADS and IndoGenius also contributed with research specially commissioned for the report.

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The views expressed are those of the authors and do not necessarily reflect those of the project partners.

Kirsten Bound and Ian Thornton
July 2012

EXECUTIVE SUMMARY

Our frugal future: lessons from India's innovation system

Aims of this report

This report sets out to explore the policies, institutions and industries that are driving research and innovation in India; to measure how India's research strengths are developing and to map how the geography of Indian research and innovation is changing. It takes a purposefully broad approach, aiming to chart the direction of travel for Indian research and innovation. All this is with a view to help UK policymakers, businesses and universities better understand the opportunities and challenges of engaging with Indian research and innovation and how to strengthen their efforts to collaborate.

Frugal innovation

Innovation has raced up the Indian Government's agenda in recent years, and the President has declared the next ten years the 'Decade of Innovation.' Yet at first glance, recent developments in India's innovation ecosystem appear not to have kept pace with its explosive economic growth. India's science budget has grown at 25 per cent a year for the last five years but expenditure on R&D remains under 1 per cent of GDP. India's record of scientific publications lags behind that of China, and the gap is widening: over the same period as India's scientific output doubled, China's grew by seven times. However, while these input-output metrics are a useful way of benchmarking research excellence, they don't capture all of what is important about Indian innovation, and miss the distinctive models and approaches to innovation of very different systems.

Traditional metrics also miss what this research uncovered as a distinctive specialism of the Indian system: frugal innovation. Combined with deepening scientific and technological capabilities, this could be an important source of competitive advantage for India, and is an overlooked opportunity for strategic collaboration with the UK.

Frugal innovation is distinctive in its means and its ends. Frugal innovation responds to limitations in resources, whether financial, material or institutional, and using a range of methods, turns these constraints into an advantage. Through minimising the use of resources in development, production and delivery, or by leveraging them in new ways, frugal innovation results in dramatically lower-cost products and services. Successful frugal innovations are not only low cost, but outperform the alternative, and can be made available at large scale. Often, but not always, frugal innovations have an explicitly social mission.

Examples of frugal innovation are found throughout the Indian system: from Dr Devi Shetty's path-breaking model of delivering affordable heart surgery, to efforts to crowdsource drug discovery driven by government labs, to Bharti Airtel's approach to cutting the cost of mobile phone calls, to the Keralan approach to palliative care which is providing access to support at the end of life for thousands in a void of formal healthcare.

A number of factors align to create the conditions for high-impact frugal innovation in India:

1. A culture of 'jugaad,' or creative improvisation, means the unusual skillset and mindset required for frugal innovation are abundant.

2. A huge market with a growing, aspirational middle class creates the perfect conditions for frugal innovation.

3. Not only is the Indian consumer base growing, but it is also extremely price-sensitive and willing to experiment, sustaining demand for frugal innovation.

4. Extreme conditions and major gaps in service provision stimulate demand for low-cost solutions in health, education and energy.

5. Strengths in service and business model innovation create an advantage in creative remodelling of product-service ecosystems.

6. New sources of social finance are lowering the cost of investing in frugal innovations.

7. An increasingly 'inclusive' science and innovation policy is prioritising getting 'more for less for more' and attempting to develop the institutional conditions that could drive high-impact frugal innovations.

This strength has particular relevance for the way India positions itself within global innovation networks. Frugal innovation is not only important in solving Indian developmental challenges, but is increasingly relevant to developed economies for a number of reasons:

- Lacklustre growth and deleveraging in developed economies will increase demands for frugal products and services and frugal innovation processes.

- Environmental constraints around climate, energy, water and other resources will increase demands for more frugal models of production and consumption.

- Caring for rapidly ageing societies will require completely new approaches to health and social care, including the radical rethinking of business models and value chains that is apparent in some examples of successful frugal innovation.

- Today's fastest growing markets are in developing and emerging economies where demand for frugal products and services is naturally high.

- New technology platforms are drastically reducing the cost of some forms of innovation, which is creating huge new opportunities for frugal innovators, particularly in services.

Frugal innovation is just one of a number of important recent trends, relevant throughout the Indian research and innovation system. Taking a closer look at particular functions of the innovation system, we find the following.

Research

Stable government support for science has led to world-class research capabilities in physics, chemistry, materials science and engineering, and advanced space and civil nuclear research. While India produces over twice as many scientific publications a year than it did a decade ago, this amounts to only 3.5 per cent of world research, and most of that is below average quality. Government continues to account for the lion's share of R&D expenditure, although business expenditure is growing. India's innovation spend is reasonably efficient when benchmarked against a selection of other BRICs and more developed countries. It produces more patents per dollar of R&D spend than China, and more scientific publications per dollar of R&D spend than USA. A long-planned expansion of the top-tier of research and education institutions is finally underway, with

a view to further linking up research and teaching in universities. Government's stated priorities are to direct research to 'providing frugal solutions to [India's] chronic problems of providing food, energy and water security to [its] people.'

Place
Drawing on new quantitative data, this report maps the geography of research and innovation excellence in India, showing the emergence of new hubs and the deepening of existing clusters. Despite pressures on infrastructure, Delhi, Mumbai and Bangalore continue to be India's dominant hubs for research and innovation. Pune, only a few years ago considered a 'second-tier city,' has now joined a premier set of hubs which include cities such as Hyderabad and Chennai, and new clusters are emerging from Trivandrum in the South to Chandigarh in the North.

Business
Government has lofty ambitions for growing private sector spending on R&D. Yet overall R&D intensity is low outside a small range of industries, with pharmaceuticals the leading spender by far. Some of India's greatest strengths in private sector innovation are hidden from traditional innovation metrics. They are often in services, in business models, and bound up in the segmented business–to–business innovation activities of global multinationals. India continues to attract greater investment in R&D by multinational companies, as despite the challenges of the business environment, the pull of India's talent pool remains strong. While there are some notable examples of academia/industry interaction with top institutions, overall collaboration throughout the system remains low.

People
India is a long way from harnessing the potential of its human capital for research and innovation. Current pools of research talent are far smaller than might be expected. Conventional approaches to education reform and institutional expansion will not be enough to meet India's demand for quality education. Achieving Government's 2020 higher education enrolment targets would require building eight universities and 417 colleges each and every month. Qualitatively different models of higher education are required, which maximise the opportunities of new technologies and experiment with new approaches. There is no shortage of vision for a new higher education system, but implementation faces severe challenges of bureaucracy and entrenched interests.

Collaboration
While the UK has made considerable efforts to grow a more strategic relationship with India on research and innovation, it is difficult to judge whether this is paying dividends. In absolute terms, UK papers co-authored with India have almost doubled in the 2006-2010 period compared to the 2000-2005 period. Yet India's international collaboration is increasing across the board as existing partners such as the US step up their efforts to forge research and innovation collaborations, and newer players such as South Korea rise in significance. The UK is still some way short of being the 'partner of choice' for India in research and innovation. The metrics most readily available to track collaboration do not adequately capture the breadth of engagement in research and innovation, making it very difficult to attribute trends to specific policy interventions. Without further investment in codifying, tracking and measuring innovation collaboration, it will be difficult to assess or steer the UK's engagement with India in the years to come.

Implications
The recent developments in India's innovation system analysed in this report suggest a range of ways in which collaboration between UK and India could be strengthened. These are predominantly designed for policymakers, although they may provide useful insights for businesses and universities with a desire to improve collaboration with Indian partners. These

cover partnerships around all types of research and innovation, not just frugal innovation. We present two recommendations for India, two for the UK, and two for both countries.

For India:

1. India should market its distinctive expertise in frugal innovation to the world.
2. India should establish a research programme on the 'science of science and innovation policy'.

For the UK:

1. The UK should develop an overarching strategy to coordinate collaborative engagement with India, tailored around India's unique model.
2. The UK should shift support to longer-term, more ambitious partnerships in priority areas.

For both India and the UK:

1. India and the UK should join forces to establish a joint £1 million challenge prize in frugal innovation.
2. India and the UK should co-fund a series of projects to design and test radical new approaches to higher education provision that draw on frugal innovation principles.

Methodology and origins of this report

This project was undertaken in partnership between Nesta, the FCO Science and Innovation Network, the UK Research Councils and the UK-India Education and Research Initiative. It draws on secondary literature and the latest quantitative data available in addition to over 130 in-depth interviews with Indian policymakers, entrepreneurs and academics in India. Three additional pieces of research were commissioned to feed into the report:

a. A review of domestic and foreign private sector investment in R&D by the Indian National Institute of Science, Technology and Development Studies.

b. An analysis of the future of higher education in India by IndoGenius.

c. A quantitative bibliometric analysis of research excellence by Evidence, Thomson Reuters.

INTRODUCTION

A heart beats unmistakeably on the monitor as Dr Devi Shetty explains the results of a scan to a concerned patient and his family. His patient reassured, Shetty switches to English to field our questions about how he built his Bangalore 'Health City'. It's an easy transition: he is getting used to the interest in his model. Winner of a 2011 *Economist* award for innovation among a string of other accolades, he has been dubbed 'the Henry Ford of heart surgery' by the *Wall Street Journal.*[1] His family business, the Narayana Hrudayalaya Group, provides world class cardiac care at radical low cost by applying the philosophies of mass production and lean manufacturing. Heart surgery costs between $2000 and $5000, compared with $20,000 to $100,000 in the US. Despite providing around 60 free operations a week to poor patients, the group makes a higher profit margin than the average American hospital.[2] Dr Shetty's audacious goal is to provide heart surgery for $800.

As befits a medical facility in one of the most populous nations on Earth, the sheer scale of the operation is impressive. Founded in 2001 with 1,000 beds, in 2009 the biggest cancer hospital in the world opened on the same site. Shetty has plans for 25,000 new beds across India in the next five years. It's a striking reminder of the scale of the market for innovation in India. At the same time, Shetty's success is about more than volume: it has also involved a wholesale remodelling of the hospital care system. The Group run their own training (surgeons operate on a thousand pigs' hearts before touching a human heart), a State–wide health insurance scheme, and are moving to designing their own consumables. Specialist surgeons' time is spent only on the most complex tasks, with others doing all their preparation and paperwork. Monitoring and continuous improvement draw inspiration from Toyota's lean manufacturing methodologies: the COO of the Heart Centre, Dr Vijay Singh, explained *"Surgeons are measured on the time they take for an operation, the number of stitches and units of blood used."*[3] The senior leadership are right on the financial pulse too: Dr Shetty receives an SMS every day with his balance sheet. While foreign visitors might expect the scale in India, they are unlikely to expect the efficiency.

Frugal innovation: an Indian specialism?

The Narayana Hrudayalaya story is a striking example of frugal innovation, an approach to innovation that has emerged as a distinctive strength of the Indian innovation system, and one that is increasingly relevant to policymakers and businesses around the world.

Innovation is the successful implementation of new ideas. It encompasses all sectors, not just the research and development (R&D) activities of science and technology specialists, and relates not just to products, but to services, processes, design and social innovation.

Frugal innovation is a distinctive approach to innovation both in its means and its ends:

Means: The methods and techniques involved in creating frugal innovations are distinctive
Frugal innovation responds to limitations in resources, whether financial, material or institutional, and turns these constraints into an advantage. Through minimising the use of resources in development, production and delivery, or by leveraging them in new ways, frugal innovation results in dramatically lower–cost products and services.

Ends: The nature of the products, services or processes developed are distinctive
Successful frugal innovations are not only lower in cost, but outperform the alternative, and can be made available at large scale. Often, but not always, frugal innovations have an explicitly social mission.

Frugal innovation is not the only noteworthy trend in India's innovation system. But as this report will show, it is a distinctive specialism that spans corporations, civil society and the public sector, and is in an important lens through which to understand the state of the Indian innovation system.

While India is often described as an 'emerging' economy – economists predict that it will be the third largest in the world by 2050 – 're-emerging' might be a more appropriate label. It's common to speak of the rise of India as a recent phenomenon, beginning with the liberalisation of the economy in the 1990s through a series of major reforms that slashed tariffs and opened up Indian stock markets to foreign investors. This set India on a new growth trajectory: its economy has grown between 6 and 8 per cent per year since 2003,[4] second after China among the BRICs. Yet for hundreds of years India was one of the world's largest economies, producing between a quarter and a third of world output.[5]

Today, the Indian stock market has more than 5,000 listed companies, a fifth of which have benefitted from foreign investment. Nearly 150 of these companies are valued at over $1 billion, and unlike many 'emerging-nation' stock markets, which focus on particular sectors, the Indian market demonstrates strengths in areas as diverse as pharmaceuticals, automobiles and IT.[6] Yet India is what the World Bank has called 'an extreme dual economy.'[7] The formal sector accounts for only 11 per cent of the workforce and while India is home to twice as many billionaires as the UK, 474 million people live below the poverty line.[8]

Like its economy, Indian's innovation system has deep roots. Evidence of its ancient scientific and technological capabilities is found in archaeology as well as religious scripture. However, this deep intellectual tradition did not lead to an industrial revolution in the late 18th and 19th centuries as it did in Europe. The modern university system was founded during British colonialism in the late 19th century, propagating the English language that would become a core advantage for India in global research and innovation.

The origins of the current research and innovation system date back to independence from the British in 1947 under India's first Prime Minister, Jawaharlal Nehru. The first nuclear research programme was launched only 11 days after independence, part of a surge towards scientific independence that included the creation of the national network of laboratories, the Council for Scientific and Industrial Research (CSIR) and the elite technology universities, the Indian Institutes of Technology (IITs).

Innovation has raced up the Indian Government's agenda in more recent years. The President has declared the next ten years 'the Decade of Innovation.' Yet at first glance, recent developments in India's innovation ecosystem appear not to have kept pace with its explosive economic growth. True, India's science budget has grown at 25 per cent a year for the last five years.[9] But expenditure on R&D remains under 1 per cent of GDP,[10] despite a national target to raise it to 2 per cent by 2007. Benchmarked against China, India's production of peer reviewed publications seems almost diminutive, and the gap is widening: over the same period as India's output doubled, China's output grew by seven times.[11] However, this report will suggest that while these input-output metrics are a useful way of benchmarking research excellence, they don't capture all of what is important about Indian

innovation, and completely miss how frugal innovation is emerging as an area of strength.

Devi Shetty is just one of a number of high profile change-makers appointed to a new National Innovation Council, set up in 2010 under the Chairmanship of iconic telecoms innovator Sam Pitroda. The Council's role is to formulate and implement a model of 'inclusive innovation.' As the Chair outlines in the 2011 report to the nation:

> *"[India's] complex challenges cannot be addressed through incremental approaches. Instead it calls for massive change – in fact, tectonic shifts that only innovation can enable...The challenge before India is to develop an inclusive model of innovation that will move the country to become not merely a knowledge-producing economy, but a knowledge sharing society that will have relevance in many parts of the world."*

The Twelfth Five Year Plan (2012–17) directs government support for innovation towards meeting national challenges. In his 2012 speech to the National Science Congress, Prime Minister Manmohan Singh clarified the drivers of science and innovation policy:

> *"The overriding objective of a comprehensive and well-considered policy for science, technology and innovation should be to support the national objective of faster, sustainable and inclusive development...Research should be directed to providing 'frugal' solutions to our chronic problems of providing food, energy and water security to our people...Science should help us shift our mindsets from the allocation of resources to their more efficient use."*

The frugal imperative

A further reason to pay particular attention to frugal innovation is its relevance beyond India, and particularly to cash-strapped policymakers in Europe and North America. There are five main reasons why frugal innovation is becoming increasingly important across the world, which will be explored further in Part 2:

- Lacklustre growth and deleveraging in developed economies will increase demands for frugal products and services and frugal innovation processes.
- Environmental constraints around climate, energy, water and other resources will increase demands for more frugal models of production and consumption.
- Caring for rapidly ageing societies will require completely new approaches to health and social care, including the radical rethinking of business models and value chains that is apparent in some examples of successful frugal innovation.
- Today's fastest growing markets are in developing and emerging economies where demand for frugal products and services is naturally high.
- New technology platforms are drastically reducing the cost of some forms of innovation, which is creating huge new opportunities for frugal innovators, particularly in services.

This report

This report sets out to map recent developments in the research and innovation system in India: to explore the policies, institutions and industries that are driving research and innovation; to understand how India's research strengths are developing and how the geography of Indian research and innovation is changing. It takes a purposefully broad approach, aiming to chart the direction of travel for Indian research and innovation.

In doing so, it aims to help UK policymakers, businesses and universities understand the opportunities and challenges of engaging with Indian science and innovation. At the same time, we hope that Indian policymakers and businesses will welcome this as an independent and constructive analysis of their research and innovation system from an outside perspective, and a resource that can be used to support and strengthen their collaboration with the UK.

The report argues that India's comparative strength in frugal innovation, and its growing relevance to businesses and policymakers in developed economies, means that frugal innovation will be critical to the way India positions itself within global innovation networks, and the strategies it adopts for collaboration and engagement with countries like the UK, in the years to come.

There has been an explosion in the amount of analysis of India in recent years, and this report draws on secondary literature and the latest quantitative data available. This is combined this with new datasets commissioned especially for this report and over 130 in-depth interviews with Indian policymakers, entrepreneurs and academics, who are listed individually in the Appendix.

The report proceeds as follows. Part 1 sets out to define frugal innovation and trace how it has developed into an area of strength for India. Understanding the future prospects for Indian innovation requires analysing the wider context of the research and innovation system, which is undertaken in Part 2 to Part 4. Part 2 charts recent trends and developments in public support for research and innovation. Part 3, using newly commissioned quantitative data on research publications, outlines the geographical distribution of research and innovation and how it is shifting. Part 4 turns to assess the business environment and innovation intensity of the private sector. Part 5 explores the pivotal issue of India's supply of human capital for research and innovation. Because the future impact of Indian research and innovation will depend not only on shifts within the system, but the connectedness of Indian actors to the global network, this is assessed in Part 6. Part 7 concludes with our recommendations for policymakers in the UK and India.

Part 1

FRUGAL INNOVATION

> *'If ever there were a symbol of India's ambitions to become a modern nation, it would surely be the Nano'*[12]

Yours for a mere 100,000 Rupees (around $2500), the Tata Nano was launched in 2009 amid much fanfare and media frenzy. Billed as the world's cheapest family car, in relative terms it was just over half the price of its nearest rival, the Maruti 800.[13] It was a car born from a social mission on the part of company chairman Ratan Tata: the need for a safe, affordable family vehicle that would remove the need to risk the lives of children every day on overburdened scooters in treacherous traffic. Hailed as a 'triumph of Indian ingenuity,'[14] the design met international standards in safety and emissions, while taking a radical approach to cutting costs. Despite marketing blunders, technical hitches and slow sales that tempered excitement for the product, the Nano remains an iconic symbol of Indian capabilities in frugal innovation. Yet it is only one of many examples, and is by no means the most radical in its impact, as shown in this section.

This section sets out a conceptual framework for understanding frugal innovation and traces its emergence as a distinctive strength of the Indian innovation system.

What is frugal innovation?

As we noted in the introduction, frugal innovation is a distinctive approach to innovation, distinguished both by its means and its ends:

Frugal innovation responds to limitations in resources, whether financial, material or institutional, and turns these constraints into an advantage. Through minimising the use of resources in development, production and delivery, or by leveraging them in new ways, frugal innovation results in dramatically lower-cost products and services. Successful frugal innovations are not only lower in cost, but outperform the alternative, and can be made available at large scale. Often, but not always, frugal innovations have an explicitly social mission.

For many people, frugal innovation may be equated to the creation of cheap, low-tech products. Four features of frugal innovation are worth exploring in detail, especially since they run contrary to this received wisdom:

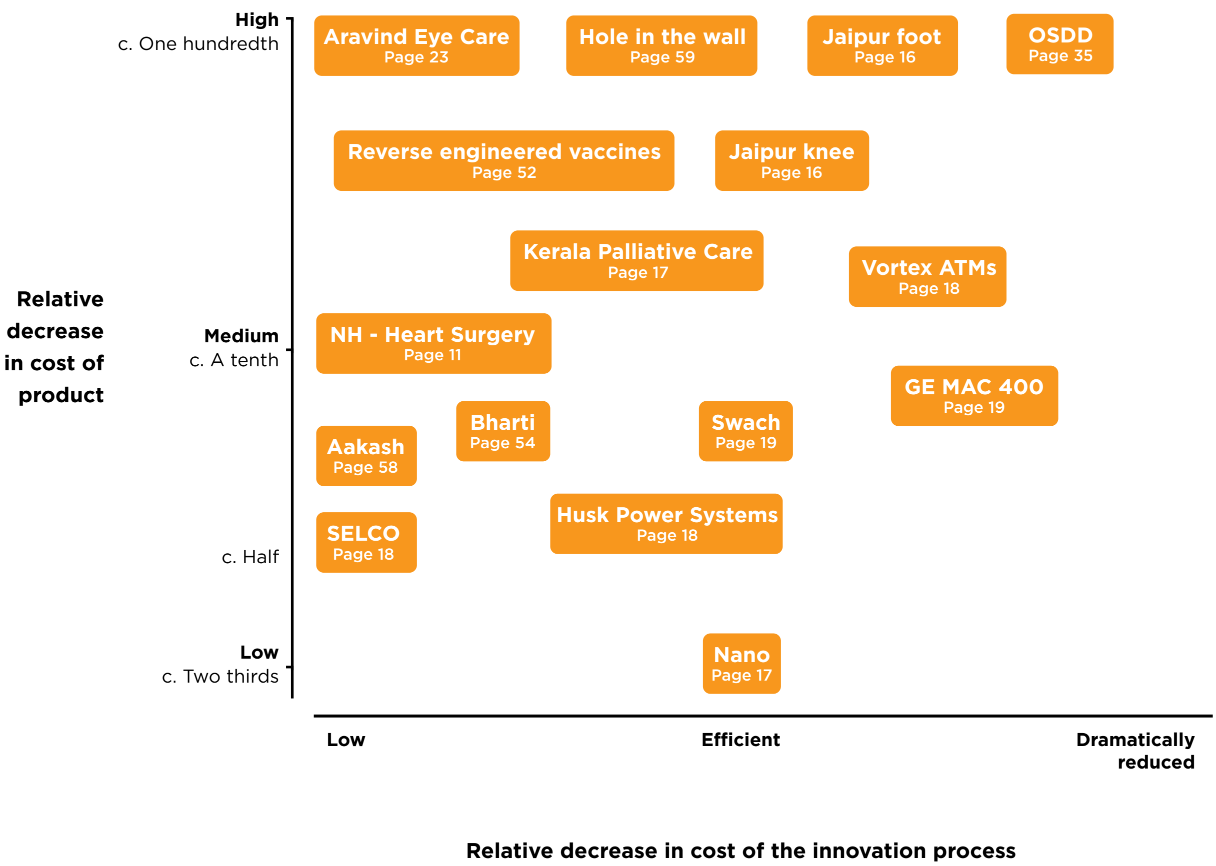
- First, it entails making better things, not just cheaper things.
- Second, frugal innovation extends to services, not just products.
- Third, frugal innovation is about remodelling, not just de-featuring.
- Fourth, low cost does not mean low-tech: frugal innovation can require, or be combined with frontier science and technology.

Better, not just cheaper

A key insight of frugal innovation techniques is that higher performance doesn't always mean higher spec. It can also mean more suitable and more efficient. One of the best known examples of frugal innovation is the Jaipur foot. The original Jaipur foot was developed in the 1960s by a temple sculptor frustrated with the lack of an affordable supply of prosthetic limbs. Costing up to $12,000, existing models were completely unobtainable for the majority of the Indian population. Using rubber, wood and tyre cord, he designed and manufactured a prosthetic foot for under $45 that had far greater functionality. The Jaipur version improved movement, but also cultural suitability: it has a lifelike foot so could be worn without shoes, it enabled squatting, sitting cross-legged, walking on uneven terrain and even withstood being immersed in water for long periods while its owner tended to his rice paddies. Today over 20,000 individuals each year receive a free Jaipur foot and there are mobile clinics in 26 countries around the world. The design turned out to be revolutionary, and has influenced the market for prosthetics around the world. Working with Stanford University, in 2009 this increasingly tech-savvy NGO, BMVSS,[15] co-developed the $20 Jaipur knee. Made of oil-filled nylon, ultra-low cost, and requiring no tools and just under an hour to assemble, it was fêted by *Time* magazine as one of the best 50 inventions in the world in 2009.[16]

In fact, as Figure 1 shows, while radical cost reduction is an important feature of frugal innovation, there is considerable variation in the relative reduction in cost of both end product and innovation process among the case studies researched for this report.

Figure 1: Frugal innovations in means and ends



Services, not just products

Some of the most radical examples of frugal innovation are in services. Approaches to frugal innovation in services include deep specialism in a niche segment of a huge market, tiered pricing systems and smarter use of human capital.

Challenging the traditional division of labour is one approach. A suite of tasks that in other settings might be done by one individual are split up, and all but the most skilled tasks made simpler through better design and training to bring them within reach of less qualified, cheaper labour. This works particularly well in a linear process like cardiac surgery as we saw earlier, one technique employed in Narayana Hrudayalaya to cut costs radically is limiting surgeons' involvement in surgery to only the very highly complex elements of the heart operation, with other tasks like preparation and paperwork being re-allocated to less expensive staff.

Often frugal innovations in services respond not only to a lack of skilled human capital, but an institutional void. Take the example of the Kerala-based Neighbourhood Network in Palliative Care. In contrast to an inadequate doctor-led hierarchical model of care, volunteers from the local community are trained to identify problems of the chronically ill in their area and to intervene effectively. While at a national level only 1 per cent of the population have access to palliative care, in Kerala the figure is 70 per cent. The network consists of more than 4,000 volunteers, with 36 doctors and 60 nurses providing expert support and advice to enable care for 5,000 patients at any one time. All the doctors and nurses in the network are employed by the community initiatives. More than 90 per cent of the resources for the projects are raised from local community donations of less than 15 cents.[17]

Remodelling, not just 'de-featuring'

Kerala's Neighbourhood Network in Palliative Care involved an entire rethink of the delivery system for social care. Often, the radicalism of frugal innovation comes not from the products and services themselves but from the root and branch methods by which innovators enable access to them at large scale.

With the Tata Nano, meeting the price target set by Ratan Tata meant the design team had to start from scratch. A key strategy was to 'de-feature' unnecessary attributes – to the extent of providing only one wing mirror and only three wheel nuts per wheel. Yet this simplification was in fact a very complex operation. The car is the product of a considerable global network of relationships. Tata Motors worked with Bosch of Germany to develop a new engine management system; Italy's I.DE.A Institute and Trilix for styling and interior design; India's Sona Koyo for lightweight steering shafts; Johnson Controls of the USA for the seating system; Japan's Toyo for the engine cooling module; Germany's Behr for the heating, ventilating and air conditioning system; and India's Madras rubber factory for tough rear tyres.[18] Innovation throughout this international supply chain was essential to achieving the Nano's cost target.

In some cases, frugal innovation entails combining a product with an entirely new service ecosystem, from customised servicing, repair or financing. Indeed, this is one area where the Nano, for all its iconic power as a frugal product, has struggled. Sales of the Nano have been disappointing, and rather than the aspiring first-time car buyers that were its target market, many customers have been wealthy urban residents buying a second car. The issue was less the price tag and more the weakness of the distribution channels in the smaller

towns and cities where these aspiring consumers live, and the comprehensive financing options that would allow the Nano to penetrate this market segment.

By contrast, SELCO, a company which is making solar power a feasible option for the rural poor, is an excellent example of creating an entirely new service ecosystem around a product.[19] The conventional policy response to widening access to solar power had been to treat it as a product, with banks subsidised by the government to give loans to customers for purchasing solar panels. But according to SELCO founder, Harish Hande, the 'pro-poor' promise of the approach was rarely fulfilled in practice.[20]

Hande understood that expecting a vegetable seller or cobbler earning just $50–100 a month to save for solar was not realistic. His innovation was to treat solar power as a service. The answer, he believed, instead of relying on subsidies, lay in a pay-per-use model, where entrepreneurs bought the technology and charged customers a tiny cut of their daily cash flow to use it – distributing the solar lights every evening and collecting them the next morning, along with payment.

The first barrier to overcome was banks' scepticism about the profitability of the technology itself. SELCO had to educate bank managers about its benefits and convince them of its revenue potential so they would lend on it. The second barrier was de-risking the investment. Banks expected regular monthly repayments and were nervous about the risk of lending to lots of individuals, many of whom lacked collateral. SELCO's solution was to act as a guarantor for the credit worthiness of the middleman. While this carries risk for SELCO, dealing with only one entrepreneur who services tens or hundreds of customers reduces SELCO's administration costs, making it still feasible to provide power cheaply.

Instead of focusing on developing a new technology, or subsidising existing technology, SELCO's model allows the full costs of solar power to be covered over time. SELCO has now brought lighting to 120,000 households in Karnataka, and Hande received the 'Asian Nobel Prize' in 2011.

Like SELCO, some of the examples of frugal innovation seen in the research for this report have a specific goal of environmental sustainability. However in many more cases, sustainable outcomes were created as a by-product of limiting resource inputs to cut costs or leveraging existing resources in new ways. For example, Gyanesh Pandey wanted to bring electricity to rural Bihar despite the conviction of the State Electricity Board that it was not feasible to service some areas due to geographical difficulties.[21] Pandey developed power plants that use a common local waste product, rice husks, closing a consumption loop. In another case, Vortex Engineering wanted to widen financial inclusion across rural India. To achieve this, they needed to overcome the unreliable power supplies prevalent in rural areas. So they designed and built an ATM with a solar panel that consumes a twentieth of the power of normal machines, in part by generating less heat so there is no need for continuous air conditioning. Not only do these machines have lower operating costs, but the capital outlay is approximately a third of the cost of standard high street ATMs.[22] This ATM is an Indian innovation with a global footprint. Vortex has export partners in Bangladesh, Nepal, Bhutan, Africa and the Middle East. In December 2011, it signed an agreement with South Africa's WIZZIT Bank as part of a United Nations programme to provide banking services to 30 million low-income people in India and South Africa by 2015.[23]

Low cost but not low-tech

Frugal innovation is not limited to low-tech sectors. It can require, or be combined with, frontier science and technology. Take water supply: Indian Government surveys reveal only a third of the rural population has access to clean water[24] and penetration of water filters in rural India is less than 1 per cent.[25]

An old wedding hall tucked away down a dusty track an hour outside of Pune is an unlikely place for a solution, but this is where to find Tata Chemicals' Innovation Centre. Chief Scientist Dr Rajiv Kumar apologises for his small facility – they are moving to permanent premises soon – but is quick to point out that the quality of the building doesn't always correlate with the quality of the science. And with some justification, since the Centre is the birthplace of the 'Swach' water filter. At $20, it is 50 per cent cheaper than the cost of its nearest competitor filter, and functions without electricity or running water. A rice husk and silver nano-particle filter developed in collaboration with Massachusetts Institute of Technology cleans up to 3000 litres of water before automatically shutting off – frugal innovation techniques combining seamlessly with advanced technology. With 894 million people worldwide lacking access to clean water[26] Tata are increasingly aware of the potential market, and are already exploring opportunities in Africa, Southeast Asia and Latin America.[27]

As multinational research becomes increasingly networked – a trend we will explore further in Part 4 – companies which have previously set up R&D centres in India to adapt Western products for the Indian market are increasingly realising that the conditions for innovation in India are conducive to creating products that could disrupt global markets. One striking example is General Electric's MAC 400 Electrocardiograph (ECG) machine. GE Healthcare's engineers were set a formidable challenge: take a hefty ECG machine that cost $5.4 million to develop[28] and squeeze the same technology into a portable device that could reach rural communities. They were also charged with developing the new product in 18 months, and with a budget of just $500,000. With such a stretching target and tight resources, the engineers combined their technical know-how with creative tweaks of off-the-shelf parts. For example, the machine's printer is an adaptation of one used in bus terminal kiosks across India. The MAC 400 cost $1500, instead of the $10,000 of its predecessor, and reduced the cost of an ECG to just $1 (50 rupees) per patient.[29] More recent versions further reduce upfront costs and bring operating costs down to just 10 rupees per patient. General Electric announced in May 2009 that it would be spending $3 billion over six years to create 100 new healthcare innovations that would substantially lower cost, increase access and improve quality.[30]

The origins of frugal innovation

Where did frugal innovation come from? As with any concept in innovation, frugal innovation builds on the theories, movements and capabilities that have come before it. This evolution is described in Table 1 (page 20). Some trace the origins of frugal innovation back to the intermediate or appropriate technology movement. Exemplified in Schumacher's 1975 publication, *Small is Beautiful: Economics as if people mattered,*[31] this evangelised the local development of low-tech, labour intensive, environmentally sound technologies as an alternative to dependence on technology-transfer from developed countries. Schumacher first articulated the idea of intermediate technology in a 1962 report for the Indian Planning Commission, and was heavily influenced by the teachings of Mahatma Gandhi, for whom local, village-based technology and production was a key aspect of the Independence Movement and the nation's future self-reliance.

After blossoming as a global movement, the popularity of intermediate and, later, appropriate technology principles waned. It became increasingly regarded as patronising, with implications of second class quality. As political and commercial awareness of environmental challenges like ozone depletion and climate change began to accelerate in the 1980s, the need for appropriate technology was overtaken by a concern about sustainable development. The 1987 Bruntland report to the UN, *Our Common Future*,[32] recognised the interdependence of both challenge and solution to sustainable growth across the developed and developing world.

At the same time, the rise of Japan from the 1960s, with the emergence of the East Asian Tigers in the 1980s and 1990s drew attention to the increasingly distributed nature of global technology design and production. Not only technologies, but management philosophies like Toyota's pioneering 'lean manufacturing' methods began spreading from East to West and not just the other way round.

The 2000s was the decade of the BRICs. The rise of China and India, documented in Goldman Sachs' 2001 report,[33] signalled a dramatic long–term realignment of the global economy. As the internet enabled ever more distributed R&D activities, 'open innovation' became a mainstream practice and multinational companies sought to position their R&D centres to capitalise on huge new markets and talent pools. This partly explains the huge impact of Management Professor CK Prahalad's work *The Fortune at the Bottom of the Pyramid: eradicating poverty through profit.*[34] Using a wide range of examples of profitable, sustainable business models serving the very poor, including several from India, this recast the world's poor as active consumers rather than passive recipients. India was once again at the forefront of the debate. With Professor Prahalad, Dr RA Mashelkar, former Director of India's Council for Scientific and Industrial Research, wrote an article for the Harvard Business Review in 2010 which posited that the frugal approach to innovation – getting more with fewer resources for the benefit of more and more people – was 'Innovation's Holy Grail'.[35]

Table 1: Influences on the development of frugal innovation

	1960s to 1980s	1980s to 2000s	2000s to 2010s	2010s onwards
Social movements	Appropriate technology	Sustainable development	Private sector–led development	Ethical capitalism?
Globalisation of science, technology and innovation	–Technology transfer from developed to developing world	–Growing distribution of technology design and production with the rise of the East Asian Tigers	–Increasingly networked global innovation system as multinationals explore new locations for R&D	–Interdependent, globally segmented innovation by multinationals. Two (or more) way flow of ideas
		–The Internet	–Cheap connectivity	–Widespread digital platforms for collaboration
Innovation management schools of thought	–Systems analysis	–Lean manufacturing –User–led innovation	–Open innovation –Design thinking –Frugal engineering	–Frugal innovation
Emerging economy markets	Peripheral	Emergent	Recognised – the fortune at the bottom of the pyramid	Towards the centre of gravity

India's frugal factors

Why has frugal innovation emerged as a distinctive strength of the Indian innovation system? While frugal innovation is not the preserve of India, and a growing community of analysts are tracking the development of the phenomenon worldwide,[36] a number of factors have aligned to create the conditions for high–impact frugal innovation in India.

1. **A culture of 'jugaad' means the unusual skillset and mindset required for frugal innovation are abundant**
   Jugaad is a Hindi word that roughly translates as 'overcoming harsh constraints by improvising an effective solution using limited resources.'[37] From connecting a diesel engine onto a cart to create a truck, to irrigation systems powered by motorbike, there are widespread examples of this kind of creative improvisation over India. The Honey Bee Network and SRISTI, the Society for Research and Initiatives for Sustainable Technologies and Institutions, have documented over 10,000 grassroots innovations of this kind, with a view to patenting them as validation of their intellectual and commercial merit.[38] The authors of *Jugaad Innovation: Think frugal, be flexible, generate breakthrough growth*[39] show how this mindset and adaptability are important not only to local innovations, but to multinationals whose innovation processes have become 'too rigid, insular and bloated to remain effective.' They suggest three reasons why

this matters: *'First, it is frugal: it enables innovators to get more with less. Second, it is flexible: it enables innovators to keep experimenting and rapidly change course when needed. Third: it is democratic: it can therefore tap into the wisdom of otherwise marginalized customers and employees.'* For some Indians, the association of frugal innovation with a jugaad mindset is limiting. It has connotations of 'making do' and of 'getting by' which overlook the increasing flows of resources into the innovation system. Yet the principles of seeking opportunity in adversity and methods of doing more with less apply even to advanced technologies.

2. **A huge market with a growing, aspirational middle class creates the perfect conditions for frugal innovation**
   "At the right intersection of price point and functionality," says National Innovation Council member Saurabh Srivastava, *"the market explodes."* [40] Growth that has pulled millions of Indians out of poverty in recent years is also leading to the rapid growth of the country's middle class (households with disposable incomes from 200,000 to 1,000,000 rupees a year.) In 2007 the Indian middle class comprised 50 million people, roughly 5 per cent of the population. McKinsey projections show that by 2025 a continuing rise in personal incomes will cause this to grow at least tenfold. The middle class will comprise 583 million people, or 41 per cent of the population.[41] Despite low individual purchasing power, the overall size of the market creates huge purchasing power at lower income levels. In *We are like that only,* Rama Bijapurkar examines the total purchasing power of some of the middle groups: the 'aspiring' class (ranked fifth by wealth), for example, still has 65 per cent of the purchasing power of the most prosperous by sheer weight of numbers.[42]

3. **Not only is the Indian consumer base growing, but it is also extremely price sensitive and willing to experiment, sustaining demand for frugal innovation**
   CK Prahalad's influential work corrected misconceptions of bottom of the pyramid consumers as undemanding. This is visible in sectors from consumer products to healthcare. As Joss Van Haaren, Head of Healthcare Research and Development for Phillips Bangalore, explains *"The first thing people are faced with when they arrive at a hospital in India is a payment counter. The nature of the system means patients have an awareness at a granular level of what treatments cost – it really makes a difference whether a treatment costs even 500 rupees or 700 rupees."* In India, over 70 per cent of healthcare is provided by private enterprise,[43] forcing providers to be extremely competitive, no doubt a factor in the highly efficient model of the Devi Shetty's Narayana Hrudralalaya hospitals. Like patients, private providers are very sensitive about what they pay for equipment and other necessary supplies. This is contributing to a rich seam of innovation in affordable healthcare.

4. **Extreme conditions and major gaps in service provision stimulates demand for low-cost services in health, education and energy**
   India's vast rural population of 833 million[44] is spread across a land area of three million square kilometres.[45] Most poor Indians lack access to basic public services such as primary healthcare, drinking water and sanitation facilities. For example, one report claims that the Government of Bihar, a State of 100 million people, growing by at least a million people per year,[46] had not built a single secondary school for 30 years before 2009.[47] According to the International Energy Agency, 400 million Indians do not have access to electricity.[48] Necessity is sometimes the mother of invention, and with over 1.5 million NGOs, India has a strong tradition of civil society, and a socially conscious private sector that are willing to fill the void left by the government with radical new approaches, as seen in the context of the education sector in Part 5 of this report.

5. **Strengths in service and business model innovation create an advantage in creative remodelling of product-service ecosystems**
   While high-tech exports are growing fast[49] India, unlike China, doesn't overwhelmingly focus on manufacturing for export. Concentrate on looking for the 'Indian iPod' and you may overlook some of the more considerable influences of Indian research and innovation around the world. While the revolution provoked by India's software outsourcing story is well known, other stories of revolutionary business model innovation are less well known. Take the story of the Aravind Eye Hospital. From its beginnings as a modest 20-bed hospital in the 80s, Aravind had already grown into a 1,400-bed hospital complex by 1992. By then it had screened 3.65 million patients and performed 335,000 cataract surgeries. It now performs 200,000 surgeries a year. At the same time as running a profitable company, it delivered nearly 70 per cent of these operations free of charge to the poor. At the heart of its business model is multi-tiered pricing or cross-subsidisation – where the core service remains the same but profits from wealthier customers cover deficits from those less available to pay. This model has been imitated around the world.

6. **New sources of social finance are lowering the cost of investing in frugal innovations**
   In addition to growing investment in frugal innovation by multinationals and global philanthropic foundations such as the Gates Foundation and the Wellcome Trust, there is a buoyant market in investment for social impact. In India, seven social venture capital funds have raised approximately £120 million and invested about £80 million in 72 social enterprises over the last six years.[50] Social investors like the Omidyar Network and the Acumen Fund are optimistic about the opportunities in India. Varun Sahni, former Country Director of Acumen Fund, predicts *"There will be £1 billion coming into this space in the next five years."*[51] The environment could develop rapidly, with government's plans for a new $1 billion 'inclusive innovation fund' already in train. Government committed a cornerstone investment of $20 million this summer that is attracting the attention of institutional and private investors the world over.

7. **An increasingly 'inclusive' innovation policy is developing the institutional conditions that could drive high-impact frugal innovations**
   While little of the frugal innovation so far has been the result of government policy – indeed, some has been stimulated by the absence of public infrastructure and services – recent policies and public statements by leading politicians promote a uniquely 'inclusive model of innovation' for India. Government's willingness to capitalise on new approaches to innovation in technology platforms, connectivity and collaboration (particularly through the National Innovation Council) is turning India, according to one USAID director, into a *"laboratory for innovation in development."*[52] One initiative with vast potential to create a platform for future frugal innovation is not framed around innovation at all, but rather around social protection. The Unique Identity Scheme, headed up by the former CEO of Information Technology giant Infosys, is already the world's largest biometric database even though it is only a sixth of the way to collecting the retinal scans and fingerprints of all 1.2 billion Indians. That said, the Government is well aware of the potential of 'Aadhar' – the Hindi name for the scheme translates as 'foundation' or 'platform – to support innovation. Combined with mobile phone technology, this scheme could herald the transformation of everything from banking to the welfare state.

A future for frugal?

Rather than a break with the past, the Indian Government's embrace of frugal innovation arguably represents the latest manifestation of a longstanding tension in Indian science and technology policy between excellence and equity. Ever since Vannevar Bush made the public interest case for post second world war public investment in US R&D with his *Endless Frontiers* report, debate has raged around the world about the relative importance of investing in creation of basic scientific knowledge versus investing in the creation of capacity for societies to assimilate and apply this knowledge. This debate is understandably acute in India, where a space programme that has budgeted for a mission to Mars in the current Five Year Plan is still based on the founding principle in 1963 that it would benefit the 'common man.'

Whether the Government's far-reaching policies can create a more supportive environment for frugal innovation in the first place, and even if it can, whether frugal innovation ultimately offers a way to resolve the tension between excellence and equity in Indian science and innovation, or merely to perpetuate it, remains to be seen.

Nevertheless, the promise of frugal innovation is that it offers a way to square this circle. In a recent interview for the *Economic Times* on the eve of the launch of a new $130 million[53] automotive research facility in Chennai in April 2012, Anand Mahindra, eponymous CEO of a company that is one of the largest R&D spenders urged: *"We have to move beyond jugaad, frugal engineering and frugal innovation is fine, but not jugaad. The age of jugaad is over, we have to do more for less and that is what Mahindra Research Valley will embody. It is not about bridging the gap, it is a new paradigm, which is Indian."*[54]

This 'new paradigm' is increasingly relevant to cash-strapped economies in Europe and North America for five main reasons:

1. **Lacklustre growth and deleveraging in developed economies will increase demands for frugal products and services and frugal innovation processes.**
   While finances remain tight, so does risk capital. Some sectors such as pharmaceuticals are already highly aware of the unsustainability of the dominant structured, investment-intensive models of innovation. The low-cost development processes entailed by many frugal innovations make them an appealing choice for venture capitalists, according to Anne Glover, CEO of Amadeus Capital Partners. *"There are two points of frugality.... There is 'How good is the product at displacing its current alternative?', and that's where you are saying it needs to be a factor of ten better, or at least ten. The second point of frugality is 'How much capital does it take to develop that product in the first place?' which is an investment question. And that's of interest to us because in today's world, the amount of risk capital is not that great."*[55] For consumers, sluggish growth in real incomes and the need to pay off debts is likely to prompt demand for frugal products and services, alongside more conventional patterns of consumption. In Europe and the US, there has already been a growth in new collaborative consumption tools that share resources between strangers – making it easier to get a bed in a foreign city, to rent a car or borrow someone else's power drill.[56]

2. **Environmental constraints around climate, energy, water and other resources will increase demands for more frugal models of production and consumption.**
   Alongside financial pressures, there are growing concerns about unsustainable consumption of water, food, energy and minerals. Between 1960 and 2000, world water use doubled and between 1900 and 2000 the amount of carbon humans released into

the atmosphere increased 15-fold. Developed economies unsustainable consumption is compounded by the uncomfortable truth that over a billion people living in poverty across the globe need to increase their resource consumption in the short term to access the higher standard of wellbeing to which they have a right.[57] While environmental sustainability is not always a strong driver of the examples profiled in this report, frugal innovation often goes hand-in-hand with more sustainable models of innovation. Radical environmental regulation could be a driver of frugal innovation, but there is also a strong profit motive for companies to respond to consumer values which favour sustainable products.[58]

3. **Caring for rapidly ageing societies will require completely new approaches to health and social care, including the radical rethinking of business models and value chains that is apparent in some examples of successful frugal innovation.**
   The pressure on the public finances as a result of the financial crisis and the long recession has brought into sharp relief the long-term drivers of government spending, such as demographic change and the need to radically rethink our healthcare systems to provide for an ageing population. By 2031, the number of over 75 year olds in the UK population will almost double. Half of the babies born in the UK today will live to over 100. These demographic changes will cost the NHS up to £1.4 billion extra each year.[59] Experiments in provision of public services for under-served populations in India could have important implications for the way health and social care are provided in ageing societies like the UK in the future.

4. **Today's fastest growing markets are in developing and emerging economies where demand for frugal products is high.**
   The rising demand for low-cost products among the aspiring consumers of the developing world will drive an enormous global market for low-cost, high-quality products. In the last ten years, hundreds of millions of consumers have entered the 'middle classes' with an associated growth in disposable income. Consultancy firm Ernst & Young predict the global middle class will reach five billion by 2030, with demand growing from US$21 trillion to US$56 trillion by 2030. Today, 10 per cent of middle class spending is in Asia; by 2030 this will rise to 40 per cent. In their survey of almost 600 executives, Ernst & Young found that more than three-quarters of respondents thought that adopting frugal innovation – which they defined narrowly as 'economical use of resource to provide products affordable by those on a lower income' is a major opportunity.[60]

5. **New technology platforms are drastically reducing the cost of some forms of innovation, which is creating huge new opportunities for frugal innovators, particularly in services.**
   Cloud computing, the rapid spread of mobile phones and new digital platforms are lowering the barriers to innovation around the world. Digital platforms enable innovators to rapidly design, prototype and test new applications and solutions. In just four years following its launch in 2005, Kenya's M-PESA mobile phone payment and money transfer system grew to 14 million users, creating access to financial services for 65 per cent of Kenya's households. Internet penetration is dramatically increasing via mobile devices, due to overtake PCs as the dominant way of accessing the Internet by 2016. In India the population of mobile phone users is growing each year by more than the population of the UK,[61] creating opportunities for rapid experimentation and platforms for innovation.

In the next section we explore the strengths and weaknesses of the policies, institutions and conditions for research and innovation, how they are shifting over time, with a view to understanding what growing expertise in frugal innovation may hold for India and the rest of the world.

Part 2

RESEARCH

The widespread disappointment among Indian scientists at spending increases averaging only 10 per cent[62] in the March 2012 budget is a sign of just how good funding in Indian science has been in recent years.[63] Government policy may be shifting towards a focus on 'frugal solutions' to India's challenges in energy, water and food, but this is combined with long-term investments in 'big' science such as nuclear. A focus on getting more for less doesn't come from being cash-strapped, yet resources and research excellence remain concentrated in a small range of institutions.

As a first step to understanding the strengths and weaknesses of the Indian innovation system, this section looks in more detail at the distribution of those resources, and how they translate into research performance.

Table 2: Economic Overview

	India	Brazil	China	UK	US
Population (World Bank,[64] 2010)	1,170,938,000	194,946,470	1,338,299,512	62,218,761	309,050,816
GDP per capita (Current US$, World bank 2010)	1,477	10,710	4,393	36,100	47,184
GDP PPP per capita (Current international $, World bank, 2010)	3,586	11,127	7,536	35,8560	47,184
GDP Growth (Annual %, World Bank, 2010)	9.72	7.49	10.30	1.25	2.85
GERD (% of GDP, World Bank, 2007)	0.80	1.10	1.44	1.82	2.72
FDI (net inflows as % of GDP, World Bank 2010)	1.40	2.32	3.15	2.09	1.62
FDI (net outflows as % of GDP, World Bank 2010)	0.76	0.55	1.02	0.47	2.41

FDI (net outflows as % of GDP, World Bank 2010)	0.76	0.55	1.02	0.47	2.41
Literacy rate (Adult total, %, World Bank)	62.8 (2006)	90.0 (2008)	94.0 (2009)	–	–
Poverty (% Population, Oxford MPI, 2011)[65]	53.7	2.7	12.5	–	–
Imports of goods and services (% of GDP, World Bank, 2009)	24.02	11.18	22.30	30.06	13.99
Exports of goods and services (% of GDP, World Bank, 2009)	26.71	11.12	19.58	27.68	11.24

India's annual R&D spend is similar to that of Brazil and Russia, but around five times smaller than that of China as shown in Figure 2. While India's huge graduate pool is often revered, in reality, the absolute number of researchers in R&D is comparatively low, and the diminutive proportion of researchers per million people is arresting – a feature of the Indian system explored further in Part 6. However, the research environment does seem to be reasonably efficient. India produces more scientific publications per dollar (PPP) of spending than the USA.[66]

At a glance: vital statistics

Figure 2: The global picture: How other countries compare to India[67]

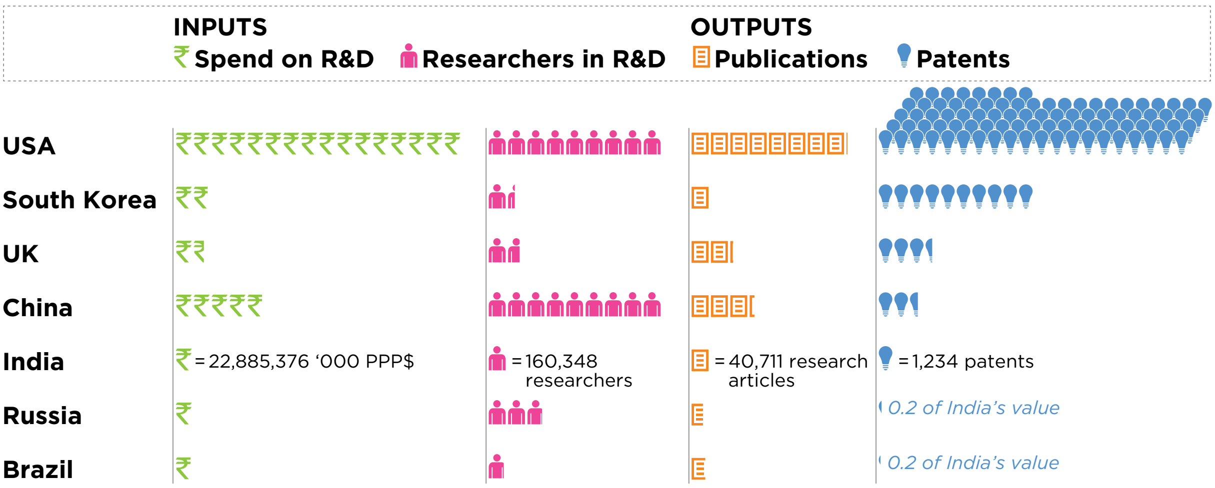
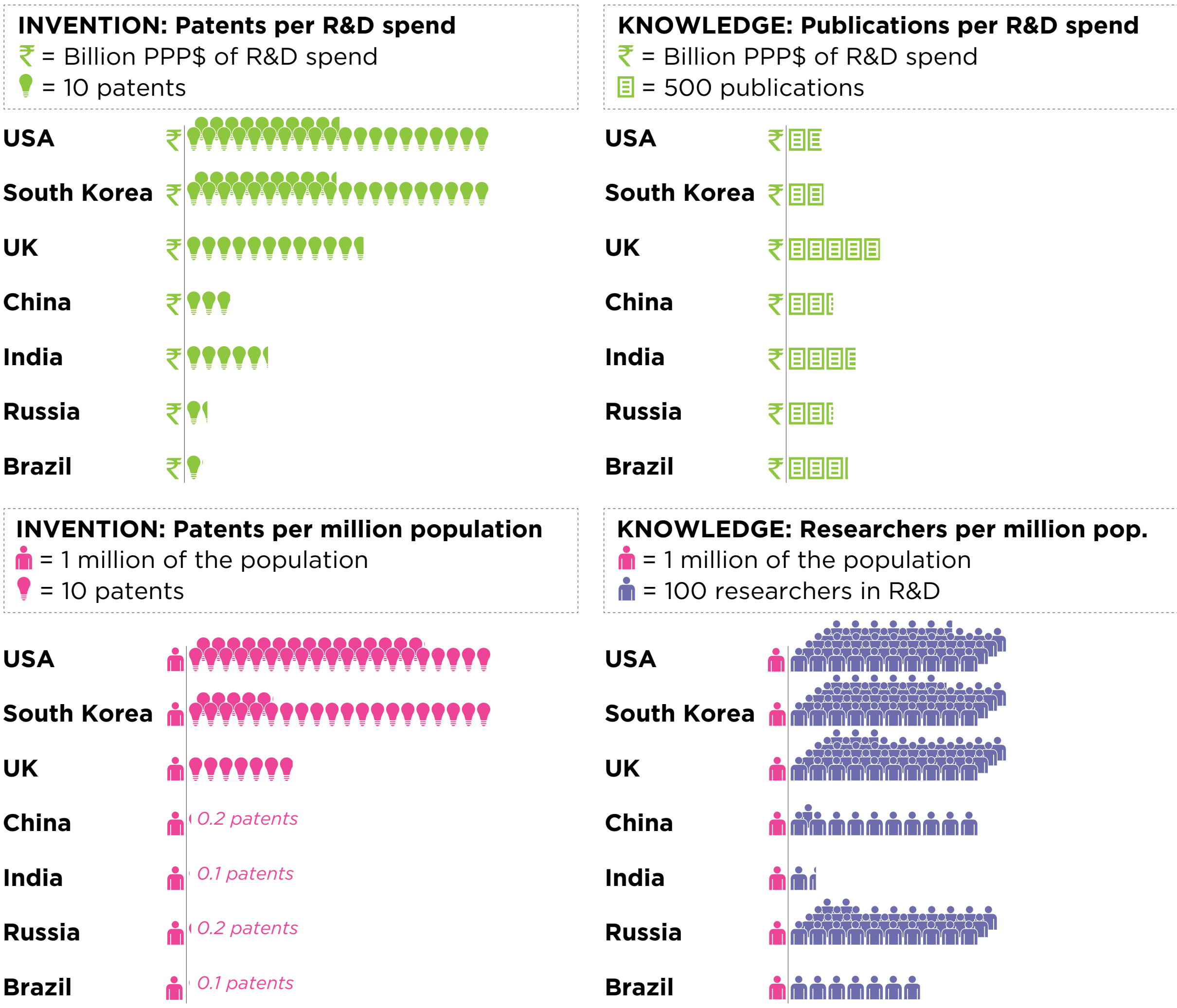
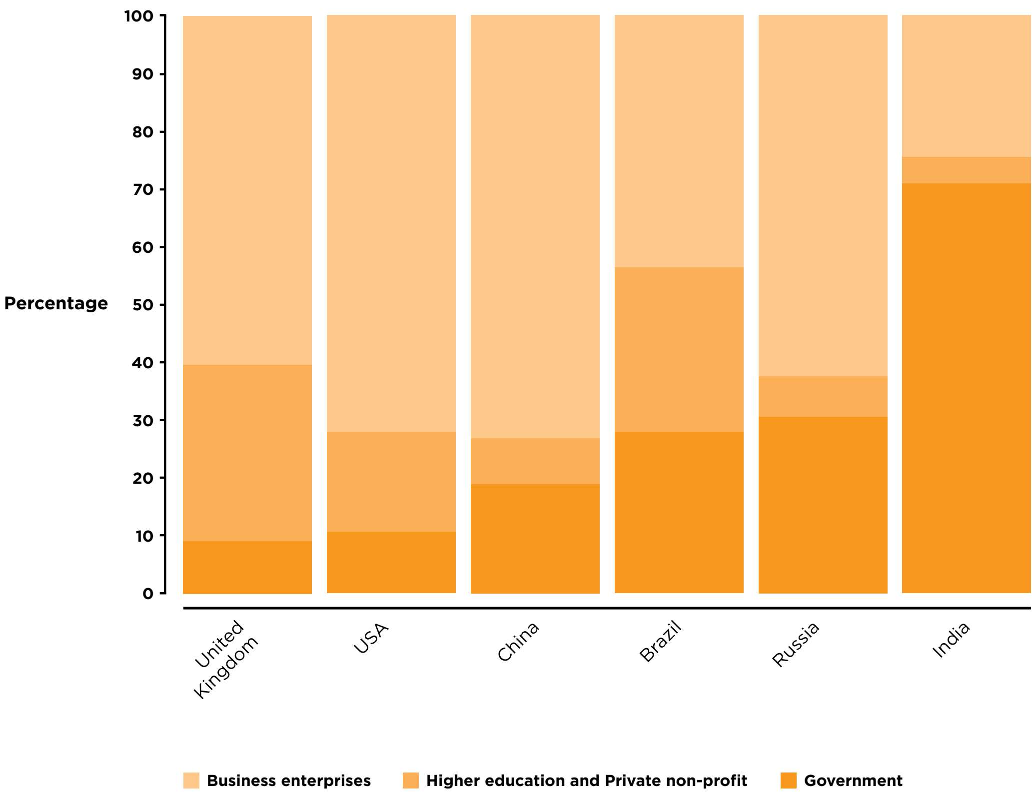


Figure 3: Efficiency of invention and knowledge[68]



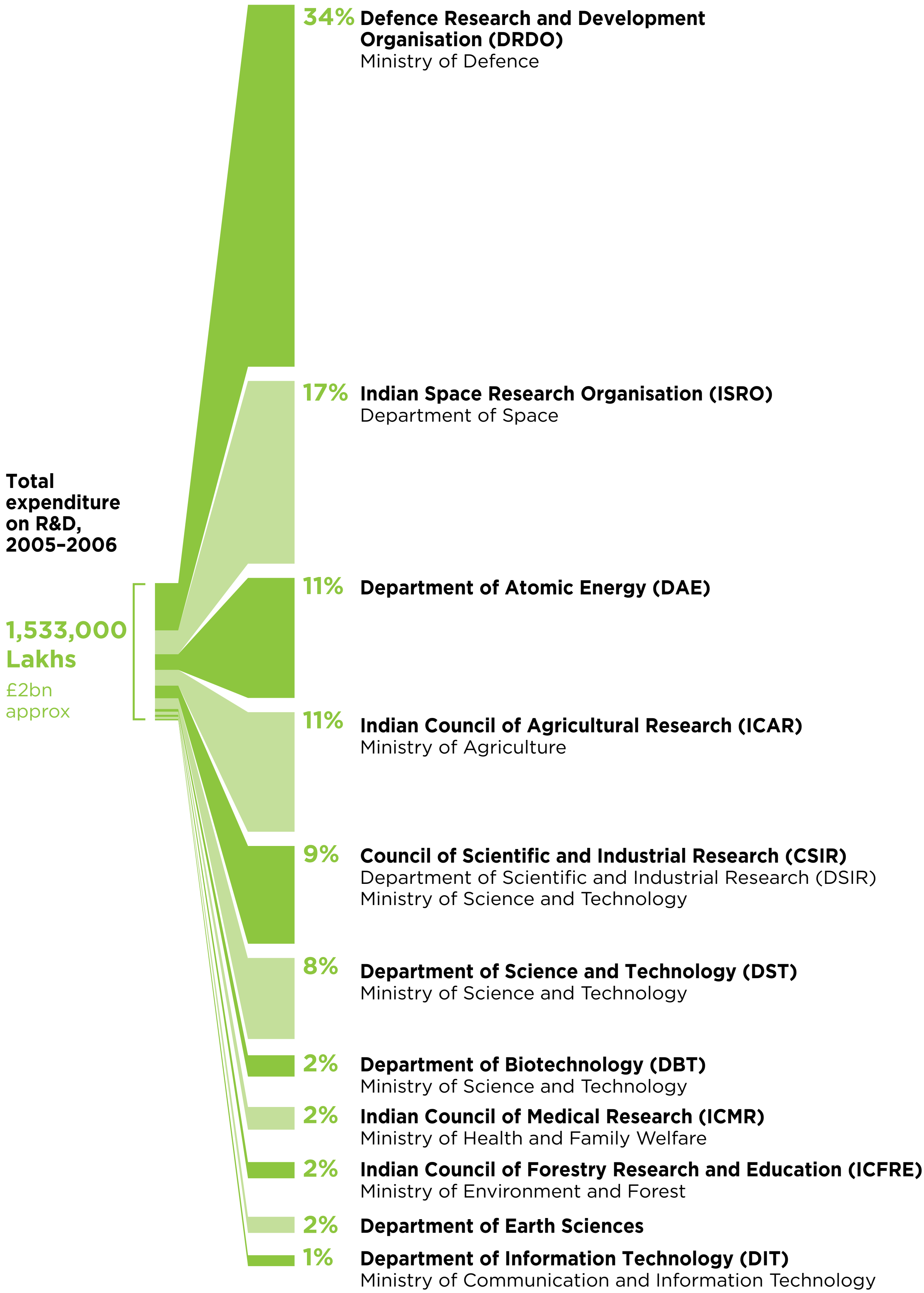
According to official statistics, around three-quarters of R&D funding in India comes from government. As Figure 4 shows, this is a larger proportion than the other BRIC countries, and far greater than the US or UK. While there is no doubt that government is the dominant player, analysis commissioned for this report found that foreign direct investment in research is not included in these figures. In 2010 this was over four billion dollars, and could slightly shift the balance.[69]

Figure 4: R&D spending in selected countries by source of funds[70]



Over 60 per cent of the R&D expenditure by major scientific agencies goes to just three government departments: The Indian Space Research Organisation (ISRO), Department of Defence Research Organisation (DRDO) and the Department of Atomic Energy (DAE). Figure 5 shows how this and the remainder of the budget is distributed.

Figure 5: R&D spend by major scientific agencies in India[71]



Research output on the rise

Increased investment in R&D has contributed to an output in peer reviewed research publications that has more than doubled over the last decade. This is a growth rate of almost 9 per cent per year[72] and Indian research now accounts for 3.5 per cent of the global total.[73] Yet as seen in Figure 6, while India's output of publications has grown faster than that of Brazil and Russia, it is dwarfed by the growth in research publications from outlier, China.

Figure 6: Publication output of the BRICs[74]

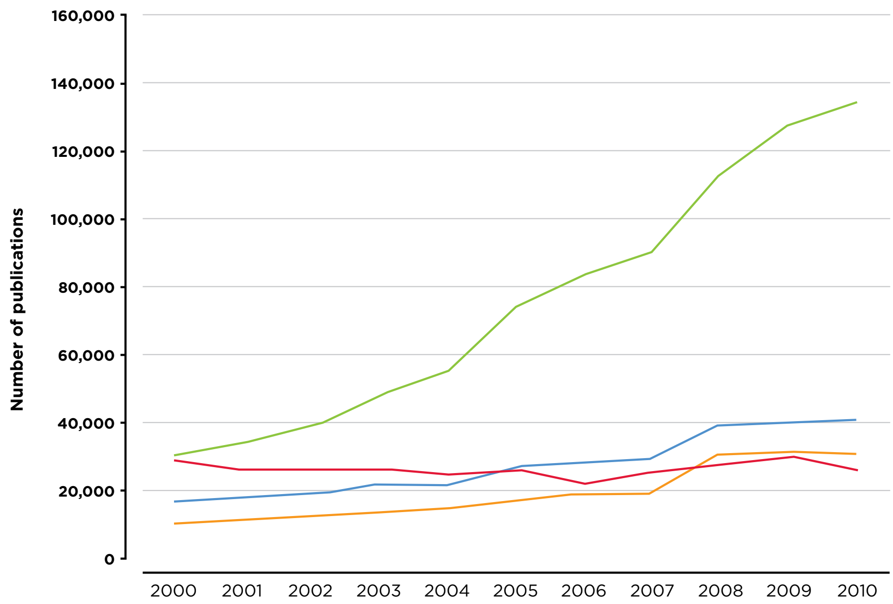
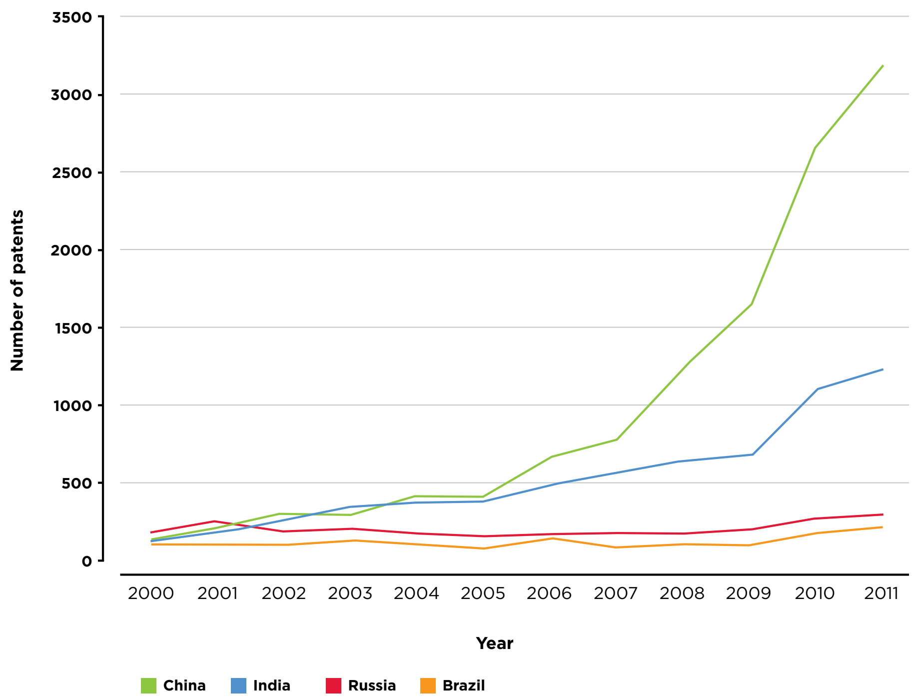


Figure 7: US Patenting by the BRICs[75]



India's share of global academic papers has been growing in almost all fields of research, with the country's largest share of world output in chemistry, materials science, agriculture and pharmacology. Only the arts and humanities showed no increase in share since 1996.[76] This doesn't mean excellent work isn't taking place. India has a vibrant arts, humanities and social sciences scene – for example the Jaipur Literary Festival is the biggest in Asia – but little of this publishing takes place in academic journals.[77]

Patenting

While rates are still far behind leading patenting nations, such as USA and Japan, patenting continues to rise rapidly in India. Figure 7 compares patents granted by the US Patent office (USPTO) to organisations from India, China, Russia and Brazil.[78] While USPTO patents granted to China and India grew at similar rates until 2005, there has been a clear divergence since 2005, with China's output growing at a far greater rate.

Leading public research institutions

Although there are a small number of high-performing research universities (see Figure 9), most universities do no research. It's worth highlighting some of the key actors in this 'top-tier' of institutions.

The Indian Institute of Science

The Indian Institute of Science (IISc), Bangalore, is India's premier institution for scientific research, though it is neither a national laboratory nor a conventional university. Founded in 1909, it only offered postgraduate education until 2011; it now also offers a Bachelor of Science. The IISc produces more scientific publications than any other Indian institute, and more world class publications,[79] as well as being a leading institution for collaboration with industry.[80] The IISc was the only Indian university to make it into the Shanghai Jiao Tong Academic Ranking of World Universities top 400 in 2011.[81]

The Indian Institutes of Technology

With the IISc, four Indian Institutes of Technology (IITs) comprise India's top five institutes in terms of output of world-class research.[82] The IITs are India's most famous educational brand not because of their research output or spin-offs, but because of the sheer quality of graduates they produce, accepting only 2 per cent of applicants. Alumni include the former CEO of Vodafone, co-founder of Sun-Microsystems and Chairman of Indian software giant Infosys. Five IITs were established shortly after Independence (1950 to 1963), modelled on the Massachusetts Institute of Technology. Four were founded with assistance from foreign organisations,[83] and these Institutes still have strong international links.

An expanding top-tier

After longstanding dissatisfaction within the scientific community about the extremely limited capacity of this top-tier of institutions, nine more IITs were launched from 2008. These reach beyond the traditional knowledge hubs to include cities such as Roorkee and Kanpur. In addition, five Indian Institutes of Science Education and Research (IISERs) and a National Institute for Science Education and Research are getting off the ground.[84] Thirty National Institutes of Technology (NITs) have also been set up, with one located in each major State or Union Territory. These autonomous engineering institutes upgrade and expand the existing Regional Engineering Colleges and offer bachelor's, master's and doctorate level courses.[85] Unusually, half of the student population is drawn from the respective State and the other half is drawn from the rest of India on a common merit list.

Describing life at one of India's new poster child institutions, Director of IISER Pune Dr Krishna Ganesh reveals *"Our start up grant [for a lab] is a blank cheque."*[86] Modelled on Western universities, the six new IISERs[87] combine teaching with research. They offer a five year integrated MSc programme. The final year is taken up by a research project, with an option to do a course in finance, management, science journalism or filmmaking. The IISERs aggressively recruit faculty from India's diaspora, luring them home with offers with incentives like those offered by Dr Ganesh. When fully operational, the IISERs will each produce 2000 PhDs in science and technology a year – doubling the current national output. Modelled on Western universities, they are a substantial break from the past, *"We thought we should build new institutions, where we could have the best research and (the) people who are doing active research should actually teach undergraduates"* [88] explains Dr Ganesh. Although still waiting for a permanent campus, the first batch of his students graduated last year, and things seem off to a good start – the 44 students have generated 15 research publications between them, and 23 are going on to do PhDs.[89]

The Council of Scientific Research

The majority of Indian research takes place, however, in public laboratories. The Council of Scientific and Industrial Research (CSIR) is India's largest R&D organisation: a network of 37 laboratories with 6000 full-time researchers that focus on applied research. CSIR labs publish around 10 per cent of India's overall research output.[90] The group also dominate Indian non-corporate patenting in the USPTO.[91] Having acquired the status of a deemed university (see Appendix 4), CSIR plans to award 1200 PhD and 2000 post graduate science degrees annually beginning this year to boost scientific manpower. However, there is substantial variation within the CSIR labs, with recent rises in publications and patents largely being driven by a small number (<10) of more dynamic institutions.

Research strengths

India's best research is often in engineering, physics, materials science and chemistry[92] (see Appendix). While any given Indian paper is likely to be well below world average quality,[93] the Indian research base has a similar impact to that of Brazil and a greater average impact than Russia's research.[94] The quality of India's academic research is rising, with the greatest improvements seen in psychology, neuroscience, social sciences, agriculture and engineering. Average quality decreased in pharmacology, microbiology and the humanities.[95]

Big science: nuclear and space

Long-term strategic investments in nuclear and space research have resulted in top-quality research, and nuclear research facilities better than those of the UK.[96] India's research on using thorium as fuel for nuclear power reactors is without equal, and this year India will bring online an indigenous prototype fast breeder plutonium reactor.[97]

India's space programme is also world class, which is impressive given its budget is almost ten times smaller than that of NASA. Instruments aboard the 2008-09 Chandrayaan-1 probe uncovered water molecules on the moon. In October 2011, India launched an Indo-French satellite to collect data on water and energy balance over the tropics in what was the nineteenth consecutive successful launch of India's smaller rocket. While the budget may be relatively small, ISRO's dreams are not modest. In the coming years, ISRO plans planetary exploration missions, a reusable launch vehicle, and a programme to send astronauts into space. In a very tough economic climate, India remains one of the few countries in the world which has maintained and even reinforced its space program. K Radhakrishnan, Chair of ISRO, is confident *"India is poised to soar higher in space,"* he says. *"But it will be done with a uniquely Indian flavour."*[98]

While India's space programme is avowedly in service of the common man, with major programmes in areas such as tele-education and meteorology, big science in India is far from frugal. Indian science is better funded than might be expected of a country with 474 million people below the poverty line.[99] Srinivasan Raghavan, a materials scientist at IISc explained to the journal *Science* that *"Money is not much of a problem."*[100] as workers put the finishing touches on a $30 million, 1300 square metre clean lab for nanotechnology, packed with kit. Major investments planned in the next five years include a $350 million Neutrino Observatory in Theni, which will be India's single largest investment to date in basic research.

Open science: crowdsourcing drug discovery

Outside these major facilities, large tracts of the country have little research infrastructure. One flagship CSIR project, the Open Source Drug Discovery programme (OSDD), is setting out to overcome this. While built on expensive computer infrastructre, it could be considered a frugal innovation as it is leveraging human capital for science in new ways to radically reduce the cost of drug discovery. Launched in 2008, it is crowdsourcing the elements of discovery of a new tuberculosis (TB) drug. The technique connects scientists from all over India, and beyond, through an internet platform, drawing on the distributed power of thousands of human brains. The community members respond to work packages posted online by OSDD: questions on everything from the biology of *M. tuberculosis* to new drug leads. Answers are tagged and credited. This 'baton passing' enables individuals to deliver on their core competence and let the results be carried forward by others with respective competences down the pipeline.

This is a radical departure from the normal approach to drug discovery. Pharmaceutical companies are reluctant to invest the money needed to develop new treatments for TB as the customers (almost exclusively in poor countries) will not be able to afford the sorts of drug prices that would let the companies recoup their investment. As a result, TB kills over 1,000 people every day in India and is still treated with a nine month programme of drugs developed 50 years ago.[101]

Together the combined brains of volunteers have achieved dramatic results. The *M. tuberculosis* genome was sequenced in 1998, but researchers had clues to the functions of only a quarter of its 4000 genes.[102] In December 2009, OSDD set out to re-annotate all possible genes. Five-hundred volunteers got the job done in a mere four months. Since then, two promising molecules have been contracted for testing[103] and Zakir Thomas, Project Director, hopes that the approach will fill the TB drug discovery pipeline in the next five years.

While the programme has not been without its critics,[104] it continues to expand and develop. In collaboration with Johns Hopkins University and Imperial College, among other leading global universities, the science crowdsourcing platform will soon begin a synthetic genome project, and could play a role in a new project to create a solar energy absorption material for 100th of the cost of silicon. For Director General of CSIR, Samir Brahmachari, it's not difficult to attract great minds from around the world to the platform – *"It's about shared motivation to do something globally good that's not for the profit of the few...it's not about creating more Warren Buffets... and the overturn of the global pharma industry shouldn't be looked at as necessarily a bad thing."*[105]

Given the potential of this platform to leverage resources in new ways – in this case human capital: the wisdom of experts and the enthusiasm of young researchers – and help drastically reduce the cost of drug discovery, it is an example of the power of combining

frugal innovation approaches with new technology platforms.

The enthusiasm for shared problem solving is infectious. According to Professor VS Chauhan, Director of the International Centre for Genetic Engineering and Biotechnology (ICGEB) in New Delhi *"The scenario for young scientists these days is so good I wish I was 30 years old again."*[106] His team are profiling biomarkers in the breath of TB sufferers to develop an almost instant breath test for the disease, removing the need for multiple expensive trips to the clinic and saving lives with early diagnosis. Having already published in top journals, including *Cell*, they secured research funding of $950,000 from Grand Challenges Canada and the Bill and Melinda Gates Foundation in November 2011. The next step for Professor Chauhan and colleagues will be to work with a Californian firm to develop a handheld, high-tech sensor for their 'e-nose.' Peter Singer, CEO of Grand Challenges Canada, has described the work as a *"bold idea with potentially big impact"* and *"testimony to the power of innovation to save lives."*[107]

Low levels of academia-industry interaction

While CSIR and other research institutions are experimenting with new ways of connecting the research infrastructure, and international linkages are growing fast, overall the domestic linkages of the innovation system are relatively poor. For Dr Arnab Bhattacharya, Assistant Professor at the prestigious Tata Institute for Fundamental Research, it wasn't a surprise when one of his PhD students decided to leave the lab to go and work for an ice cream company. After years growing semiconductor crystals in the lab he had developed a deep understanding of how to stunt crystal growth – and thereby to improve texture in ice cream. The surprise is how well-connected Dr Bhattacharya's lab is with industry. He is one of very few academics to bring in money to support fundamental research from industry, and to support his students to choose private sector careers.[108] Academia-industry collaboration in India is growing, but from a low level – a sign of an innovation system with significant room for improvement in connectivity. While there is very little systematic, let alone quantitative research, academia-industry collaboration is led by a small number of sectors, firms and academic institutions such as the IITs and the IISc Bangalore[109] and is concentrated in training and short term consultancy projects, often around engineering.

Despite the increase in educational infrastructure for education, and government moves towards a more coordinated innovation policy (see Part 4), India's innovation ecology is still underdeveloped. As Dr Aditya Dev Sood, CEO of innovation consultancy, the Centre for Knowledge Societies explained *"There is the state, the public sector, the social sector, the private sector and rarely do these parties join forces and build hybrid mechanisms through which to work together. This is a grave shame in the moment and a tremendous opportunity in the future."*[110]

Part 3

PLACE

Sprawling for 79 square miles on the banks of the River Sabermati, the city of Ahmedabad has always prided itself on its willingness to take on the *status quo*. Legend has it that in the 15th century Sultan Ahmed Shah was camping on the banks of the river when he saw a hare chasing a dog. Inspired by the act of bravery, which his advisors attributed to the unique qualities of the land, he decided to build the capital of his sultanate nearby. Five–hundred years later, the city he named Ahmedabad would play an important role in the Indian independence movement. In the 1919, workers from the city's burgeoning textiles industry – Ahmedabad was known as 'the Manchester of the East' – burned down government buildings in protest at the extension of wartime emergency powers. In 1930, Gandhi began his famous 240 mile Salt March to the village of Dandi from the ashram he had founded in the city.

Despite this historical significance, and the mantle of being the seventh largest city in India, Ahmedabad has not had a strong global profile when it comes to innovation. Today a new spotlight is on Ahmedabad, and other 'second–tier' cities like it. The deadly riots of 2002 still have political repercussions, but feel increasingly long ago. Gujarat's economic growth is twice as fast as many other Indian states.[111] The infrastructure and electricity are reliable, and the administration is open to international investment. Ahmedabad has evolved from a textile hub to become a centre for advanced materials and composites.

While opinions remain divided about its future impact, the city is home to one of the best management schools in India (IIM–A), the National Institute of Design and one of the best incubators (the Centre for Incubation, Innovation and Entrepreneurship) and a large space research complex. The pharmaceuticals sector is blossoming too – accounting for 42 per cent of India's pharmaceutical turnover, and 22 per cent of exports.[112] Sunil Parekh, Strategic Advisor to the pharmaceutical firm Zydus Cadilla, believes *"We're going to have some major breakthroughs for the world coming out of Ahmedabad in the next two years."*

Will this bold hope be realised? Will differential State policies or the comparative advantages that cities like Ahmedabad enjoy over the existing hubs allow new hotspots for innovation to emerge? Or will India continue to be dominated by a handful of major hubs? The evidence assembled in this section suggests that both trends are happening. On the one hand, India remains 'an uneven innovator',[113] with the lion's share of innovation resources concentrated in Delhi, Mumbai and Bangalore, which look set to remain major hotspots for Indian innovation in the future. There are also large swathes of India registering little innovation, at least as measured by conventional metrics. On the other hand, a number of the cities that were on the cusp of emerging as hotspots five years ago have clearly broken through. And a number of new rising stars, like Ahmedabad, have emerged with the potential to join them in the years to come.

In this section we unpack these developments, using specially commissioned data to identify trends and research strengths of the major metropolitan areas across India. We also examine the way in which government policies, including efforts to expand the network of top–tier research institutes and universities, are shaping these trends.

A word on data

Most data related to innovation in India is available at the national or State level, which makes comparisons at city level difficult. In most cases, States are dominated by one metropolitan area and so the State level data is likely to be a reasonable proxy. However, the picture is cloudier in the case of New Delhi which spills into a number of adjoining States, and Maharashtra State where both Mumbai and Pune are major cities.

Still an uneven innovator?

Demos' 2007 report *India: the Uneven Innovator* found that there was a small 'premier league' of research and innovation hubs led by Bangalore, Delhi and Mumbai, but that overburdened infrastructure in Bangalore risked damaging its pulling power for inward innovation investment. It also highlighted a host of 'second–tier cities' set to rapidly emerge, foremost of which was Pune in Maharashtra.

Looking at developments in the last five years, four trends stand out:

- The continuing dominance of the three major hubs as destinations for research and innovation, despite pressure on infrastructure in some areas.
- The breakthrough of Pune into the innovation big league.
- The (re)emergence of a growing pool of new 'rising stars,' which we map using new data on the geographical distribution of research excellence.
- The continuing paucity of innovation activity in large swathes of the rest of India.

The net effect of these trends is that while the geography of Indian research and innovation has changed significantly in recent years, the overall concentration of resources has not.

The big three

Three major hubs continue to dominate Indian research and innovation – Delhi, Mumbai and Bangalore. As shown in Figure 8, they are all big cities: Delhi and Mumbai have populations of over 20 million, and Bangalore nearly nine million.[114] They are also India's most competitive cities, according to the 2011 *India City Competitiveness Report,*[115] which ranks city performance across indicators of financial, social and business performance as well as technology and inward investment (see Table 3). Karnataka (the State in which Bangalore is located) and Maharashtra (the State where Mumbai is located) top domestic R&D spend rankings,[116] are both in the top three for foreign investment in R&D,[117] and rank first and second among the 28 States for filing US patents.[118] Between them, as shown in Figure 9, they host eight of India's 21 highest quality research institutes.[119]

Figure 8: Inputs to Indian innovation: A geographical view

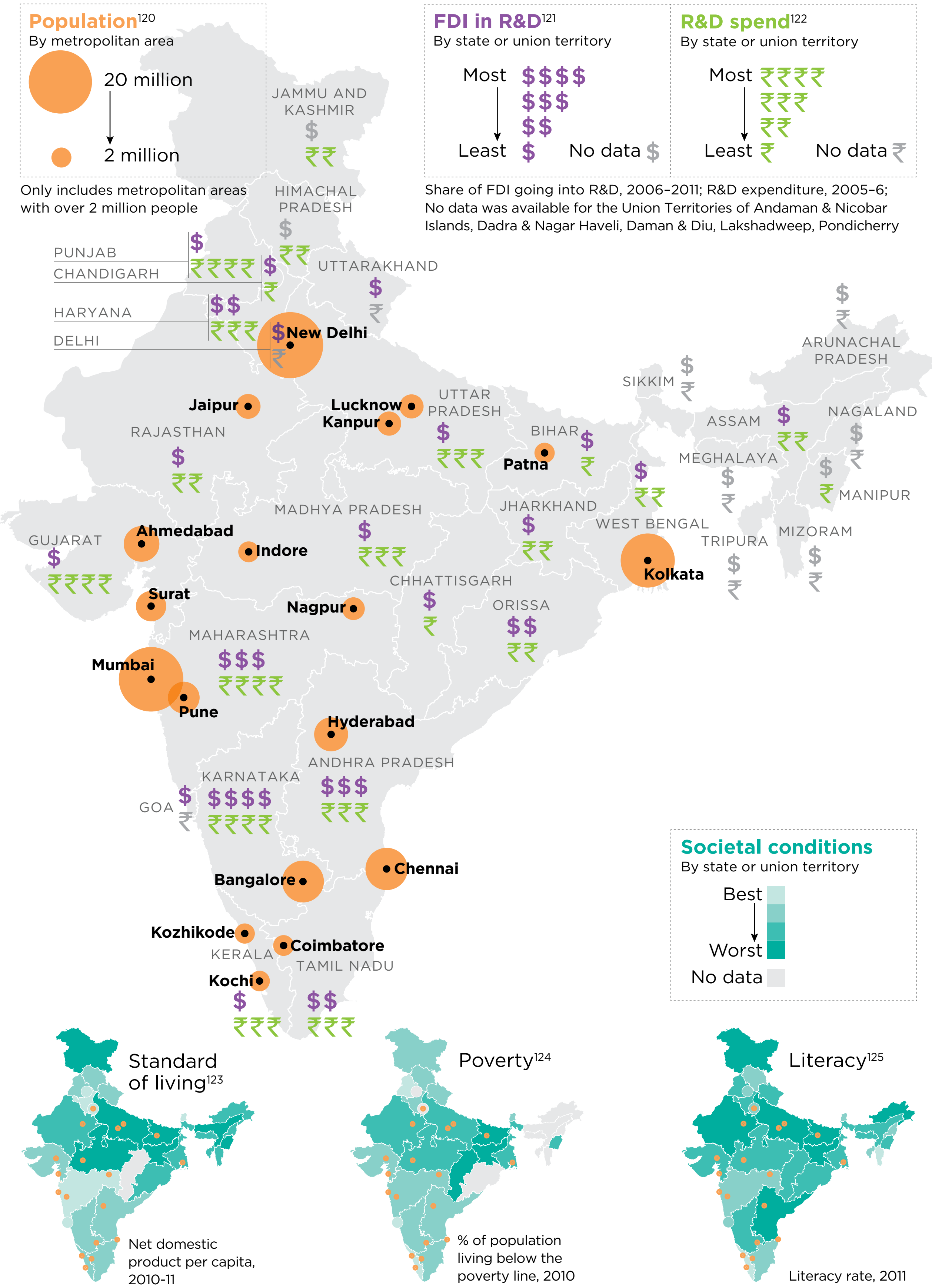
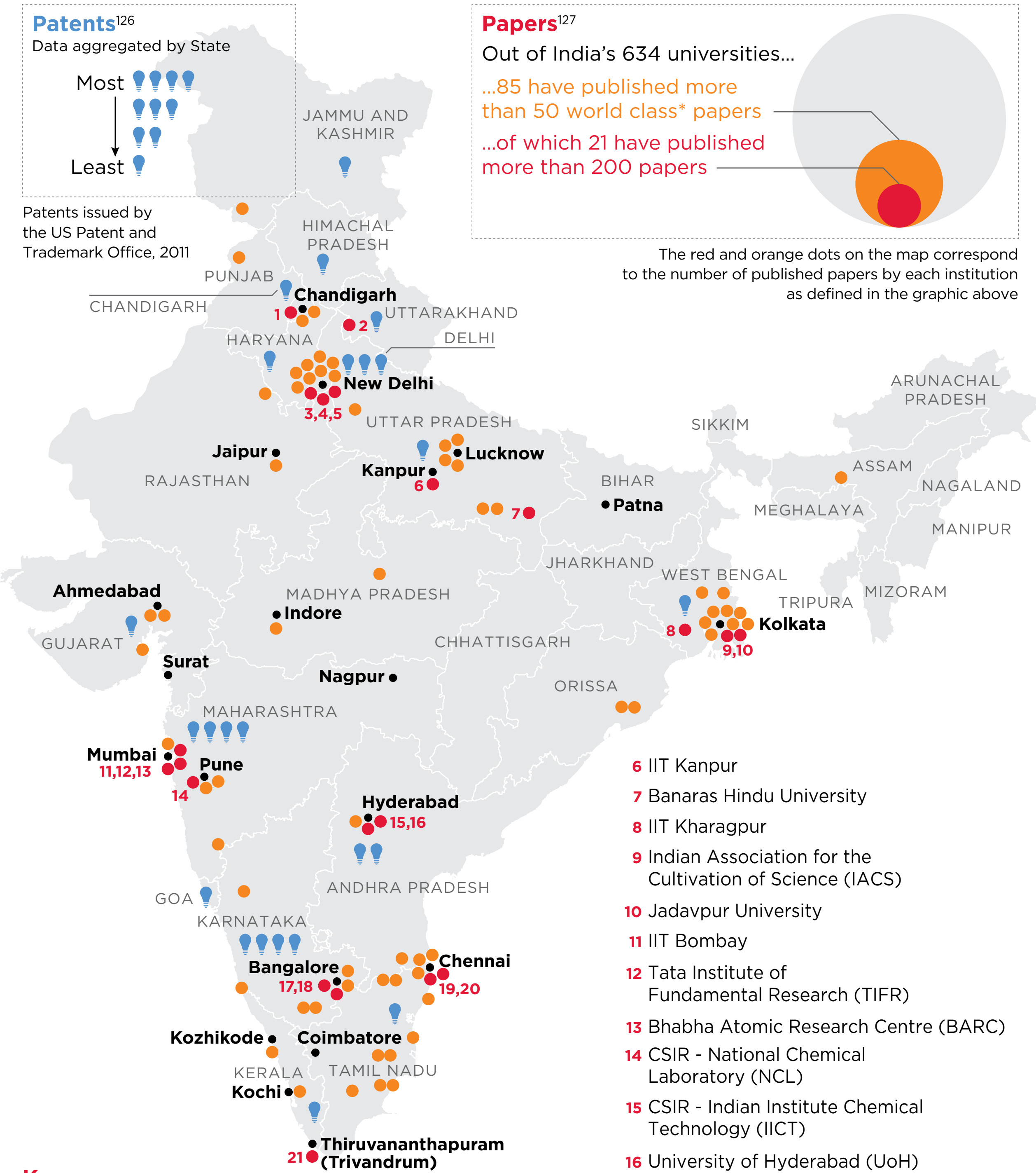


Figure 9: India's innovation output: hotspots for quality research and invention



Key

India's 21 institutions that have published more than 200 world class* papers

1 Panjab University
2 IIT Roorkee
3 IIT Delhi
4 University of Delhi
5 All India Institute of Medical Sciences (AIIMS)
6 IIT Kanpur
7 Banaras Hindu University
8 IIT Kharagpur
9 Indian Association for the Cultivation of Science (IACS)
10 Jadavpur University
11 IIT Bombay
12 Tata Institute of Fundamental Research (TIFR)
13 Bhabha Atomic Research Centre (BARC)
14 CSIR - National Chemical Laboratory (NCL)
15 CSIR - Indian Institute Chemical Technology (IICT)
16 University of Hyderabad (UoH)
17 Indian Institute of Science (IISc)
18 Jawaharlal Nehru Centre for Advanced Scientific Research (JNCSAR)
19 IIT Madras
20 Anna University
21 CSIR - National Institute for Interdisciplinary Science and Technology (NIIST)

*__World class papers__ are the top decile (top 10 per cent) of citations corrected for field, year and number of authors, 2001–2010

Delhi

As Figure 9 shows, **Delhi** hosts a large number of top quality research institutions. A complete overhaul of infrastructure in preparation for hosting the 2010 Commonwealth Games combined with the rapid development of its satellite cities is making the cluster, known as the National Capital Region, or NCR, increasingly attractive to inward investment in research and innovation. After Mumbai, Delhi satellites Noida and Gurgaon have the strongest business incentives of any cities.[128] Gurgaon barely existed 20 years ago but today is a metropolis of outsourced IT services, call centres, and corporate R&D centres. In addition, the NCR is developing as a base for start-ups: according to one survey, at least 220 technology start-ups were launched in the Delhi area over the past three years, compared with 159 in Bangalore.[129]

Bangalore

Growth continues to take its toll on **Bangalore**, but the density of the innovation cluster remains extremely attractive. *"The infrastructure is not good. It drains staff energy and productivity. All the infrastructure is creaking,"* explains Sunil Maheshwari, co-Founder and CEO of successful start-up, Mango Technologies.[130] But while the disadvantages seen in 2007 remain, the densely packed cluster of high-quality public research institutions and national and multinational research centres still has a strong pull for research and innovation activity. One in six of GE's technologists worldwide is now part of the 4,300 strong facility there, and Intel's centre is their largest outside of the US, established with a $1 billion investment.[131] As Maheshwari explains, *"Bangalore does have good networks, experts, MNCs offices: the attractions are more about the human side of things."* Karnataka State alone receives 42 per cent of India's FDI in R&D, four times more than any other State. And according to the most recent data, concentration appears to be increasing.[132]

Mumbai

Mumbai is India's buzzing commercial capital, home to corporate headquarters and India's best financial infrastructure[133] including banks and venture capital investors. It has an excellent public educational and research infrastructure: the only Indian university to make it into *The Times World University Rankings* – IIT Bombay, [134] and two of India's best public labs – the Bhabha Atomic Research Centre (BARC) and the Tata Institute for Fundamental Research (TIFR). Domestic spend on R&D is high (see Figure 9) and Maharashtra State accounts for nearly 11 per cent of India's FDI in R&D, [135] though Pune also makes a large contribution to this total. The Bollywood industry has led to Mumbai's emergence as India's creative economy hotspot.

Table 3: Top ten cities on the 2011 India City Competitiveness Index[136]

1	Delhi	6	Gurgaon
2	Mumbai	7	Kolkata
3	Bangalore	8	Hyderabad
4	Pune	9	Ahmedabad
5	Chennai	10	Jaipur

Breakthrough Pune

Pune, three hours inland of Mumbai, used to be considered a satellite city in innovation terms, but it has outgrown that tag. It now ranks fourth behind Delhi, Mumbai and Bangalore on the City Competitiveness Index, and ahead of a host of other major cities including Chennai, Kolkata and Hyderabad.[137] It has an urban population of five million people, grown from 3.7 million ten years ago, but retains a small town feel.[138] It is packed with higher educational institutes, one of the top public labs – the National Chemical Laboratory, and its Venture Centre, one of the best science and technology incubators in India. South Asia's first Biosafety Level 4 lab, handling the most dangerous pathogens, is soon to be up and running at the National Institute of Virology in Pune,[139] and the city hosts private sector innovation centres in areas from automotive to pharmaceuticals, including those of home-grown giants Tata Chemicals and Reliance. Estimates from analysis of US Patent Office data suggests researchers based in Pune have filed three quarters as many patents as those based in Mumbai.[140]

The new rising stars

A wide range of cities could compete for the rising star sobriquet in addition to Ahmedabad. One example of a strong contender in research and innovation terms is Trivandrum. Figure 10 shows the volume and impact of India's leading research institutes. Trivandrum's National Institute for Interdisciplinary Science and Technology (NIIST), part of the CSIR network, publishes the highest proportion of world-class papers of any institute in India[141] – world-class research accounts for 14 per cent of the total institutional output. A visit to the office of the Director, Dr Suresh Das, demonstrates the determination of the lab to keep raising its game. One wall of his office is dominated by a large board with the latest data on his institution's publications, citations, patents and external revenue. Dr Das is not alone in increasing performance in Trivandrum. The city climbed from 29th position in 2010 to 17th position in the 2011 City Competitiveness Index.[142] Professor VNR Pillai, Principal Secretary of the Kerala State Department for Science and Technology, explained *"We have foregone big science in our early years of development, but now it's high time for us to jump in."*[143] Kerala's unusual socio-political history (communist governments and strong bipartisan investment in health and education) has shaped its path. What the city lacks in infrastructure it makes up for in human capital: literacy rates and other social indicators are the highest of any of the Indian States.[144] As well as hosting India's launch pad for rockets, the city hosts one of the largest IT parks in Asia.

Figure 10: Excellence in research: Leading lights and rising stars

Volume: Number of top decile papers published 2006–2010[145]
Impact: Citation impact of the research 2006–2010[146]
Arrows: Indicate positive growth compared to 2001–2005[147]

State (from north to south)	*Map reference number for institution in Figure 9*	**Volume**	**Impact**	**Key field of research***
Chandigarh	Panjab University *1*	↑	●	Physics, Multidisciplinary
Uttarakhand	IIT Roorkee *2*	↑	●	Materials Science, Multidisciplinary
Delhi	IIT Delhi *3*	↑	●	Electrical & Electronic Engineering
	University of Delhi *4*	↑	↑	Biochemistry & Molecular Biology
	All India Institute of Medical Sciences (AIIMS) *5*	●	●	Paediatrics
Uttar Pradesh	IIT Kanpur *6*	●	●	Materials Science, Multidisciplinary
	Banaras Hindu University *7*	↑	●	Materials Science, Multidisciplinary
West Bengal	IIT Kharagpur *8*	↑	●	Materials Science, Multidisciplinary
	Indian Association for the Cultivation of Science (IACS) *9*	↑	↑	Materials Science, Multidisciplinary
	Jadavpur University *10*	↑	●	Chemistry, Multidisciplinary
Maharashtra	IIT Bombay *11*	↑	●	Materials Science, Multidisciplinary
	Tata Institute of Fundamental Research (TIFR) *12*	●	↑	Astronomy/ Astrophysics
	Bhabha Atomic Research Centre (BARC) *13*	●	●	Materials Science, Multidisciplinary
	CSIR - National Chemical Laboratory (NCL) *14*	●	●	Physical Chemistry
Andhra Pradesh	CSIR - Indian Institute Chemical Technology (IICT) *15*	●	●	Organic Chemistry
	University of Hyderabad (UoH) *16*	●	●	Chemistry, Multidisciplinary
Karnataka	Indian Institute of Science (IISc) *17*	↑	●	Materials Science, Multidisciplinary
	Jawaharlal Nehru Centre for Advanced Scientific Research (JNCSAR) *18*	●	●	Physical Chemistry
Tamil Nadu	IIT Madras *19*	↑	●	Materials Science, Multidisciplinary
	Anna University *20*	●	●	Materials Science, Multidisciplinary
Kerala	CSIR - National Institute for Interdisciplinary Science and Technology (NIIST) *21*	↑	●	Materials Science, Multidisciplinary

*__Key fields of research__ are created by aggregation of selected journals. The 'Materials Science, Multidisciplinary' category includes journals reflecting a broad discipline approach to Materials Science.

Innovation laggards

However, in other parts of India there is scant evidence of an upturn in innovation activity. Of course, this does not mean there is no innovation taking place. But it isn't picked up by conventional metrics. Eight of India's 28 States would be among the largest 25 countries in the world by population if they were independent.[148] For example, the northern state of Uttar Pradesh alone has a bigger population than that of Brazil. Bihar has roughly the same population as Vietnam, but 80 per cent of Bihar's population live below the poverty line,[149] it receives no FDI in R&D,[150] had a domestic R&D spend of around just £500,000 according to latest data.[151]

Some of the underperforming cities are surprising. Kolkata, for example, is a major city of 14 million people,[152] and host to a large cluster of top quality research institutes, including two of India's best (see Figure 9) and seven more that have published over 50 world-class papers in the last decade. In research terms it is an intellectual powerhouse. However, the rate of patenting is very low for such a big city,[153] suggesting the commercial machinery of the city's innovation system could be underdeveloped. Further investigation is required to understand if the shift in West Bengal's communist leadership in recent years towards competition-based growth is having a significant impact on Kolkata's commercial promise.

Prospects for change

Given the persistence of these patterns in the geography of Indian research and innovation, to what extent is change likely in the coming years? Two possible drivers, one exogenous and the other endogenous, stand out.

The role of government

A major exogenous factor is government policy. A number of government policies are seeking to foster a more distributed innovation system in India. In addition to enlarging the network of top-tier institutes (see Part 1), which is creating new spikes of activity, the National Innovation Council is striving to distribute innovation hotspots more widely. Plans include developing 20 traditional craft clusters (for example in brassware in Moradabad, Uttar Pradesh) with greater use of technology and higher value added activities. The National Knowledge Network – a new fibre optic broadband network connecting India's universities, research laboratories and libraries – is also intended to play a role in distributing innovation, offering connections to virtual clusters from across wider geographical areas and thus perhaps counteracting the 'agglomeration externalities' that economists believe tend to drive the clustering of innovation activities around existing hotspots.

State Governments have also experimented with setting up Science and Technology Councils (governance structures to coordinate and promote science and innovation), creating Special Economic Zones (designated areas with specific infrastructure and incentives such as tax breaks to encourage companies to locate there), and business incubation facilities. Yet according to Kiran Mazumdar Shaw, CEO of Indian pharma giant Biocon, the role of State Governments in stimulating innovation remains undeveloped. Even Karnataka, a State regarded as a national success story *"accidentally"* created an environment conducive to innovation[154] by engaging business leaders in policy challenges.

New sources of comparative advantage

The major endogenous factor is the emergence of novel sources of comparative advantage for new hubs. Lower labour costs, and overloaded infrastructure in the existing hubs are key among them. The 2011 City Competitiveness Index ranks the Northern city of Chandigarh, and Southern cities Kozhikode and Kochi highest on their 'Innovation' factor after the major cities.[155] These second–tier cities have operating costs that are 20 per cent to 30 per cent lower than established technology hubs like Bangalore.[156]

The size of the talent pool has been one of the major attractions of cities like Mumbai and Bangalore. But for IT companies like Tata Consultancy Services (TCS), Asia's biggest employer of software developers, keeping wage bills down is hugely important. Last year, TCS announced it is shifting its recruitment to emerging cities as it struggles to maintain profitability amid spiralling labour costs. The company, based in Mumbai, is building campuses and hiring workers in cities as far apart as Ahmedabad, Pune, Bhubaneswar, Nagpur, Indore and Kochi.

Conclusion

In this section we've shown the continuing dominance of Delhi, Mumbai and Bangalore as hubs for innovation, with Pune joining a premier league of cities which also includes Hyderabad and Chennai. While Kolkata is an intellectual powerhouse, there are suggestions it could be underperforming in invention relative to its rich supplies of research and human capital. The 'second' and 'third'–tier city labels that have become common terms in the last decade could be unhelpful as a range of new hubs for research and innovation emerge across India, each with their own distinctive strengths and opportunities. While swathes of the country appear not to be registering innovation, this is partly down to the limitations of the metrics available to judge innovation performance.

Part 4

BUSINESS

For Eugene Welte, CEO of the Airbus Engineering Centre in Bangalore, the attraction of doing R&D in India is straightforward: *"We cannot afford not to have access to talent in India."*[157] Airbus set up their R&D centre five years ago to focus on high-tech aeronautical engineering – building the advanced capabilities in modelling and simulation crucial to the design and production of high performance aircraft. Airbus is allocating increasingly knowledge-intensive projects to its Indian team. According to Welte *"We started at five out of ten in terms of R&D complexity, and have been quite successful in ramping it up to seven of ten."* Airbus's centre employs over 250 people and is one of around 750 multinational company (MNC) R&D centres in India that employ up to 400,000 professionals; up from fewer than 100 such centres in 2003.[158] Bangalore is home to the lion's share, with the others mostly located in major cities.

India continues to attract foreign investment in R&D from countries around the world, despite a challenging business environment overall. Disadvantages seem outweighed by benefits and India is one of the top three most attractive destinations for foreign direct investment in the world.[159] While there is a perception that R&D in India is dominated by foreign players, domestic companies' investment in innovation is growing rapidly in sectors such as pharmaceuticals and automotive, and there are high hopes for younger Indian sectors such as clean tech. The overall innovation intensity of the private sector remains low, particularly if judged on classic indicators such as patents. Yet, as explored in this section, some of India's greatest strengths in innovation – in services, processes and business models, are overlooked by these measures of performance. Those wishing to understand how innovation capabilities in India are growing, shouldn't overlook these 'hidden' strengths.

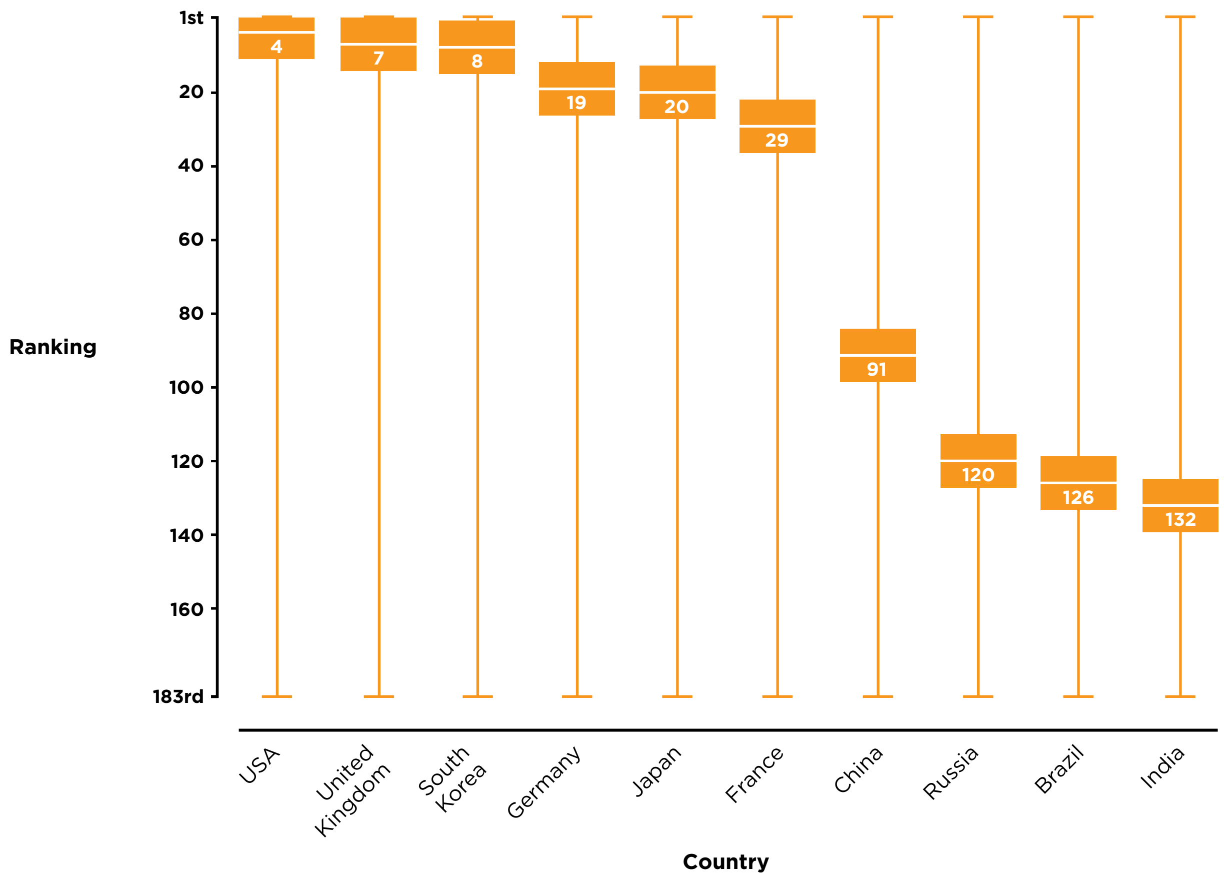
This section looks first at some of the important environmental conditions for innovation in India and how they are shifting. It then turns to briefly map innovation in the private sector before elaborating on India's 'hidden' innovation strengths.

A challenging business environment

While conditions vary throughout the cities and regions, there's no doubt that overall India is not an easy place to do business. The country ranks 132 out of 183 in the World Bank's Doing Business Index.

Table 4: India's relative position in the World Bank/International Finance Corporation Doing Business rankings

(An aggregate ranking against ten topics[160] including how easy it is to start a business, enforcing contracts and getting electricity)



Despite legislative reform companies still have legitimate concerns about the protection of their IP rights.[161] Corruption is a live issue: India ranks just outside the bottom third of countries for control of corruption according to the World Bank.[162] Political inertia and red tape are impeding a much needed overhaul of the nation's infrastructure. Annual investment in infrastructure has almost doubled over the last five years to $414 billion, but many of the projects have not been completed, and much of the country's infrastructure is poor. Most airports – with the exception of those in Hyderabad, Bangalore, Delhi and Mumbai – have not been upgraded since the 1960s, though passenger numbers have soared by about 20 per cent annually.[163] The Twelfth Five Year Plan aims to attract and invest $1 trillion in infrastructure over the next five years, as well as build 100 cities from scratch.[164] For this to take place, major reforms are needed, although it's unclear what might finally force the government to push these through.

Increasing support for innovation in firms

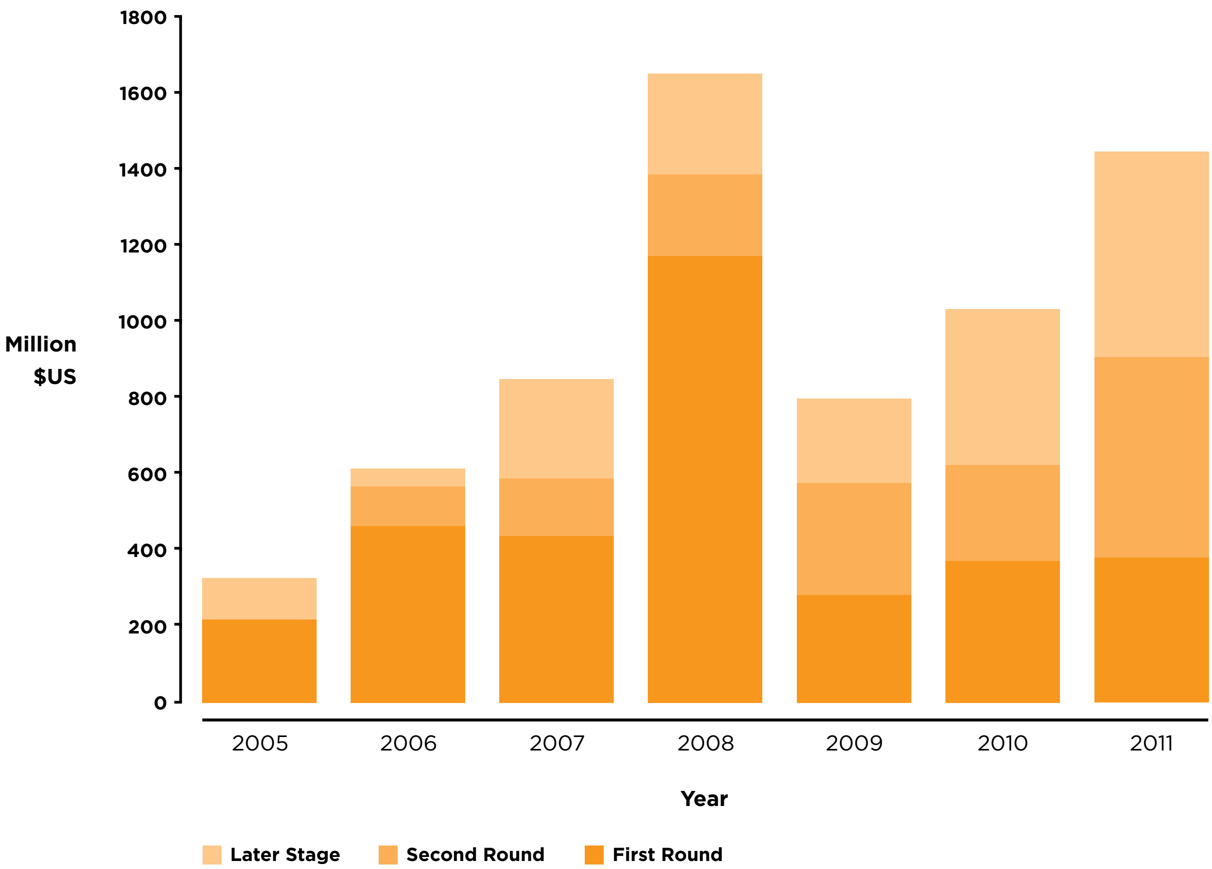
Although efforts to incentivise and support innovation have suffered from a lack of strategic and integrating vision in the past, there are increasing moves towards overarching innovation policy with the work of the National Knowledge Commission, and later the National Innovation Council. For the first time, there is a dedicated section on innovation

in the Twelfth Five Year Plan. This Plan calls for a quadrupling of private sector R&D spend as a proportion of GDP by 2017. The target excludes FDI in R&D[165] and achieving it would represent a major upturn in investment by Indian firms.

There are now a generous set of tax breaks for R&D expenditure and for exports of indigenous products that have obtained international patents.[166] R&D tax credits have been extended from 150 to 200 per cent and widened to include new sectors in 2010.[167] There are also five central funding schemes designed to support early-stage innovation in firms with a combined value of $100 million in 2010[168] (see Appendix for details). Availability of private finance for innovation is improving, albeit from a low level and according to investment experts, India's credit market is robust.[169] Venture capital investments are growing – they have quadrupled since 2005, and bounced back strongly after the global financial crisis.[170] Yet this increase is from a very low level, and investors prefer the plentiful 'low-hanging fruit' in IT services than higher-risk technology ventures. Government programmes remain by far the largest source of early-stage funding for companies.

There are over 150 business incubators and science and technology parks across India.[171] Yet these are unevenly distributed and vary substantially in quality, with very few geared to support innovation. Very few technology transfer offices are in operation, concentrated in a handful of the best universities.

Figure 11: Venture capital investment in India[172]



Venture Source data records only 13 seed round investments between 2005 and 2011

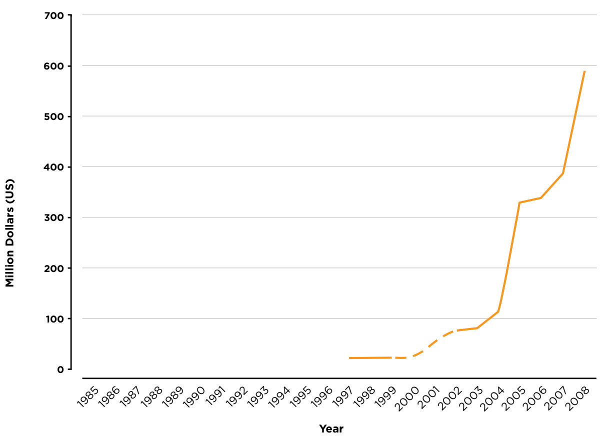
Mapping Innovation in the private sector

While the overall innovation intensity of the private sector is low, investment in R&D by firms is rising. The share of private sector firms in overall expenditure on R&D grew from 18 per cent to an estimated 28 per cent between 2003 and 2007.[173] After a closer look at the work of multinational R&D centres, this section will briefly examine the domestic system.

MNC R&D centres

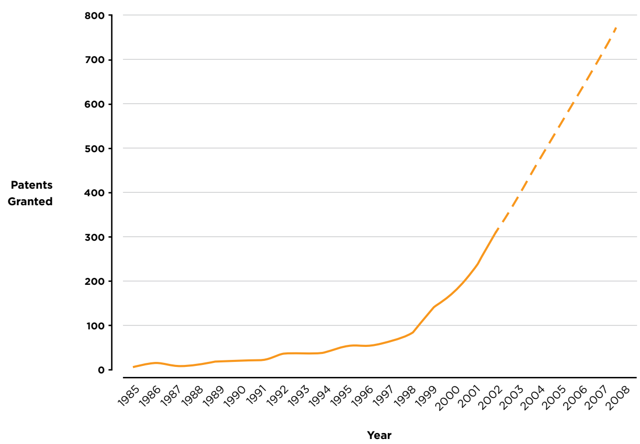
As outlined above, India attracts the R&D operations of some of the world's most innovative companies, including Cisco, AstraZeneca, General Electric (GE), Microsoft, ARM, Unilever, Google, and Intel. As shown in Figure 12, investment in R&D by MNCs has risen very sharply in recent years, particularly since 2000.[174] Both the quantity and the quality of the R&D are increasing.

Figure 12: Investment in R&D by US MNCs in India[175]



Dotted line indicates estimation – data for 2000 and 2001 not recorded by the National Science Board

Figure 13: Patenting by US MNCs in India[176]



The growth in investment appears to come slightly after the major upturn in the rate in US patenting by MNC R&D centres. Figure 12 shows this picked up in 1998 and doubled between 2000 and 2003.[177]

While in the past many of these centres were restricted to low-value R&D activities, signs are that many are moving rapidly up the value chain, and these centres have had an increasing impact on global operations of their respective companies. A study of USPTO patents made by the Indian R&D centres of US companies in the semiconductor industry found that patents filed in India were cited as much as patents filed in any of the other global R&D locations – suggesting the quality of innovation is at a global level.[178]

One reason why the quality of work in these centres can be overlooked is that, as corporate innovation systems and supply chains become more segmented and globalised, attributing innovations to one location will become more and more difficult. In aerospace, Indian technology company HCL developed two mission-critical systems for Boeing's latest 787

Dreamliner.[179] This business-to-business innovation is easy to overlook. While Boeing works with a wide network of Indian companies on R&D, many other MNC R&D centres remain relatively disconnected from the domestic innovation system.

Homegrown heroes

The current growth in R&D spend is led by the pharmaceutical and automotive sectors.[180] In real terms, they account for 45 and 17 per cent of business R&D spend respectively.[181] Between 2000 and 2006 R&D spend in these sectors grew six-fold and 2.4-fold respectively, whilst other sectors only grew more slowly from lower bases.[182]

Figure 14: R&D spend by private sector domestic enterprises divided in selected sectors[183]

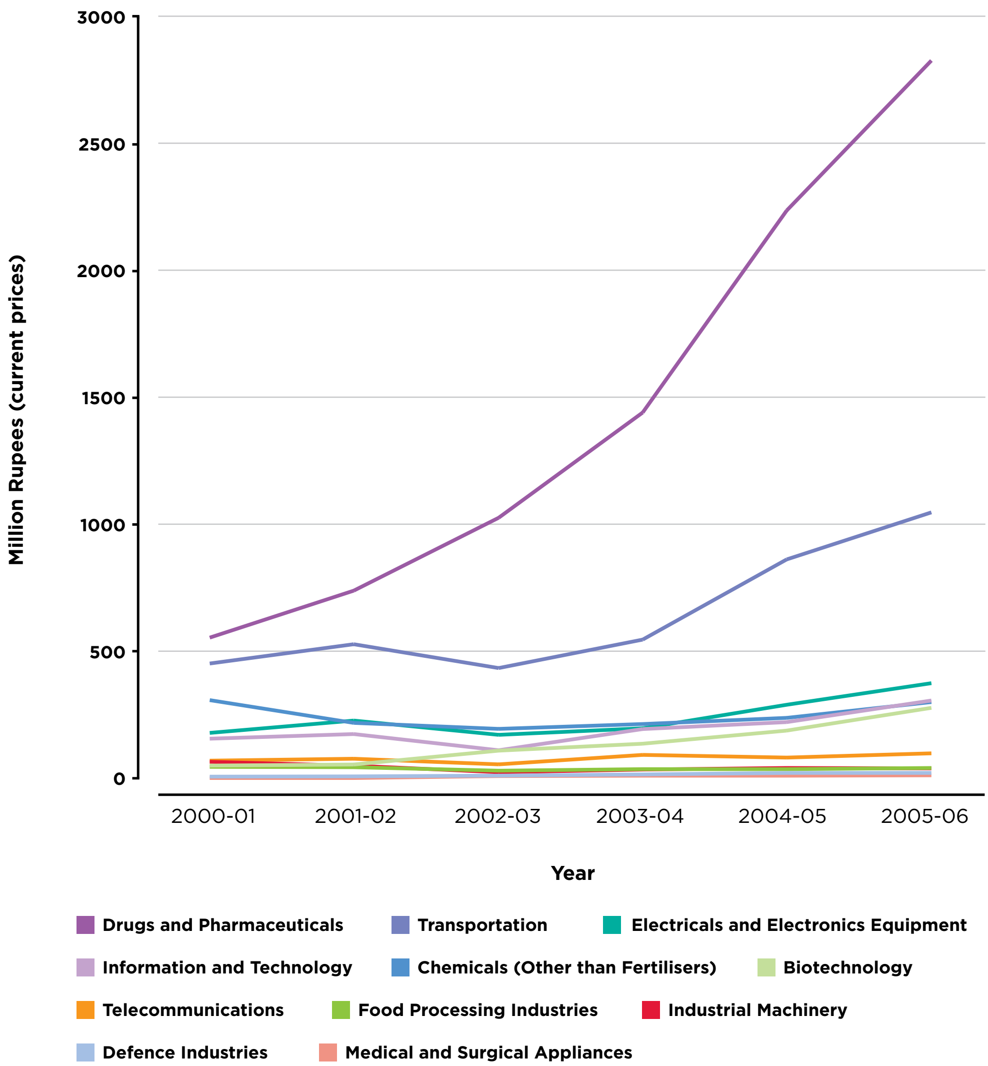


Figure 14 shows the considerable growth in R&D spending in the pharmaceuticals industry in relation to other industrial sectors. The average R&D expenditure per firm grew almost 35 per cent per year between 2000 and 2008.[184] This unprecedented growth in R&D spending is largely due to the introduction, in 2005, of a system of product patents in compliance with World Trade Organization regulations.[185] Prior to this, only patents for

processes were permitted – a factor that has been instrumental in the global success of India's domestic generic drug industry. Today India is the largest exporter of generic drugs.[186] The new patent regime catalysed a shift across much of the domestic industry from reverse engineering to contract research and manufacturing, and among the top-tier of companies' new drug development.

Yet recently, top Indian pharma companies seem to have backed off a little from the huge financial risks that come with development of new molecular entities. While pharma R&D remains at 60 per cent of the cost of comparable R&D in the US or Europe,[187] the cost advantage is steadily decreasing. According to analysis by PricewaterhouseCoopers, drug candidates initially formulated in India are likely to be further developed by Western drug makers, because few Indian companies can afford the high costs and failure rates associated with pushing a drug right through the pipeline.[188] In tandem, the global industry is undergoing major changes. R&D productivity (the number of new molecular entities developed per billion R&D dollars) is declining[189] and start-to-finish drug development by one firm is increasingly rare. Instead, acquisition and co-development with other firms or academia are becoming the dominant models for new drug development.

The 'reverse engineering' that contributed to India's current dominance in the global generics and vaccines market – India produces 60 per cent of the world's vaccines and up to 80 per cent of those purchased by the United Nations each year[190] – is often discounted as a signal of India's innovation capabilities, but it can also be seen as a striking example of process innovation. For example, low-cost manufacturing know-how enabled the Serum Institute of India to produce a safe, effective meningitis vaccine for the African market at less than 50 cents a dose – MenAfriVac, a global collaboration led by the WHO, was developed, tested and produced in less than half the time and for one-tenth of the historical cost.[191]

When assessing India's innovation capabilities, it's important not to overlook the value created by this process' expertise, in a global pharmaceuticals industry that is searching for new operational models.

Invisible innovation

Process innovation in drug production and development is just one example of a number of strengths in the Indian system which can be overlooked by traditional R&D metrics. There is little systematic, let alone quantitative, research on the impact of business model, process or services innovation in India. Yet 55 per cent of India's economic growth is driven by services,[192] which have been growing in productivity by 10 per cent a year.[193]

India's role in the IT outsourcing revolution is well known, but it may be less widely acknowledged that India plays a leading role in a global market in offshore R&D services in industries from aerospace to pharmaceuticals – worth \$20 billion in 2012.[194] While this radically reduces costs for the commissioning firms, this is more cost arbitrage than frugal innovation. Successful service innovations are often however, frugal in nature. Extreme specialisation on a mega scale is a theme of many of India's most successful service innovations. In the introduction, we highlighted the case of Narayana Hrudayalaya hospital in Bangalore, which achieves a significant profit while offering heart surgery at only \$2000. There are many more cases of radical service innovations in healthcare – often applying a cross-subsidy model of tiered pricing that was made famous by the Aravind Eye hospital. While richer clients pay for the privilege of private rooms, the same quality healthcare is provided to poorer clients on a 'no frills' basis. Lifespring hospitals, for example, is an expanding chain of not-for-profit hospitals focusing on maternal care. Funded by a

partnership between Hindustan Latex (one of the world's largest condom manufacturers) and the New York-based Acumen Fund, the business model will enable the service to reach 82,000 women in a country where almost 60 per cent of births are still unattended by a health worker. The chain's first hospital broke even after eight months and now achieves up to 140 deliveries a month, compared to 25 in an average private hospital.[195]

In addition to service innovations, Indian business model innovations have made waves in the global community. One example is the 'six-sigma' levels of efficiency – less than 3.4 errors per million achieved by Mumbai's dabbawallahs. This delivery service staffed by semi-literate workers delivers 200,000 lunches a day to Mumbai's workers using no documentation – only a simple colour-coding system – has been the subject of business school case studies the world over. Likewise the radical new business model developed by telecoms provider Bharti Airtel, has attracted analysis by management scientists.[196] It resulted in both an impressive profit and the cheapest mobile talk time in the world. It is a frugal innovation that resulted from a radical re-thinking of the firm's relationships with both customers and suppliers.

Bharti Airtel

Instead of focusing on average revenue per user, Bharti Airtel realised that signing up millions of Indians each generating a tiny revenue would still generate large overall revenues, and if costs could be lowered enough, large profits. To achieve this they took collaboration to extremes. They outsourced all functions except for six. Clever contractual arrangements allowed the company to incentivise quality whilst still profiting from predicted growth. For example, they outsourced IT services to IBM, promising to pay a minimum monthly payment. Bharti tied IBM's revenue into its own growth, thus incentivising performance. Beyond a certain growth threshold however, IBM's percentage revenue declined, allowing Bharti to gain from economies of scale.

Cooperation with competitors on sharing costs for passive infrastructure, like towers, air conditioners and generators enabled massive expansion into rural India.

Now though, the low-cost telecoms boom might have reached its limits and Bharti may now need to think of a whole new operating system for the company. Chairman Sunil Mittal, revealed in September 2011 that the cost of servicing rural customers and low-usage levels had made things unprofitable. Prices are expected to go up across the industry.[197]

Conclusion

This brief overview of the landscape of private sector innovation has shown a challenging environment for business in India. This is important because innovation is inherently a speculative activity. Government needs to help foster an environment where the risks of innovating are reduced and the rewards maximised.

Renewed policy efforts on the part of government are in train, with lofty ambitions for growing private sector spending on R&D. Yet overall R&D intensity is low outside a small range of industries, with pharmaceuticals the leading spender by far.[198]

Innovation that creates value and drives productivity goes far beyond R&D spending however. Some of India's greatest strengths in private sector innovation could be easy to overlook, and difficult to measure and track, hidden from traditional innovation metrics.

They are often in services, in business models, and bound up in the segmented business–to–business innovation activities of global multinationals. India continues to attract greater investment in R&D by multinational companies, as despite the challenges of the business environment, the pull of India's talent pool remains strong.

Part 5

PEOPLE

India is *"at a crossing point"* according to Dr Samir Brahmachari, Director of India's leading network of public labs. *"Either we will become one of the world's most influential nations, with the largest science and technology population, or we will have the largest population in the world of the uneducated middle-aged. Innovation in education is the prime question."* [199]

From one angle, India's higher education system seems huge, producing over 2.3 million graduates and nearly 750,000 post-graduates each year.[200] Yet the quality of education those students receive varies wildly, and the demand for higher education vastly exceeds the supply. There's an acute awareness of this challenge across society. Government targets aim to increase enrolment in higher education from 12.4 per cent[201] to 30 per cent by 2020. This would equate to a staggering 40 million students in the higher education system.[202] On current models, reaching this target would require eight additional universities and 417 additional colleges each and every month.[203] With radical new approaches required, there is no shortage of vision, yet crucial reforms are mired in bureaucracy and parliamentary stagnation. If there is one area where radical frugal solutions are required, this is it.

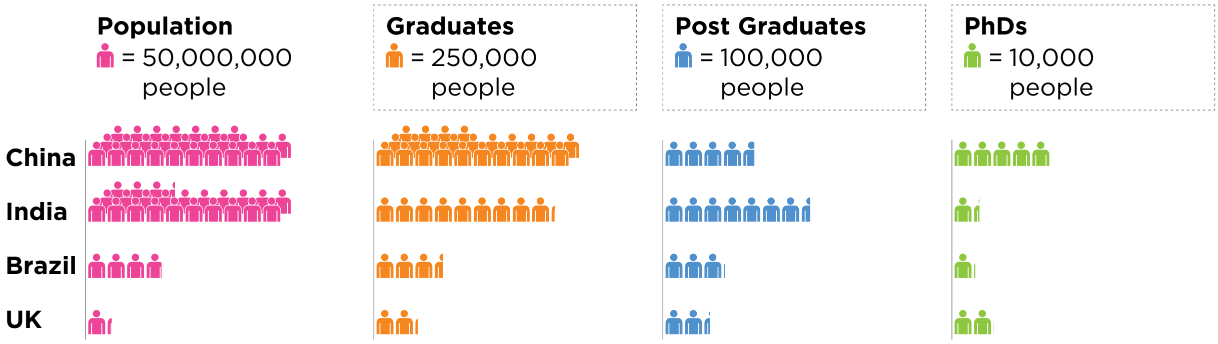
After an overview of the education system in India, this section charts how India might rise to its education challenge.

The higher education system

Numbers

The Indian higher education system is one of the biggest in the world, with 634 universities and university level institutions and 33,023 colleges hosting around 16 million students.[204] Yet given India's vast population, as Figure 2 shows, the labour pool for science and technology is smaller than one might expect. It has around 119 researchers engaged in R&D per million people; Brazil has nearly 700, China over 1,000 and the UK over 4,000.[205] As Dr Mashelkar, former Director General of CSIR, often points out, *"everything looks small when divided by one billion."* Nevertheless, the total size of India's R&D talent pool, estimated to be between 100,000 and 300,000 people, is three times smaller than China's.[206] The 13,000 PhDs produced each year (2007–2008)[207] is equivalent to less than 2 per cent of post graduates.[208] India produces three times as many postgraduates as the UK, but the UK produces 1.5 times more PhDs than India. For technology intensive innovation, India's labour pools are perhaps more a 'mirage'[209] than a reality.

Figure 15: Annual graduate production[210]



Quality

The quality of the Indian HE system is very variable. The public institutions at the apex of the system – highlighted in Parts 2 and 3 – are world class. The IISc Bangalore and IIT Bombay are rated amongst the top 400 universities in the world. Just 2 per cent of the 300,000 applicants to IITs secure a place each year, following one of the world's most challenging entrance exams, compared to 23 per cent of applicants to Oxford.[211] The expansion of the network of institutions of national importance outlined in Part 2 is extremely positive. Yet roll out will not be problem free. Even the IITs and the Indian Institutes of Management (IIMs) are facing a severe faculty shortage with nearly one third of the posts vacant.[212] Moreover, according to Government estimates, more than half of lecturers lack postgraduate education.[213]

Outside of the so called 'institutions of national importance', the system isn't as strong. Public institutions represent a relatively small slice of India's higher education infrastructure. More than 90 per cent of IT, engineering and management colleges in India are private.[214] Unfortunately the quality of this provision is extremely variable. Many private institutions offer little in the way of laboratory or practical training. Curricula are outdated and there are crippling shortages of teaching staff.[215]

A World Bank study reported that 'Overall, 64 per cent of employers are only somewhat satisfied or worse with the quality of engineering graduates' skills'.[216] Concerns centre on critical thinking, team working and soft skills. Estimates of this proportion vary substantially – one CEO of a multinational company R&D centre complained that *"90 per cent of graduates are not employable."*[217]

A note on primary and secondary education

India's education challenges start well before university. While there have been considerable improvements in access to primary education in recent years, there remain major challenges of increasing quality and growing the proportion of students who continue to secondary school. Ninety–five per cent of children now live within half a mile or so of a school[218] and primary school enrolment is 91 per cent, up from 79 per cent in 2000.[219] The Right to Education Act[220] (proposed in 2005 and passed in 2009) made education a fundamental right of every child between the ages of six and 14. The Union Budget 2012–13 outlined an 18 per cent increase on last year's spending for education,[221] but this still only equates to 0.64 per cent of GDP.[222] If

State spending on education is taken into account, then this rises to just under 4 per cent of GDP.[223] Back in 1966 the Kothari Commission recommended that India should be spending on average 6 per cent of GDP – which is a rate similar to most industrialised countries – 46 years on, India still has not reached that ratio.

Quality hasn't kept pace with infrastructure expansion: according to some estimates, 50 per cent of teachers are absent at any one time.[224] Only two-thirds of government schools have any form of toilet facility, only 25 per cent of government schools have any laboratories, and only 50 per cent have a library.[225] While primary education is free, the cost of books and uniforms is still a significant barrier for some parents. Many of these factors contribute to drop outs before secondary school. Enrolment is currently at 60 per cent – up from 46 per cent at the start of the decade.[226] But these national statistics mask substantial internal variations: one report claims that the Government of Bihar, a State of 100 million people, growing by at least a million people per year, had not built a single secondary school for 30 years before 2009.[227]

Rising to the education challenge?

Policy proposals for transforming the system

Nandan Nilekani, former Infosys Chairman turned policy maverick, is one of many critics calling for smarter regulation of standards, and greater private and foreign investment to help rebalance the 'hyper-Darwinian' selection process for the small number of high-quality institutions. 'Our universities', he says, 'have become islands untouched by the fast-changing economy that surrounds them. Their weaknesses have deeply undermined people's access to skills and the knowledge they need to take advantage of the jobs in a growing and rapidly changing market.'[228]

The search is on for new ways of widening access to quality education, and there is no shortage of radical thinking among some policymakers. One initiative that has attracted a great deal of attention within and beyond the country are the Innovation Universities, originally recommended by the National Knowledge Commission in 2007. Each of the 14 proposed universities would be research-intensive and focused on a particular thematic area such as public health or water. They would be set up either by the government or through public private partnerships, and would be granted unusually high levels of autonomy.[229]

Another proposal for the creation of a 'meta-university' takes the proposed reforms well beyond incremental improvements. According to the National Innovation Council:

> *"The Meta University will reinterpret the concept of a university as not just a traditional, physical space of learning, but as a repository of knowledge and information that can be delivered in multiple ways, and can be accessed from anywhere and anytime. It will seek to enhance the learning experience through new and innovative delivery models of education that allow students and institutions to collaborate in unprecedented ways."*[230]

The meta-university aims to tap into India's distributed HE system, with students enrolled at one institution permitted to take distance learning courses from others. Building on the National Knowledge Network (the new fibre optic broadband network connecting India's universities, research laboratories and libraries) the students will be able to select customisable, interdisciplinary courses. Plans are still to be finalised, but to its supporters,

the meta-university promises to be *"a test bed for experimenting with a new model of teaching and learning that may show the way for a new education model for the future."*

With a vast rural population of 833 million[231] spread across a land area of three million square kilometres,[232] technology-enabled learning is almost certainly going to be a key part of any effective approach to widening access to education. With internet penetration at just 2 per cent, there is a long way to go. Yet, as personalised, open access learning spreads around the world, and as internet access grows across the country, India is positioning itself to benefit. Major experiments are underway, from Sakshat, the National Mission on Education through ICT, to the National Programme on Technology Enhanced Learning, which broadcasts lectures from the prestigious IITs using YouTube. Another example is the Government's support for the development of the Aakash tablet computer. This ultra low-cost touch screen tablet, produced by UK company Datawind in collaboration with IIT Rajastan, will be made available to Indian students at a subsidised price of only $35 dollars and is set to link 25,000 colleges and 400 universities in an e-learning programme.

However, would-be reformers face stern opposition from vested interests. Nandan Nilekani has described the systemic reforms originally outlined by Sam Pitroda's National Knowledge Commission as *"a fist-sized pill to swallow"* for engrained interest groups. Resistance to change among college administrations and government officials has historically been both powerful and pervasive, leading to what some commentators have described as *"a Niagara Falls of reports on educational policy issues and a Sahara of Action."*[233]

The proposals for the Innovation Universities are a case in point. The ambition of the original plans has been significantly scaled back. The Bill in question now allows for upgrading existing institutes to the status of Universities of Innovation, and in February 2012 the Ministry of Human Resource Development revised down their estimates for the number of institutions that would be created, saying they would be content with setting up only a *"couple"* of the universities.[234]

The experience of the Foreign Educational Institution (Regulation of Entry and Operation) Bill is also symptomatic of the wider legislative environment for reform. The proposed reforms, under which international universities would be allowed to set up their own campuses[235] but not to extract profits from India,[236] would represent the most significant reforms in a higher education in a generation, and so have rightly received healthy discussion. Yet the Bill, the third attempt to bring foreign universities to India, has recently stalled and looks unlikely to pass any time soon.[237] At the time of writing, at least eight[238] pieces of legislation related to innovation are currently under discussion,[239] but no major legislation has been passed by Parliament since 2009[240] and some commentators doubt that this will change before the next national elections, due by 2014. Moreover, as Minister for Human Resource Development, Kapil Sibal openly acknowledged, *"A large number of politicians own educational institutes and this is standing in the way of reforms."*[241]

Beyond the State

Yet government policy is not the only place to look for initiatives that could unlock the potential of Indian human capital. We now look at how corporations and NGOs are transforming the system.

The Indian IT industry is a striking example of how corporations have compensated for the weaknesses of the government-funded education system. In a 2008 study for the Kauffman Foundation, Vivek Wadwa and his team describe the 'highly advanced, innovative...workforce development practices' employed by leading Indian corporations.[242]

In one of the most striking examples, Infosys, the IT giant, is expanding and recruiting aggressively – looking to hire 45,000 people in 2011/12. To equip employees with the skills they need, it has built the world's largest corporate university in Mysore, with a residential capacity of 13,500. Graduates receive five months of retraining at their campus. This represents a $184 million investment in employee education.[243]

We saw in Part 2 how India's vibrant civil society has for many years played an important role in the delivery of services such as health and education. In one of the best known examples, through training women with high school education to run reading groups from their living rooms, PRATHAM has reached over 2.4 million children with their Read India programme, providing pre-school education for only $10 per child per year, thanks to their delivery model. They have inspired hundreds more education NGOs, and act as an important partner to the state in many areas.

Inspiring solutions have come from experimental approaches, such as Sugata Mitra's hole in the wall model. In 1999, the computer scientist decided to cut a hole in the wall separating the office of his software company into the adjoining Delhi slum and provide a computer for the slum-dwelling children to use. Within a matter of hours the children had taught themselves to use the computer, and propagated the learning to others through peer support without adult supervision. Convinced of the power of this self-directed approach to learning, which he called 'minimally invasive education,' Mitra set out on a field trial of this method, initially in 17 locations in rural India for nine months. This initiative led to a range of experiments in unsupervised learning and today over 500 computers have been installed in sites across India and Africa, reaching up to one million children. The scale of the experiment, and the quantitative evidence produced has had a considerable impact on global pedagogy.[244] A recently founded initiative, STIR education, is seeking to tap the thousands of 'micro-innovations' in teaching and learning across India, and develop networks to replicate and scale what works across the country and around the world.

There's a strong and growing sentiment that the solutions to India's education challenges will come from the bottom-up, distributed practices and experiments around the country as well as from the top-down reform by government. Sam Pitroda, Chair of the National Innovation Council recognises only too well the need to completely re-think education in India. *"Completely new models are required. The use of IT in education will be transformative, but we also need to break the 'rules' of education – like requirement of four year degree courses – and explore for example how to transform teachers into mentors for self-directed learning. For all the great collaboration between the US and India on education – they would have far greater impact to design a programme to transform a million teachers into mentors."*[245]

Conclusion

The crossing point set out by Dr Brahmachari at the start of this section is pivotal for the future of India's innovation system. He is optimistic: *"If we play our cards correctly and the economy continues to grow, there will be sufficient resources to take India out of this education resource bottleneck."*[246] Yet while the top tier of educational institutes is growing, and a range of significant reforms are proposed, ensuring the dividend from India's demography will require radical re-thinking of the delivery of education. These experiments could have implications for education systems the world over.

Part 6

COLLABORATION

It took David Cameron just ten weeks after being appointed Prime Minister to make his first visit to India, accompanied by a large delegation of business leaders. In a recent essay, he set out the reasons behind this trip: *"I wanted to make clear the strength of our commitment and the scale of our ambition for this new relationship."*[247] Stronger links in science and innovation form an important part of this 'new relationship', building on the work of the Indo–UK Science and Innovation Council which had resulted in the launch of RCUK India in 2008.

The UK is not alone in wanting to forge a more strategic partnership with India on innovation. This section assesses how well the UK seems to be faring relative to other nations, and compares some of the institutional arrangements that the UK has put in place to foster collaboration with India to the approaches adopted by a number of other countries. It finds that the weakness of the evidence base remains a major barrier to a more strategic approach: measuring the outcomes of international collaboration on innovation remains difficult, and associating these outcomes with specific policy interventions even harder.

Open India?

India's innovation system is increasingly open and cosmopolitan when it comes to talent, investment, intellectual property and research, as Tables 5 and 6 show:

Tables 5 and 6: India's international connections

Strong Connections		Year	Strengthening Connections		Year
Number of internationally co-authored publications	9,111[248]	2010	Growth in international publications	10% a year[253]	2000–2010
Proportion of patents with an international applicant	1 in 4[249]	2011	Growth in triadic patenting	20% a year[254]	2000–2010
Inward FDI	3.6% of GDP[250]	2008	Rise in inward FDI	21% per year[255]	2000–2008
Outward FDI	1.6% of GDP[251]	2008	Rise in outward FDI	40% per year[256]	2000–2008
Rank as a destination for FDI in E&Y Survey	2nd of 12 major global regions[252]	2012			

- **Talent.** India has long realised the value of its diaspora in research and innovation, and is encouraging expatriate Indians to return home. The 22 million-strong Indian diaspora worldwide has come to be recognised as a powerful asset for research, entrepreneurship and innovation.[257] In Europe and North America, the Indian diaspora tend to be among the best educated and wealthiest immigrants.[258] The contribution of Indians to technology and innovation outside India, particularly in the US, has been well documented by academics such as Anna Lee Saxenian and Vivek Wadwha. From 2000 to 2007, Indians founded more engineering and technology companies in the US than immigrants from the UK, China, Taiwan and Japan combined.[259] Many retain close links with friends or former colleagues who are still in India. In a survey of Silicon Valley, Saxenian found that more than half of Indian scientists and engineers regularly shared tips about technology and business opportunities with people at home.[260] Many of these individuals first join the Indian diaspora as students. Today there are over 200,000 Indians studying abroad, representing a four-fold growth since 2000.[261] While in the past this would have been lamented as brain drain, it has increasingly come to be seen as 'brain circulation'. Although precise data is hard to come by, anecdotal evidence points to an increasing flow of skilled scientists, engineers and entrepreneurs returning to India over the past decade. According to research by IT and Engineering recruitment specialist, Kelly Services India, *"As many as 300,000 Indian professionals are expected to return to their homeland in the next four years."*[262] In a recent interview for *The Economist*, the CEO of IT giant Tata Consulting Services was asked how many of his top employees had worked abroad. *"All of them,"* he replied.[263] Indian government policies have set out to support these flows with a number of initiatives in place to attract returnee talent.

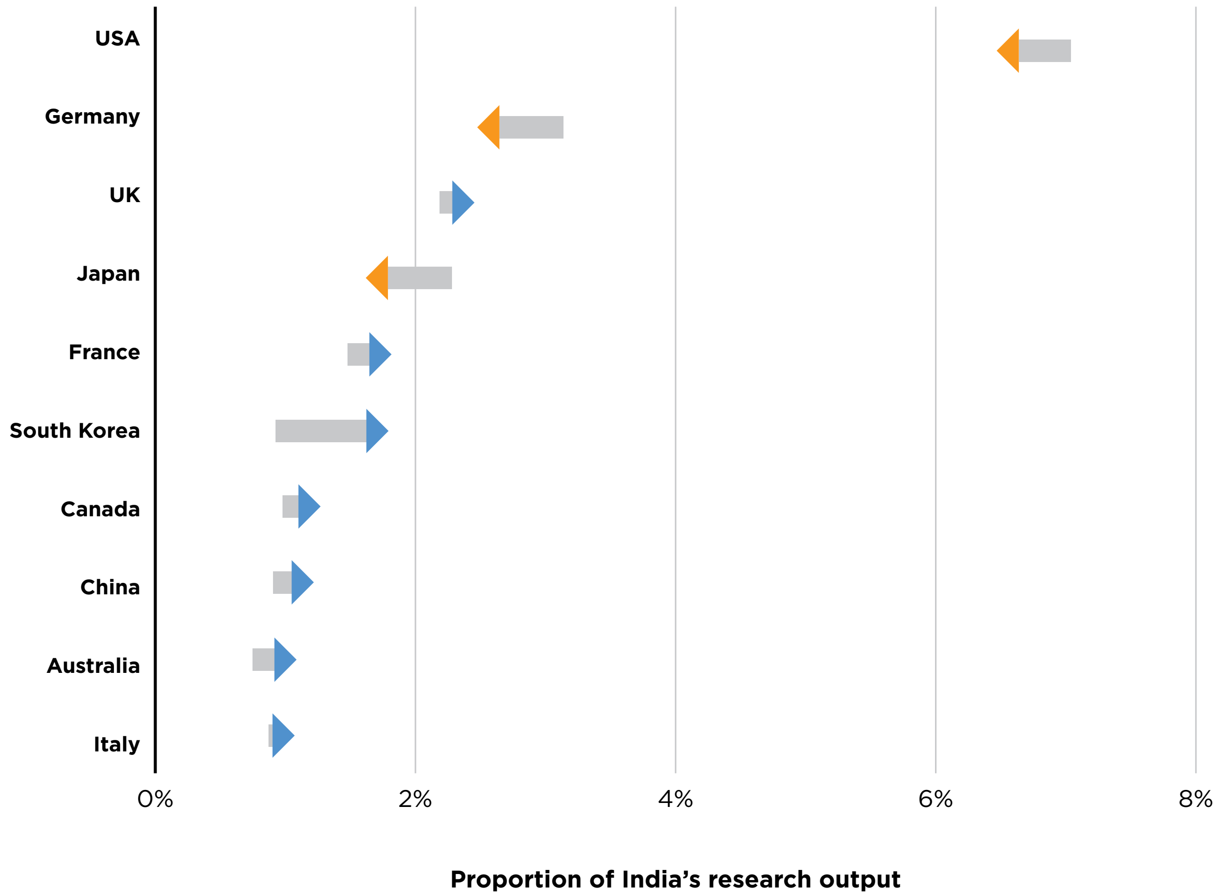
- **Investment.** Alongside flows of people, flows of investment in and out of India are increasing. FDI was 330 times greater in 2010 than 1991. Although India (like many other countries) saw a drop off in FDI after the financial crisis, from 2003 to 2008 it increased ten-fold. Foreign investments by Indian companies have also risen significantly, peaking at 1.6 per cent of GDP in 2008 before the financial crisis.[264]

- **Intellectual property.** Historically, Indian companies patented very little, but that has changed considerably in the last decade and the number of triadic patents owned by Indian organisations has been growing by 20 per cent per year. Much of this recent growth has been led by the CSIR labs and by MNC R&D centres. The prominence of these centres, with international teams often working on the same project, perhaps explains why India files more patents with international co-inventors than would be expected: 24.7 per cent of total patents.[265] This is close to the UK level (24.5 per cent), and significantly more than the USA, China and Brazil (11.5, 10.3 and 17.5 per cent respectively).[266] A significant proportion of overseas investments by Indian companies have also involved the acquisition of R&D capabilities. One striking example was Tata Steel's takeover of Corus, Europe's second-largest steel producer in 2007. Before the takeover Tata did not hold a single US patent; through the takeover it acquired more than 80 patents and almost 1,000 researchers.[267]

- **Research.** The number of publications by Indian researchers with an international collaborator has been growing by 10 per cent per year, and reached more than 9,111 in 2010.[268] That said, there is clearly potential to deepen international collaboration further: 21.5 per cent of India's research is co-authored with an international researcher, below the world average of 35 per cent[269] and significantly less than the 50 per cent of UK or German research.[270] Most of India's international collaboration is with well-established research leaders. Its top five partners are, in descending order, the USA,

Germany, the UK, Japan and France.[271] Indian researchers author 2.5 times more papers with researchers from the US than any other country.[272] The UK ranks third in co-authored publications, with collaboration strongest in physics, clinical medicine and chemistry, with engineering, space science and materials science also significant disciplines.[273] These patterns of international collaboration are likely to predominate for the foreseeable future, though emerging players like South Korea are substantially increasing their collaboration with India too. Figure 16 shows the changing distribution of India's international collaboration among selected countries over the last decade as measured by co-authored publications.

Figure 16: Research collaboration with India: relative changes between countries over the last decade[274]



UK–India Engagement

Using data specially commissioned for this report, we can, for the first time, systematically map the geography of research collaborations between India and the UK at the institutional level, as shown in Figures 17–20. This analysis shows a number of trends:

- The institutions leading collaboration on both sides are some of the best in each country. In the UK, research intensive Russell Group universities publish the most papers with India. In India, the IITs, IISc and other 'institutes of national importance' such as TIFR and BARC in Mumbai lead the way.

- There are however, a small number of Indian institutions collaborating more than their low UK profiles would suggest. For example, Panjab University in Chandigarh publishes more papers with the UK than the IISc in Bangalore. Similarly, the Universities of Jammu and Rajasthan are both in the top 15 Indian collaborators with the UK – but have very low profiles in the UK.

- Drilling down to the collaboration patterns of individual institutions:

  - Imperial College and the TIFR and each collaborate substantially with three foreign partners, and after that there is a substantial drop before the next most prolific partner. Other institutions demonstrating a similar pattern include the University of Manchester, Lancaster University, and the University of Delhi.

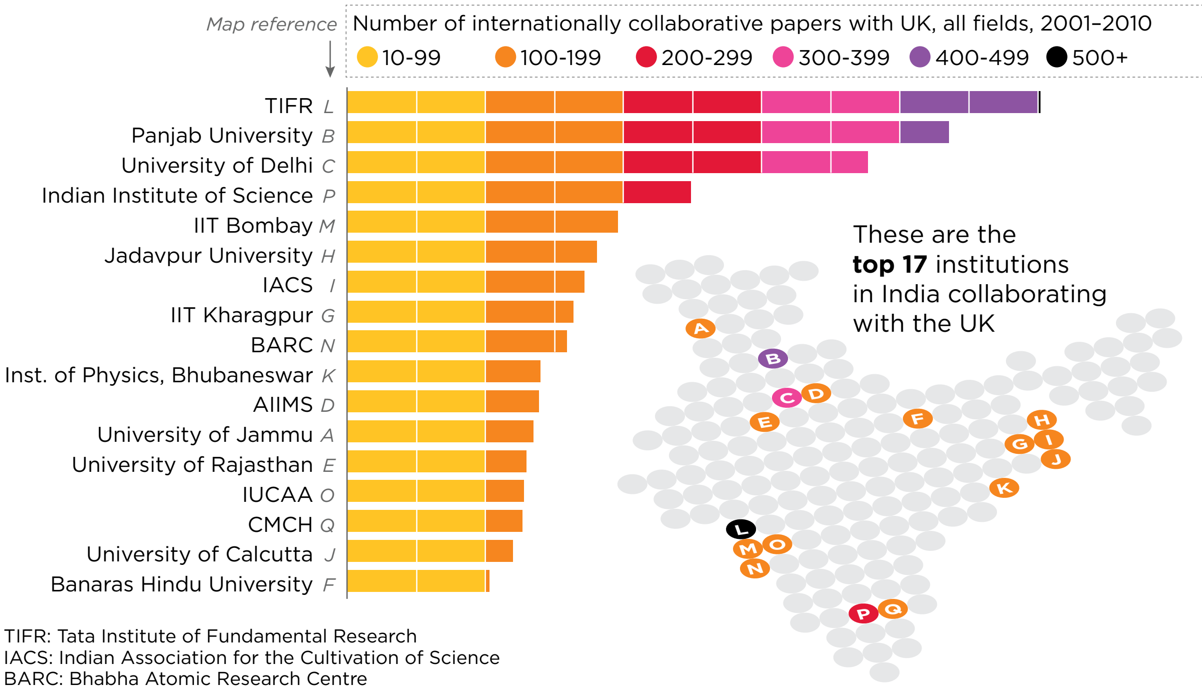
  - Oxford and Cambridge Universities and the Indian Institute of Science collaborate more evenly across a wider range of institutions. As do the University of Birmingham, UCL, IIT Kharagpur and BARC.

  - It seems researchers at Reading University almost exclusively collaborate with researchers in Kolkata. Five-out-of-six institutions that Reading collaborates with are in Kolkata, with the sixth also in West Bengal.

A full exploration of the factors behind these patterns is beyond the scope of the report, but may be useful for institutions or groups of institutions as they look to shape their international relationships.

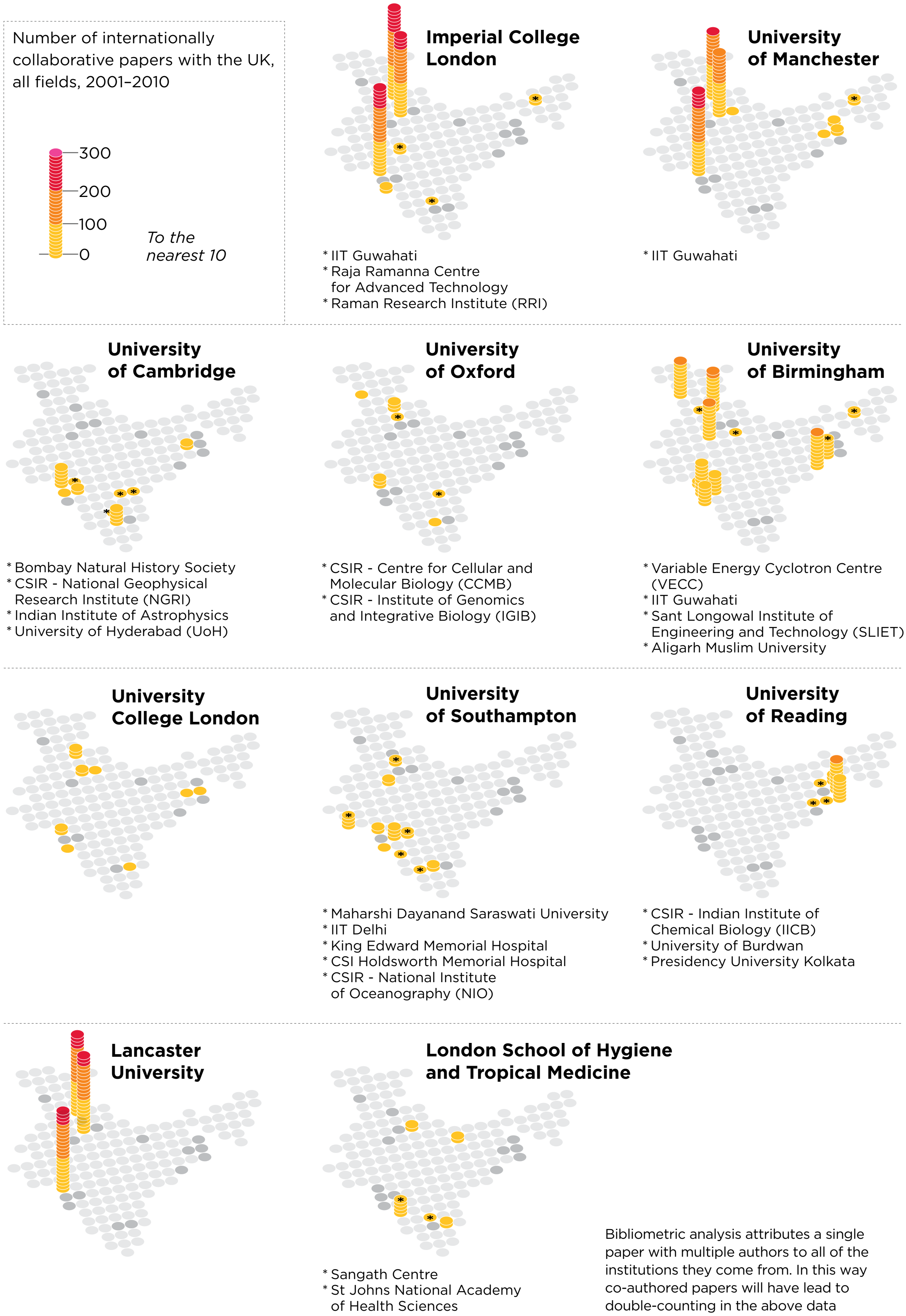
Mapping the geography of UK–India collaboration[275]
A new dataset specially commissioned for this report, allows us to unpack collaboration patterns at the institutional level between the UK and India. Twenty-one UK universities and 17 Indian universities published more than 100 papers with UK and Indian authors between 2000 and 2010.

Figure 17: India's top institutions collaborating with the UK



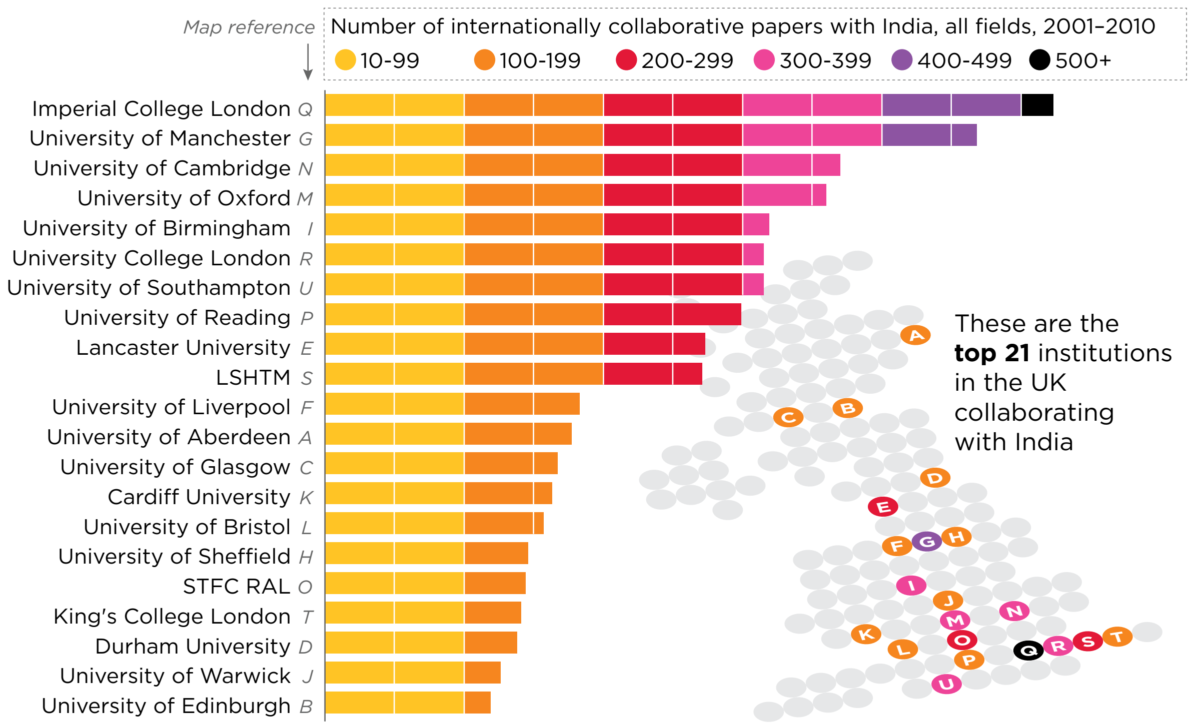
TIFR: Tata Institute of Fundamental Research
IACS: Indian Association for the Cultivation of Science
BARC: Bhabha Atomic Research Centre
AIIMS: All India Institute of Medical Sciences
IUCAA: Inter-University Centre for Astronomy and Astrophysics
CMCH: Christian Medical College and Hospital, Vellore

Figure 18: The Indian relationships of the UK's institutions leading bilateral collaboration



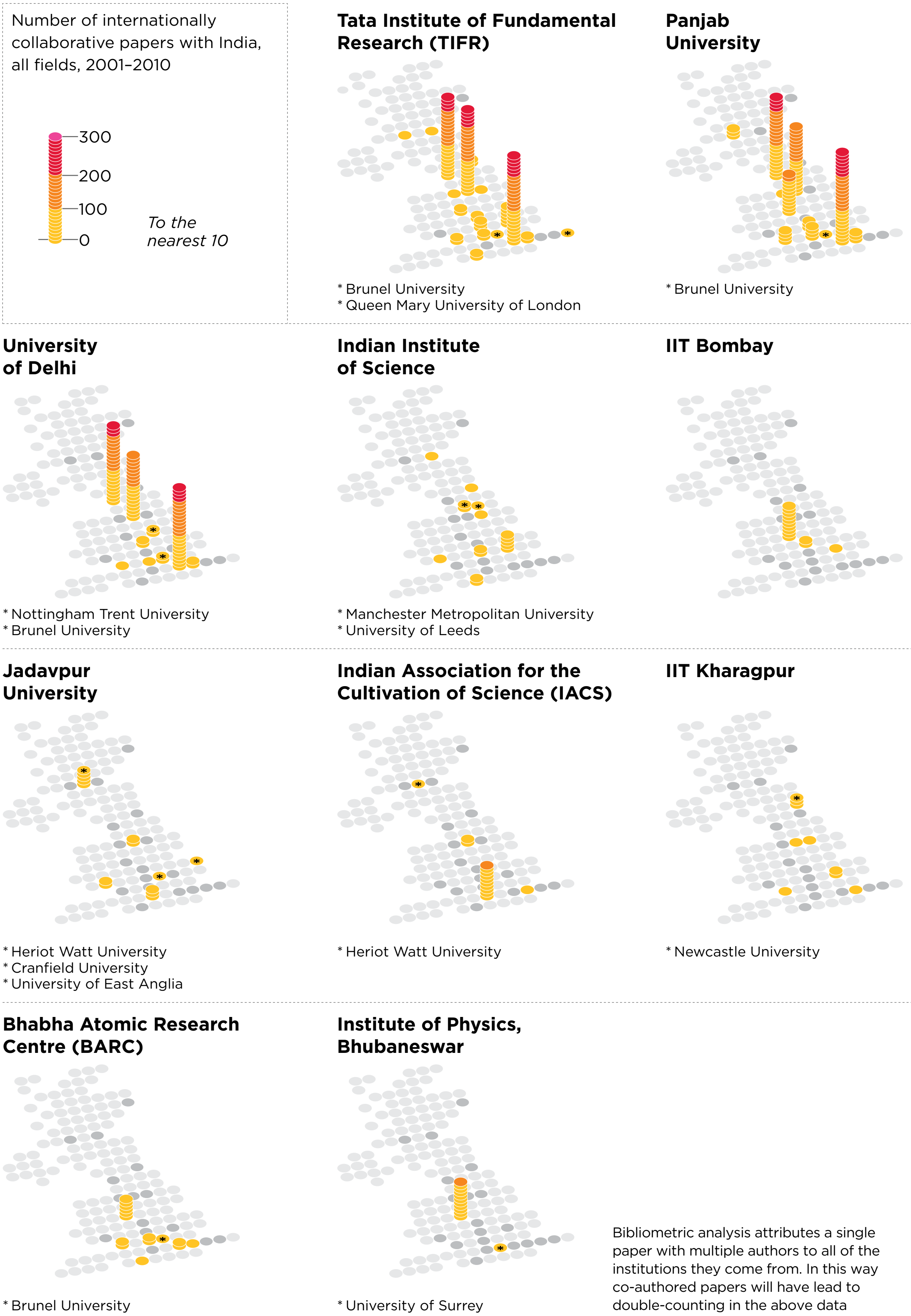
Bibliometric analysis attributes a single paper with multiple authors to all of the institutions they come from. In this way co-authored papers will have lead to double-counting in the above data

Figure 19: The UK's top institutions collaborating with the India



LSHTM: London School of Hygiene & Tropical Medicince
STFC RAL: STFC Rutherford Appleton Laboratory

Figure 20: The UK relationships with Indian institutions leading bilateral collaboration



Bibliometric analysis attributes a single paper with multiple authors to all of the institutions they come from. In this way co-authored papers will have lead to double-counting in the above data

Towards a more strategic partnership?

Efforts to strengthen the UK's partnership with India around research and innovation are broad in scope, and have ramped up in recent years. Research Councils UK (RCUK) India was launched in 2008. Since then the portfolio of joint funding between RCUK, Indian partners and third parties has grown to over £90 million.[276] Prior to 2008, the portfolio of joint research was just £1 million. There are now co-funded collaborations with seven research funders in India across a range of fields from chronic disease to next generation networks (see Box below). Energy research is a significant focus. The relationship around civil nuclear science is an example of how collaborative relationships can contribute to wider strategic aims. India is currently at the forefront of reactor technology, and long-term collaboration by UK scientists offers the opportunity to co-develop reactors in anticipation of the future energy needs of the UK.

Next Generation Networks

The India-UK Advanced Technology Centre, co-led by Ulster University and IIT Madras, is developing low-cost solutions for rural access to broadband, as well as applications for rural health monitoring, emergency and disaster communications, and social TV-Virtual Classrooms. Funded by both countries, the ultimate aim is to produce scalable solutions to benefit citizens in both countries.

The Centre was one of the first collaborations that the RCUK Office in India brokered, and has been highly productive: employing 200 scientists in both countries and producing 103 peer reviewed papers, six books, eight technical prototypes, 12 cloud-wireless testbed demonstrators, and 16 patents.[277]

Alongside the major research funders, there are a number of UK government departments engaging with India on research and innovation:

- The Science and Innovation Network, under the Foreign and Commonwealth Office, seek to build relationships between academics and companies in each country. As part of a 'network shift' to align UK foreign policy better with emerging powers, a substantial increase in diplomatic roles in India is underway.[278]

- UK Trade and Investment, whose remit is necessarily wider than innovation, will engage at the request of UK or Indian businesses to scope potential opportunities, and connect firms to potential partners. UKTI manages the Indo-UK Joint Economic & Trade Committee (JETCO), which meets annually with the aim of enhancing bilateral trade and investment. This is supported by a range of trade forums including the UK-India Business Council.

- The India-UK CEO Forum brings together ten major CEOs or Chairpersons from each country to drive greater trade, investment and commercial links between the two countries through recommendations to policymakers. The first meeting, in February 2011, suggested a number of broad priority areas, and working groups are now exploring these in more detail.

- DFID funds academic research focused on poverty alleviation jointly with the UK Economic and Social Research Council. As part of a rapidly growing departmental commitment to research, DFID's first regional research centre, covering five countries, opened in New Delhi in 2010. In addition, DFID is changing the balance of its support

for India, with a focus on the poorest states and a private sector programme which uses 'returnable capital' to deliver results. As part of this, DFID is considering supporting the National Innovation Council's Inclusive Innovation Fund (see Part 1).

- In March 2012, the UK Defence Science and Technology Laboratory agreed its first collaborative project with India's Defence Research Development Organisation on energetic materials technology.

The British Council also plays a role in deepening collaboration between the UK and India across the education sector, through the UK–India Education and Research Initiative (UKIERI). The Initiative grew out of initial discussions between Tony Blair and Manmohan Singh in 2004 and 2005, and has since developed into a coordinated partnership. Phase 1 (2006–2011), worth just over £20 million, involved:

- 182 UK–India partnerships across Higher Education and Research; Schools and Professional and Technical Skills, involving over 600 institutions
- 55 individual awards through PhD scholarships and fellowships
- 40 events in policy dialogue and networking[279]

The half way review noted that 'while UKIERI has, understandably, not managed to achieve a 'step change' in the past five years alone, the contribution it has made towards reaching the long-term goal has been both significant and strategically useful.'[280] Phase 2 (to 2016) has been confirmed with joint funding from both governments worth about £5 million a year.[281] It is focusing on four themes: leadership development, innovation partnerships, skills development and enhancing mobility.

Data Box: The connections between the UK and India are deep and diverse

- There are one million people of Indian origin in the UK.[282]
- Over one million people travel between the UK and India every year.[283]
- The bilateral trade relationship is worth £13 billion a year,[284] having increased by more than two thirds between 2004 and 2009.[285] However, the UK was only India's twenty-second most important source of imports in 2009.[286]
- Investment between the two countries is strong. FDI to India from the UK was a record $2.75 billion during the first ten months of 2011–12.[287] India is the third largest investor in the UK.[288]
- While some of this investment is innovative, not all of it is. Blackburn Rovers, a major football team, was bought by the Indian poultry company Venky's in 2010.
- London plays a key role in raising investment for India. Over 20 per cent of the financing raised in the London markets in 2010 was for Indian companies.[289]
- The UK is a key hub for India in Europe: 700 of 1,200 Indian companies based in Europe are in the UK).[290]

Also outside the UK government, the Wellcome Trust has agreed £125 million of joint funding with the Indian Department of Biotechnology since 2008.[291] In 2008 they announced an £80 million Alliance to boost biomedical research through a series of four fellowship programmes that aim to build excellent career pathways in India for scientists. Two years later, the two organisations announced another joint initiative – with each putting £22.5 million into R&D for affordable healthcare: aiming to deliver safe and effective healthcare products at affordable cost, without compromising on quality. To get the money to the right people, Shirshendu Mukherjee, Strategic Advisor to the Trust in India, spends a large proportion of his time going around the country, travelling off the beaten track to find exciting examples of medtech innovation to support.

Affordable healthcare
The Trust is supporting the development of a low-cost 'smart cane' at IIT Delhi. It uses ultrasonic sensors to detect obstacles up to 3m away, with the range of the detected obstacles conveyed to the user by various vibratory signals. With over 15 million blind people in India, reducing dependence on sighted assistance at a feasible cost – targeted at £30 – will improve sufferers' independence and wellbeing and free up their carers' time for more productive endeavours.

Benchmarking the UK's approach

One way to interpret the strengths and weaknesses of the UK's approach is to profile some of the models of engagement adopted by India's other international partners. We highlight the elements of selected models that are particularly popular with Indian stakeholders as possible elements of best practice for the UK.

USA

The US approach to government-led collaboration with India seems largely similar to that of the UK, albeit on a larger scale. Opportunities for collaboration in research and innovation and higher education are led by multiple government departments in both countries.

US-India joint R&D funding is rising by around $7.5 million a year, with collaboration around specific themes (such as particle physics) due to add at least another $40 million a year starting in 2012.[292] The two countries authored nearly 12,000 articles together between 2006 and 2010, three times as many as the UK and India. The US remains the preferred destination for Indian students with 104,000 Indian students choosing the US to study[293] compared to the 39,090 who chose the UK.[294] While David Cameron talks of crafting a *"new special relationship,"* Obama has described the US-India connection as an *"indispensable partnership."*[295] The US' landmark 2008 civil nuclear deal for example, which began with an agreement in 2005, was explicitly a business oportunity. Other key research, technology and innovation programmes in recent years include:

- **The Indo-US Science and Technology Forum** is the most nimble and active mode of bilateral collaboration[296] and has established 24 virtual joint research centres and organised more than 30 training programs and 150 bilateral conferences since 2000, two-thirds of which have resulted in long-term partnerships.[297] It has also facilitated the travel of nearly 10,000 scientists between the US and India in the last decade.

- **Project X:** Cooperative R&D around particle physics, contributing to the proposed

high-intensity proton accelerator research complex at Fermilab in the US.[298] This will be worth $40 million a year from 2012–2016.

- **The US–India S&T Endowment Board** will spend around $2.5 million a year[299] to promote commercialisation of innovative technologies. Call for joint proposals around priority areas, 'Healthy Individuals' and 'Empowering Citizens'[300] in spring 2012.

- **Data.gov:** joint commitment to develop an open source platform to provide citizens access to government information and a package of e-Governance applications to enhance public service delivery.

- **Civil Space Working Group:** working together to share information on tropical weather, monsoon forecasting and climate change.[301]

- **Joint Clean Energy Research and Development Centre.** New $100 million+ joint research centre using a public private partnership model to bring together industry and academia in both countries. The National Renewable Energy Laboratory, University of Florida and Lawrence Berkeley National Laboratory have been selected from the US, with industrial partners including IBM. The Indian Institute of Science, Bangalore, the Indian Institute of Chemical Technology-Hyderabad, and CEPT University, Ahmedabad were selected in India.[302]

- **The Millennium Alliance:** an innovation partnership launched in late 2011 with $7.5 million each from USAID and FICCI[303] to source and scale development solutions being developed and tested in India.[304] The ambition is to raise $50 million in seed capital, grants, loans, guarantees, and technical support for base of the pyramid solutions.

Case Study: Stanford-India Biodesign
Funded by the Department of Biotechnology, Stanford University, and other supporters including the Indo-US S&T Forum, this programme is a partnership between the All India Institute of Medical Sciences (AIIMS), New Delhi, and Stanford University. The goal is to train the next generation of medical technology innovators in India through a fellowship model where approximately half the time is spent at Stanford University and the other half spent in India. Fellows work in a multidisciplinary team joining other innovators with a combination of engineering, medical and business backgrounds. The team examines clinical needs within the Indian setting, identifying opportunities for medical technology innovation. Working closely with Stanford, AIIMS and IIT Delhi faculty, the teams prototype, develop and patent new technologies.

Seventeen fellows have now completed the programme, with one fellow being part of the small team that designed the Jaipur Knee (see page 16). Other products under development include Neobreathe, a low-cost, easy-to-use device to prevent neonatal death through birth asphyxia.)[305]

Germany

Germany combines a breadth of engagement, like the UK and the US, with moves towards providing one focal point for engagement through the new German House for Research and Innovation. This is very popular with Indian stakeholders. Germany's research infrastructure is complicated and fragmented:[306] Torsten Fisher, Head of the DFG office in India admits *"it is difficult for Indians to understand the German system,"* so moves to open a single central information resource for collaborative opportunities[307] are welcomed

by Indians. The various German government ministries and organisations that support collaboration should all be located together in one building in New Delhi later this year.

The Indo-German Science and Technology Centre complements academia-only collaboration, with thematic calls (e.g. Materials Science and Nanotechnology, or IT and Communications) that bring together industry and academia in both countries for joint R&D projects.

Germany already has the strongest research links with India among European countries. Interestingly, this is despite relatively small numbers of Indian students studying in Germany. There are only 4,500 Indian students in Germany[308] – just over a tenth of the UK number – but there are slightly more German-India co-authored papers published each year than UK-India ones.[309] Bottom-up, purely responsive funding provides around €3-4 million a year to German researchers wanting to work with Indians – this money is matched by Indian partners.[310]

European Union

The main channel of engagement for the EU is through the Framework Programmes – €54 billion of research consortia funding. Under Framework Programme 7,150 research projects have Indian and European partners, with €35 million coming into India. The European Commission also runs 'top down' joint calls for research with Indian government departments. A call focused on water, for example, includes €10 million from the Department of Science and Technology and €6 million from the Department of Biotechnology, match-funded by the EU.[311] The European Commission office in New Delhi acts as a focal point for information for Indian partners. An annual road show travels to over 30 cities advertising opportunities to Indian researchers. A brand new programme seeks to create a third model of engagement and will see the creation of an Indo-Europe Joint Innovation Partnership and Forum. It aims to provide coherence between the multilateral engagement of the EU/EC and the bilateral engagement of all of the member states – with synergies between the levels driving greater scope, scale and impact from the collaboration.

Finland

Finland's highly-focused approach differs from the British, US and German models. FinNode, a small, responsive office with an accessible 'point man' has the objective of helping Finnish companies secure market access. FinNode acts as a conduit to the relevant Finnish agencies. Riku Makela, Director of FinNode, recalls a visit to an Indian incubator where he spotted a technology he thought was interesting. He rang the CTO of Nokia the next day, and discussions to acquire the technology started shortly afterwards.[312] While the UK's ambitions in India are more multi-faceted than Finland's, the obvious engagement point and clear rationale for being in India are popular with Indians. What is more, such a defined objective lends itself more easily to measurement, evaluation and adjustment of strategy as required.

South Korea

South Korea's engagement with India on research shows that government-led relationships are not always necessary to drive increases in collaboration. Co-authored publications between South Korea and India more than doubled over the two halves of the last decade, from 979 between 2000 and 2005 to 2,093 between 2006 and 2010, the largest relative growth of the selected countries.[313] There is a $10 million joint R&D fund between the two countries for joint research projects, human resources exchanges, workshops, and other science and technology cooperation programs.[314] There are plans to launch an 'India-

Korea Great Innovation S&T Challenge' in 2012.[315] But overall, joint funding between the governments is not particularly significant, suggesting that the link between funding streams and trends in international co-authorship is not straightforward.

This is not to say that government-government relationships are unimportant: India-South Korea relations have undergone a significant and qualitative shift in recent years, propelled by successful and regular high-level visits[316] including the signing of a civil nuclear cooperation agreement in 2011. Bilateral trade between South Korea and India has increased by around 70 per cent since a Comprehensive Economic Partnership Agreement came into force in January 2010, overtaking the value of trade between the UK and India and crossing the $20 billion mark in 2011.[317] This example shows how quickly new partnerships can become influential.

Conclusion

Is the UK's investment in developing a more strategic relationship with India paying dividends? For the time being, it is difficult to judge, for three main reasons.

First, because India's overall international collaboration is increasing, there is a degree to which 'a rising tide lifts all boats'. In absolute terms, UK papers co-authored with India have almost doubled from 2,325 in 2000-2005 to 4,086 in 2006-2010, but relatively as a percentage of India's internationally co-authored output this represents only a marginal change from 10.8 to 11.1 per cent.[318] Clearly holding ground is better than losing ground, but at the very least this suggests the UK is still some way short of being the 'partner of choice' for India.

Second, the metrics most readily available to track collaboration do not adequately capture the breadth of engagement in research and innovation. For example, there is little systematic analysis or data on business linkages – like those between Silicon Valley and India – other than aggregated trade data, even though this is a key form of collaboration whether it is sharing ideas, innovation methods, or transfer of staff.

Third, and most challenging, is the difficulty of attributing these trends to specific policy interventions. Overall, at least in the short to medium term, it is doubtful whether patterns of international collaboration are that sensitive to policy interventions – for example, US, German, UK, Japanese, and French co-authorship with Indian researchers are all led by physics,[319] irrespective of the national model of engagement or stated priority areas. There is a substantial time-lag between research funding and research publication and patenting, so the very recent increases in international collaboration with India are unlikely to show up yet. More generally, without a counterfactual, it is hard to know whether recent developments in the UK's partnership with India happened because of the additional support provided in recent years, or whether it would have happened regardless. Of course, this is hardly a problem that is unique to policies on research and innovation, but nevertheless it requires careful thought in future.

Overall, the UK looks well positioned to collaborate with India across a breadth of areas within research, and to benefit from India's strong and deepening links into global networks for research and innovation. However, without further investment in tracking and measuring innovation collaboration, it will be difficult to assess or steer the UK's engagement with India in the years to come.

Part 7

CONCLUSIONS AND RECOMMENDATIONS

If Sam Pitroda, Chairman of the National Innovation Council were to make a bet on which Indian innovations were to influence the world, it wouldn't be on particular products or companies, but entire systems. *"Health and education are the places to look – think of health: it's not about a particular technology, but bringing together a whole range of things to change behaviour and improve lives – its yoga, plus meditation, plus diet, plus technology, software platforms and science."*[320] Innovation has raced up the public agenda in India in recent years, and there is a strong recognition that building an 'inclusive' model of innovation in India could help solve the dilemma of improving excellence in a way that is not at the expense of equity. According to Pitroda, *"The best brains have been working where they are least needed, on the problems of the rich. The big transition in India is to a place where they are working on the problems of the poor."*[321]

There is no doubt that India is a country in transition. Yet we're not necessarily seeing the type of transition we might have expected at the peak of BRICs hyperbole. While Indian investment in science and innovation has continued to rise, and science is growing in both output and quality, during the last decade China has raced ahead of India, Brazil and Russia in terms of research spending and overall scientific output. There are limits to what we should draw from this contrast. While the BRICs acronym drew the attention of policymakers and entrepreneurs to the rapidly shifting centre of global economic gravity, it also created a practice of aggregating emerging economies that masked the considerable differences between them. In fact, it now seems to obscure as much as it illuminates. An important implication of our research is that UK stakeholders need a finer-grained understanding of different emerging economies, and the variations within them, and must tailor their strategies to collaborating on research and innovation accordingly.

This report set out to map and analyse recent shifts across India's research and innovation system, and the likely impact of these developments for both India and the rest of the world. It focused on the last five to ten years. This is a very short window in the lifespan of research and innovation, yet the breadth of change even in that time points to the importance of strengthening connections between the UK and India, and focusing the resources of government on the greatest mutual opportunities. What are the implications of our analysis? This section summarises some of the key findings and outlines a set of recommendations for how UK-India research and innovation linkages can be strengthened, and support for collaboration can be directed in more strategic ways. These are predominantly designed for policymakers, although they may provide useful insights for businesses and universities with a desire to improve collaboration with Indian partners.

As we explored in Part 2, government spending still accounts for the lion's share of investment in R&D, although the balance is shifting – private sector spending grew from 18 per cent to 28 per cent of the total from 2003 to 2007. Stable government support for science has led to world-class research capabilities in physics, chemistry, materials science and engineering, and advanced space and civil nuclear research. While India produces over twice as many scientific publications a year compared to a decade ago, these

concentrations of excellence aside, India is not yet a science superpower. This amounts to only 3.5 per cent of world research, and most of that is below average quality.

A long planned expansion of the top-tier of research and teaching institutions is finally underway, and results so far are extremely promising. Yet, as we saw in Part 5, this considerable advance can sometimes feel like a drop in the ocean when faced with meeting the future demand for quality education. Achieving government's 2020 enrolment targets would require building eight universities and 417 colleges each and every month. Qualitatively different models of higher education are required, which maximise the opportunities of new technologies, and challenge bureaucracy and entrenched interests.

In Part 3, drawing on new quantitative data on the geographical distribution of scientific excellence, we mapped the geography of science and innovation in India. Some aspects are changing fast. For example, Pune, only a few years ago considered a 'second-tier city,' has now joined a premier set of hubs which include cities such as Hyderabad and Chennai, and new hubs are emerging from Trivandrum in the South to Chandigarh in the North. Despite pressures on infrastructure, which five years ago seemed like they might dissuade future investment, Delhi, Mumbai and Bangalore continue to be India's dominant hubs for research and innovation.

While these hubs continue to attract international investment from multinational companies, innovation in the Indian private sector is by no means restricted to the research centres of multinationals. The pharmaceuticals and automotive sector continue to dominate domestic R&D spending. Yet metrics such as R&D spending and patent outputs, the traditional measures of innovation capabilities are severely limited as indicators of India's innovation performance. Many of India's greatest strengths in innovation – in services, business models and processes – are invisible to these metrics, and 'hidden' from view in business-to-business relationships and global supply chains.

Despite the positive trends and transitions our research uncovered throughout the Indian innovation system, the country remains largely a challenging place to be a researcher or to do business. Moreover, India has spent the last couple of years in a rut, with dropping economic growth largely compounded by the paralysis of a government rocked by corruption scandals, neglecting infrastructure investment, and unable to pass necessary reforms across the board. It remains to be seen whether this is just a blip, or whether it will have longer-term implications in coming years, with negative effects on India's innovation system.

In some cases, these infrastructure gaps and India's challenging context has itself helped a certain type of innovation to thrive. This trend was particularly striking and distinctive throughout our exploration of the Indian innovation system: the emergence of frugal innovation.

This isn't a niche activity; examples are found throughout the system from corporate labs to civil society. From Devi Shetty's path breaking model of delivering affordable heart surgery, to Bharti Airtel's approach to drastically cut the cost of mobile phone calls, to the Keralan approach to palliative care which is providing access to support at the end of life for thousands in a void of formal healthcare. This strength has particular relevance for the way India positions itself within global innovation networks, and the strategies it adopts for collaboration and engagement with countries like the UK. While it has grown in profile in recent years, many radical examples date back decades.

Today this strength has a new significance. The pressure for financial austerity and environmental sustainability are making frugal approaches to innovation attractive to developed economies. New technology platforms such as mobile, are transforming the potential impact of frugal innovation. While India is by no means the only country experimenting with frugal innovation models, a number of factors have come together in India to create an environment that is particularly conducive to frugal innovation: a vast, price-sensitive market; a culture of creative improvisation; a vibrant civil society; an emerging funding system for social innovation; and a government keen to create an 'inclusive' model of innovation that aims to connect India's leading scientists with its greatest societal challenges. India's got the Frugal Factor, at a time when frugal innovation has ever-greater relevance around the world.

Recommendations

The recent developments in India's innovation system analysed in this report suggest a range of ways in which collaboration between UK and India could be strengthened. These are predominantly designed for policymakers, although they may provide useful insights for businesses and universities with a desire to improve collaboration with Indian partners.

For India:

1. **India should market its distinctive strengths in frugal innovation to the world**
   In the last 50 years, a select cadre of countries have had a visible influence on international innovation policy through the study, imitation or adaptation of their national models of innovation. This includes the Silicon Valley cluster model from the US, Japanese lean manufacturing, or the 'Finnish model' of technology investment. India could be poised to join them if it succeeds in building an 'inclusive' model of innovation that draws on strengths in frugal innovation and connects efforts across business, academia and civil society.

   India should become an even more vocal advocate and ambassador for the methods and outcomes of frugal innovation. With Europe, the US and other developed economies facing the twin pressures of financial austerity and environmental constraints, frugal innovation can only become more important over the next decade and beyond. India can be highly influential by promoting frugal innovation around the world, and reaping the many benefits (in terms of economic growth, trade, cultural capital, and networks) that will flow from it.

2. **India should establish a research programme on the 'science of science and innovation policy'**
   Worldwide, there is still a limited body of rigorous evidence of which policies and interventions work in supporting high-impact research and innovation. But several countries have made substantial investments in the last five years in a more rigorous understanding of what works. The US has its Science of Science and Innovation Policy programme to improve the models, analytical frameworks and metrics that are applied in science policy decision making. Japan and Norway have both developed initiatives along similar lines. India should now do the same: the Federal Government should develop a programme to coordinate and substantially increase research into what works in science and innovation policy in India. This should build on the existing work of groups like NISTADS, NSTMIS, the CII, and FICCI. It should also include the National Innovation Council and draw on independent academics.

This programme should be tailored to distinctive Indian strengths: its focus should be on developing new metrics that capture the breadth of India's innovation (including in design, training, organizational or process innovation etc.) and provide new tools for charting India's progress. This should draw on and adapt international expertise where it exists, such as that of Nesta's *Innovation Index.* Given the scope for India to experiment with different approaches to stimulating high-impact innovation in coming years, this will be of interest to many countries outside India.

For the UK

1. **The UK should develop a strategy to coordinate collaborative engagement with India tailored around India's unique model**
   The UK government is rightly proud of the substantial increases in joint research and higher education partnerships with India over the last five years. India will remain an important focus for UK collaboration: the December 2011 *Innovation and Research Strategy for Growth* highlights 'building strategic links with high growth economies' as one of its 'five pillars' of international engagement.[322]

   At the same time, bespoke approaches are needed which take account of the differences among high-growth economies; a diversity which is sometimes obscured by collective discussion of 'the BRICS'. The UK should develop a strategy for engagement tailored specifically to India's strengths and the opportunities it presents. This would need to bring together the Foreign and Commonwealth Office's S&I Network, RCUK, UKIERI but also UKTI, the TSB, DFID and others. As part of this strategy, the UK should prioritise identifying those opportunities for collaboration which would benefit from coordination across different government funded agencies – for example around innovations with both social and commercial impact such as clean energy, healthcare, education and design – all of which could have frugal elements.

2. **The UK should shift support to longer term, more ambitious partnerships in priority areas**
   The substantial increase in joint research funding with India has largely been achieved through relatively short-term joint projects, with each of the Research Councils using disparate models of engagement. This makes collaborations more complex than they need to be. As the UK continues its increase in resource allocation in research and innovation, funding bodies should move to more ambitious, longer term programmes in priority areas.

   There is scope to further increase joint research funding with India – and while the Research Councils investment in joint research has grown considerably, the current annual investment is still only roughly equivalent to 0.3 per cent of the UK research budget.[323] India is the world's fourth largest economy and only going to become scientifically more powerful. If one UK goal from research collaboration, as stated in the 2011 *Research and Innovation Strategy*, is to be 'partner of choice,'[324] the UK will need to move to deeper collaborations and to increase the resource envelope available.

For both India and the UK

1. **India and the UK should join forces to establish a joint £1 million challenge prize in frugal innovation**
   Challenge prizes, which have low barriers to entry and reward achievement of a specified objective, can be a cost-effective way of stimulating innovation and building new networks of innovators, including among small businesses. The UK and India

have no shortage of historical linkages, but significant effort is required to ensure this partnership between the two countries evolves and gains new relevance. Given the global importance of frugal innovation, a joint challenge prize could be a valuable element of a toolkit of ways to stimulate useful innovation, encourage skills transfer and build the new dynamic partnership that the UK and India need. The UK and India should together define a focus area within today's biggest shared priorities including water, energy and food security.

2. **India and the UK should co-fund a series of projects to design and test frugal approaches to higher education provision**
   India is very unlikely to meet the national demand for quality higher education using conventional models. The limited institutional resources available and vast potential market are creating conditions ripe for frugal innovation. Yet the UK higher education institutions seeking to build relationships in India are often looking to engage around conventional campus-based models, despite the policy changes required to allow this still being stalled, and the nature of higher education changing the world over. The UK once led the world in open access education through the BBC, Learn Direct and the Open University, and UK players retain a strong position in global markets. UK and Indian higher education providers and NGOs should work together to design and test new models of education based on frugal principles that capitalise on the latest technologies. Udacity, the Khan Academy and MIT-Harvard's edX project could be valuable sources of inspiration here. UKIERI could play a key role in advocating for this approach, and coordinating the activities of individual UK institutions that choose to engage in this way.

Part 8

APPENDICES

Appendix 1: Acronyms

AIIMS	All India Institute of Medical Sciences
BARC	Bhabha Atomic Research Centre
BCG	Boston Consulting Group
BRICs	Brazil, Russia, India and China
CERN	Conseil Européen pour la Recherche Nucléaire
COO	Chief Operating Officer
CSIR	(Indian) Council of Scientific and Industrial Research
CTO	Chief Technology Officer
DAE	(Indian) Department of Atomic Energy
DBT	(Indian) Department of Biotechnology
DFG	Deutsche Forschungsgemeinschaft
DFID	(UK) Department for International Development
DRDO	(Indian) Defence Research and Development Organisation
DST	(Indian) Department of Science and Technology
ECG	Electrocardiograph
ESRC	(UK) Economic and Social Research Council
FDI	Foreign Direct Investment
GDP	Gross Domestic Product
GE	General Electric
ICGEB	International Centre for Genetic Engineering and Biotechnology
IFC	International Finance Corporation
IIM	Indian Institute of Management
IISc	Indian Institute of Science
IISER	Indian Institute of Science Education and Research
IIT	Indian Institute of Technology
IP	Intellectual Property
ISRO	Indian Space Research Organisation
MIT	Massachusetts Institute of Technology
MNC	Multi National Company
NASA	(US) National Aeronautics and Space Administration
NCR	National Capital Region
NGO	Non-Governmental Organisation
NIIST	National Institute for Interdisciplinary Science and Technology
NIT	National Institute of Technology
OECD	Organisation for Economic Co-operation and Development
OSDD	Open Source Drug Discovery
PWC	PricewaterhouseCoopers
R&D	Research and Development
RCUK	Research Councils UK
SMEs	Small and Medium Enterprises
SMS	Short Massage Service
TB	Tuberculosis
TCS	Tata Consultancy Services
TED	Technology, Entertainment and Design
TIFR	Tata Institute of Fundamental Research
UKIERI	UK-India Education and Research Initiative
USAID	United States Agency for International Development
USPTO	United States Patent and Trademark Office
WB	World Bank
WHO	World Health Organisation

Appendix 2: Interviewees

Mr Pawan Agarwal, Adviser (Higher Education), Planning Commission

PK Agarwal, CEO, TiE Global

Sanmit Ahuja, Chief Executive, ETI Dynamics

Sheryl Anchan and Leena Arora Kukreja, Advisers, Science and Innovation Network, Foreign and Commonwealth Office

Dr Parveen Arora, Director, NSTMIS Division, Department of Science and Technology

Professor Suma Athreye, Professor of International Strategy, Brunel Business School, Brunel University

Satish Babu, Director, International Centre for Free and Open Source Software, Trivandrum

M Balasubramanian, Private Sector Development Advisor, DFID India with Meenaskshi Nath, Head, Private Sector team, DFID India

Dr Parthasarathi Banerjee, Director, National Institute of Science, Technology and Development Studies, (NISTADS)

Srinath Batni, Member of the Board, Infosys, and colleague

Naomi Beaumont, Head of International Strategy, Arts and Humanities Research Council

Ms Poyni Bhatt, Chief Administrative Officer, Society for Innovation and Entrepreneurship, IIT Bombay

Dr Arnab Bhattacharya, Associate Professor, Tata Institute of Fundamental Research

Professor S Bhattacharya, Former Director of TIFR and on the Council of the IITs

Payal Bhoj, serial entrepreneur

Prasanta Biswal, Senior Manager – Mission, SELCO Solar Light Ltd

Sean Blagsvedt, CEO, Babajob

Dr (Father) V Braganza, Principal, St Xavier's College, Ahmedabad

Dr SK Brahmachari, Director General, CSIR

Mike Bright, Head of International Policy and Strategy, and Suzanne Austin, Senior Policy Manager, International Team, Economic and Social Research Council

Dr Veronique Briquet-Laugier, Science and Technology Counsellor, French Embassy in India

Dr A Chakraborty, Director, Indo-German S&T Centre

Dr K C Chandrasekharan Nair, Secretary and Registrar, Technology Business Incubator, and colleagues, Technopark, Trivandrum

Chief Minister O Chandy and colleagues, Government of Kerala

Dr Subra Chattapodhyay, Associate Director, Operational Grid Garuda and Infrastructure, Centre for the Development of Advanced Computing

Dr Shubham Chatterjee, Partner, Invensis Consulting

Professor VS Chauhan, Director, International Centre for Genetic Engineering & Biotechnology

Chris Darby, Head of Energy and Earth Resources, Government Office for Science

Dr Suresh Das, Director, National Institute for Interdisciplinary Science & Technology, Trivandrum

Dr Phillipe de Taxis du Poet, Head of Science and Technology, and Dr Indraneel Ghose, S&T Analyst, the Delegation of the European Union to India

Amrita Dey, Assistant General Manager, Marketing, Tata Chemicals

Rebecca Fairbairn, Principal Policy Manager, Postgraduate Training and Career Development, Economic and Social Research Council

Dr Torsten Fischer, Deutsche Forschungsgemeinschaft (DFG), India

Dr K Ganesh, Director, Indian Institute of Science Education and Research, Pune

Sally Goggin, Director Education and Malyaj Varmani, Head, Scholarships and Skills Development, UK India Education and Research Initiative

Mr R Gopalkrishnan, Secretary, National Innovation Council

Professor MV Rajeev Gowda, Chairperson, Centre for Public Policy and Professor, Economics and Social Sciences, Indian of Management Institute Bangalore

Dr Alicia Greated, Director and Rita Sharma, Deputy Director, Research Councils UK India

Dr Jason Green, Head of Energy, Economic and Physical Sciences Research Council

Professor Ashok Gupta, Dean of Alumni Affairs and International Relations, IIT, Delhi

Professor Anil Gupta, Founder, HoneyBee Network and IIM Ahmedabad

Dr Pranay Gupta, Centre for Innovation, Incubation and Entrepreneurship, IIM Ahmedabad

Mrs Seema Gupta, Director, Confederation of Indian Industry

Vishal Gupta, Founder, Seclore

Jos van Haaren, Senior Director Philips Research Asia

Martin Haemmig, Center for Technology and Innovation Management

Blair Parks Hall, Jr, Minister Counsellor, Economic, Environment and Science Affairs, and colleagues, Embassy of the USA

Dr Mariappan, Head, School of Health Systems Planning, Tata Institute of Social Sciences

Richard Heald, CEO, UK India Business Council

Prashanth Hebbar, Cybermedia and DARE

Sharath Jeevan, Founder and CEO, STiR Education

Professor ED Jemmis, Director, IISER Trivandrum

Cherian Joseph, Acumen Fund Fellow

Dr A Joshi, Associate Professor, Industrial Design Centre, IIT Bombay

Hanna Nari Kahle, PhD Student, Cambridge University and WHU Otto Beisheim School of Management

Dr C Karkaria, President, Biotech R&D, Lupin

Parag Khanna, Director, Hybrid Reality Institute

Sid Khanna, Director, Saffron Education

Guncha Khare, Host, and Tej Dhami, Director of Incubation Support, The Bombay Hub

Professor Sunil Khilnani, Director of the Kings India Institute, Kings College London, and Dr Jahnavi Phalkey, Lecturer in the History of Science and Technology

Suhasini Kirloskar, Director, British Trade Office, Pune and Anvnish Malhotra, Senior Trade and Investment Officer, UK Trade and Investment

Manjeet Kriplani, Director, and Akshay Mathur, Head of Research, Indian Council on Foreign Relations

Professor VV Krishna, Professor in Science Policy, and Chairperson, Centre for Studies in Science Policy, Jawaharlal Nehru University

Professor Rishikesh T Krishnan, Professor of Corporate Strategy & Jamuna Raghavan Chair Professor of Entrepreneurship, Indian Institute Management Bangalore

Mr Aniruddha Kulkarni, Chief Technology Officer, Force Motors

Professor Nirmalya Kumar, Professor of Marketing, London Business School

Mr Ajit Kumar Verma, Adviser for Science and Technology, Planning Commission

Dr Rajiv Kumar, Chief Scientist, Innovation Centre, Tata Chemicals

Sophie Laurie, Head of International, Research Councils UK

Mr Barry Lowen, Director, UK Trade and Investment India

Riku Makela, Director, FinNode

Sunil Mani, Planning Commission Chair in Development Economics, Centre for Development Studies, Trivandrum

Jasjit Mangat, Director, Investments, Omidyar Network India

Ajay Maniar, Investment Team, Aavishkaar

Osama Manzar, Founder and Director, Digital Empowerment Foundation

Ejaz Hoda, Marketpulse India, Santanu Chaudhury, Dean, Undergraduate Studies, IIT Delhi, Professor SK Saha, IIT Delhi

Dr R A Mashelkar, National Chemical Laboratory

Sonia Mehra, Chief Operating Officer, Mqure

V R Mehta, Executive President, Delhi Centre, Bhagwan Mahaveer Vikalang Sahayata Samiti, Jaipur (Jaipur Foot)

Ashish Mehta, UKTI First Secretary, Mumbai and TR Giridhar, Senior Trade and Investment Adviser, UK Trade and Investment, Creative Industries, Mumbai

Deepam Mishra, CEO, i2india and Brian Graves, Director of Business Development, Imperial Innovations

Tapan Misra, Head of Innovations Management, ISRO Space Application Centre

Dr Arabinda Mitra, Adviser and Head, International Cooperation, Department of Science and Technology

Harkesh Mittal, Secretary, Technology Development Board, Department of Science and Technology, and colleagues

Professor MS Mohan Kumar, Secretary, Karnataka State Council for Science and Technology and colleagues

Dave Moore, Deputy Head of Mission & Head of Trade & Investment, UK Trade and Investment, Mumbai

Dr Shirshendu Mukherjee, Strategic Advisor, Wellcome Trust India

Manoj Nambiar, Head, Performance Engineering Research Centre, Tata Consultancy Services

V 'Naresh' Narasimhan, Co–Founder, Chaia

Dr Narayanan, Dean of the Department of Humanities and Social Sciences, IIT Bombay

Kannan Natarjan, Global Business Head – Public Sector and Higher Education, and colleagues, Wipro

Sam Pitroda, Adviser to the Prime Minister on Public Information Infrastructure & Innovations and Chairman, National Innovation Council

Toby Norman, PhD student, Judge Business School, Cambridge University

Sunil Parekh, Adviser, Zydus Cadilla Healthcare Limited

Anand Parthasarathy, Editor, IndiaTech Online

Uday Phadke, Chief Executive, Accelerator India

Dr M Phadke, Senior Vice President, Reliance Innovation Centre

Nancy Pignataro, Senior Policy Adviser, Bilateral Relations, Intellectual Property Office

Professor VNR Pillai, Executive Vice President, Kerala State Council for Science, Technology and the Environment

Ms Brune Poirson, and Mr Nicolas Miailhe, Sisyphos

Vandana Poria, CEO, Get Through Guides

Nitin Prabhakar, Chief Operating Officer, Avinash Prabhakar, Chief Technology Officer, Artin Dynamics

Dr Premnath V, Head NCL Innovations, National Chemical Laboratory

Dr B Purniah, Head, International Studies Division, Department of Atomic Energy

Dr T Ramasami, Secretary, Department of Science and Technology

Sukhman Randhawa and Rahul Nayar, Office of the Adviser to the Prime Minister, Public Administration Infrastructure and Innovations

Meghna Rao, Director, Acumen Fund India

Dr SR Rao, Adviser, Department of Biotechnology

V Ravichandar, Board Member, Bangalore Agenda Task Force

Dr Girish Saraph, Founder and CEO, Vegayan Systems

Mrs Rashmi Sarita, Deputy Director, STI Division and Mr Dipanjan Banjeree, Deputy Senior Assistant Director, STI Division, Federation of Indian Chambers of Commerce and Industry

Professor Venkatesan, Senior Fellow, and colleagues, National Centre for Applied Economic Research

Sunil Shah, Chairman, Gujarat Innovation Society

LK Sharma, journalist and editor

Dr A K Sharma, Director, Ahmedabad Textile Industry Research Association

Dr Devi Shetty, Chairman and Managing Director, Narayana Hrudayalaya, with Dr Vijay Singh C, Chief Operating Officer, Centres and Heart Diagnostics

Mark Sinclair, First Secretary, Head, Science and Innovation Network, and Kinchit Bihani, Foreign and Commonwealth Office, New Delhi

Jayant Sinha, Partner and Managing Director, Omidyar Network

Lina Sonne, Associate Professor, Azim Premji University

Aditya Dev Sood, CEO, Centre for Knowledge Societies

Kushagra Srivastava, Product Marketing Manager, Google

Dr Saurabh Srivastava, Chairman, CA Technologies, Chairman Emeritus, the Indus Entrepreneurs, New Delhi and Member of National Innovation the Council

Chandar Sundaram, Consultant, NSR Centre for Entrepreneurial Learning, Indian Institute of Management Bangalore

Ravi Sundarrajan, Founder and CEO, Just Books and Vinod Kumar, Just Books.

Zakir Thomas, Project Director, Open Source Drug Discovery Project, Council for Scientific and Industrial Research

Dr Louise Tillin, Lecturer in Politics, Kings India Institute, King's College London

Alexander Usikov, Chief Scientific Officer, DeCore

Professor CE Veni Madhavan, Director, Society for Innovation and Development, Indian Institute of Science Bangalore

Sanjay Vijayakumar, Co-Founder and CEO, Mobile Media Entertainment

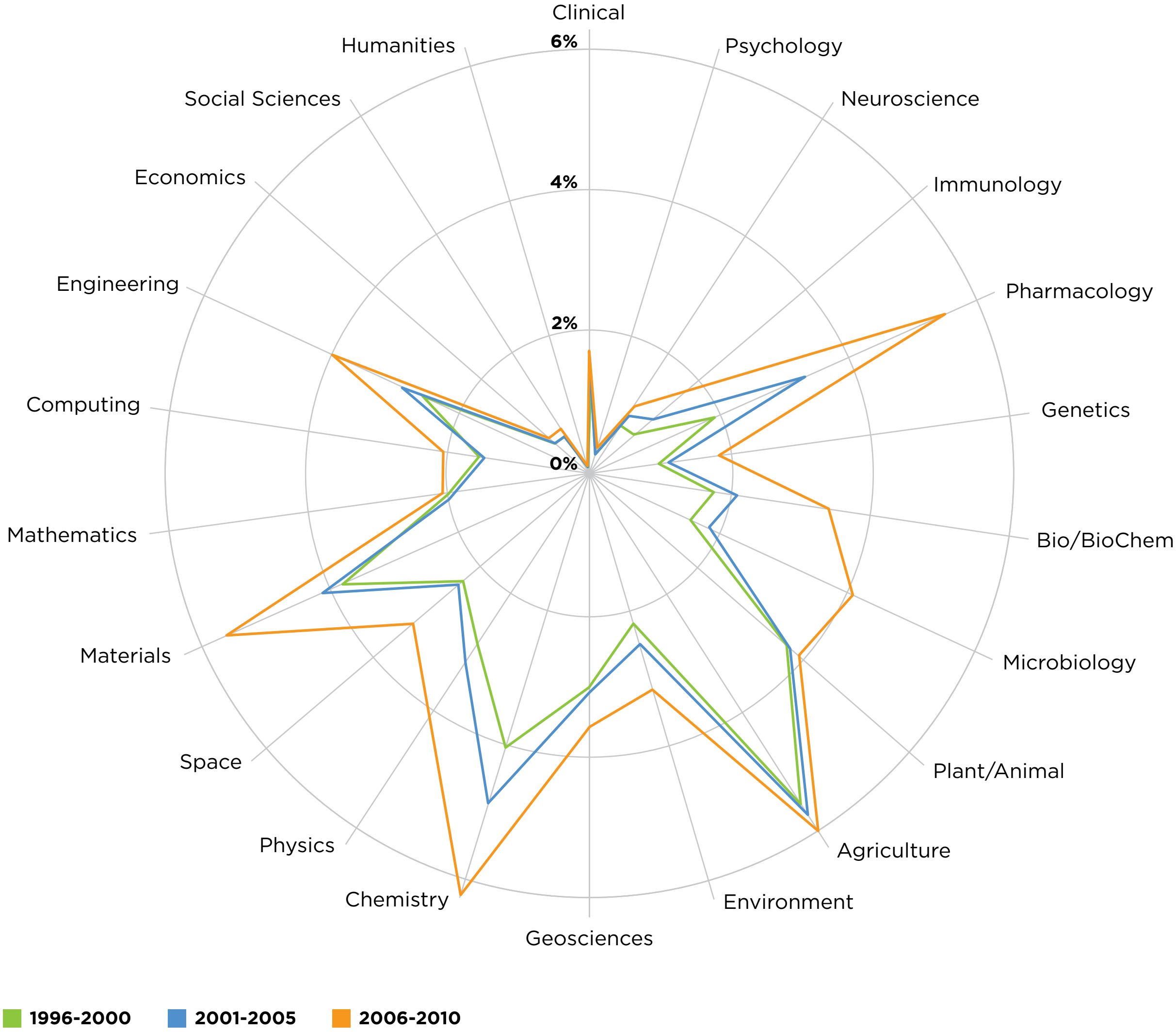
Dr Shai Vyakarnam, Director of the Centre for Entrepreneurial Learning, Judge Business School, Cambridge University

Dr P Vyas, Director, National Institute for Design

Dr Anil Wali, Managing Director, Foundation for Innovation and Technology Transfer, IIT Delhi

Appendix 3: The quantity and quality of Indian research

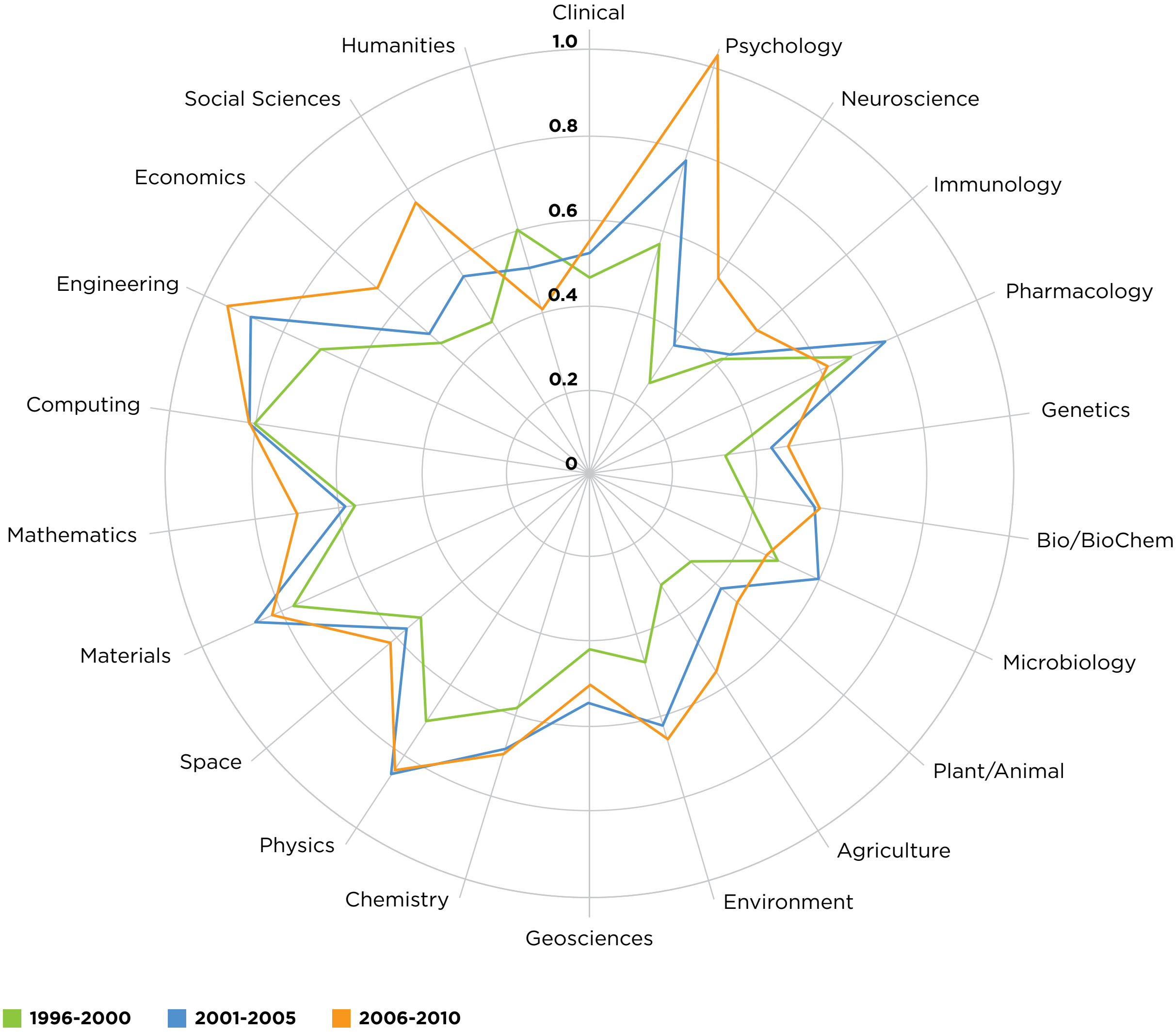
Figure 21: The quantity of research produced as a share of world research in that field.



Data and analysis: Evidence, Thomson Reuters.

Figure 22: The quality of Indian research – by field.

A score of 1.0 would mean that the average Indian paper in that field is global average quality (as measured by citations).



Data and analysis: Evidence, Thomson Reuters.

Appendix 4: The structure of the higher education system

In India the institutional framework is complex. It consists of:

- 40 Central Universities established by an Act of Parliament e.g. JNU
- 243 State Universities established by an Act of a State Legislature e.g. University of Mumbai or Calcutta
- 130 Deemed Universities (institutions which have been accorded the status of a university with authority to award their own degrees through central government notification) e.g. the IISc or TIFR
- 33 Institutes of National Importance (prestigious institutions awarded the status by Parliament) e.g. the IITs, National Institutes of Technology. It is proposed to add the IIMs and IISERs to this list.
- 76 State Private Universities set up under an Act of State Legislature. For example Azim Premji, Bangalore. These are currently in 18 States.
- Private Universities e.g. Sikkim Manipal University
- 33,023 Colleges, some of which are affiliated with a university (both government-aided and unaided). NB: undergraduate teaching does not normally take place in formal universities, instead it happens in these colleges.

Source: (2011) '40 million by 2020: Preparing for a new paradigm in Indian Higher Education.' Ernst & Young - EDGE 2011 report. Data from the MHRD Annual Report 2009-10.

Appendix 5: Government of India schemes to support innovation in firms

1. Research grants

There are five major grant or loan schemes:

1. Finances from the Technology Development Board (TDB)
2. Techno-entrepreneurs Promotion Programme (TePP)
3. The New Millennium India Technology Leadership Initiative (NMTLI)
4. The Home Grown Technologies Programme (HGT)
5. The Programme Aimed at Technological Self Reliance (renamed as the Technology Development and Demonstration programme) (TDDP)

1. TDB: The TDB falls under the DST and primarily provides low-cost loans (up to 50 per cent of costs at 5 per cent interest) to companies to support commercialisation. It also occasionally takes an equity stake (up to 25 per cent) or makes outright grants.
2. TePP: The programme by provides small grants to individual (particularly 'grassroots') innovators. It helps the inventor to identify and network with an appropriate R&D/academic institution for guidance, assists in for filing and securing of intellectual property rights and then linking up with appropriate source of finances for commercialisation of the product.
3. The NMTILI, under CSIR, supports joint work between Indian companies and the government laboratory network to create technology leadership positions in industries/technologies where India has a potential competitive advantage in global markets. The Government funds the entire project (in most cases) as a grant-in-aid for publicly funded R&D/academic partners and as a soft loan (3 per cent interest) to the industry partner and also underwrites the risk of failure.
4. The HGT provides low-cost loans for the adoption of technologies developed by research institutions.
5. The TDDP, under the Department for Scientific and Industrial Research, also provides low-cost loans for the development and scaling of industrial technologies.

Source: Adapted from Krishnan, R. (2011) 'From jugaad to systemic innovation.' (pp108) The Utpreraka Foundation, and Biswas, P.K. and Pohit, S. (2012) 'Private Sector Investment Opportunities in Indian R&D.' New Delhi: NISTADS.

1. Tax incentives

India offers a variety of tax incentives to support R&D. These incentives can broadly be classified as input-based and output based. Offering fiscal incentives to stimulate business R&D has emerged as an increasingly popular policy tool over the past decade. The tax credits provide an indirect means of supporting R&D, in contrast to the direct government funding of business R&D through grants or contracts. In 2011, 26 OECD countries provided tax incentives to support business R&D, with similar incentives also offered by Brazil, China, India, Russia, Singapore and South Africa.

1. Input based:
   - A 200 per cent super deduction for in-house R&D expenditures, including capital expenditures (other than land and buildings). The super deduction is limited to taxpayers in bio-technology or manufacturing and producing products.

- A super deduction of 125 per cent to 200 per cent for payments to entities carrying out R&D in India.

- 100 per cent deduction for R&D expenses that do not otherwise qualify for the above super deductions.

Research expenses, including clinical trials, incurred by pharmaceutical companies also qualify for the 200 per cent super deduction if the company manufactures or produces the drugs in India.

Prior to April 2010, the incentive for conducting R&D was a 150 per cent super deduction (instead of 200 per cent). Mani[354] studied the pre-2010 regime and was unable to draw any firm conclusions about the effectiveness of R&D tax credits in India. The delayed Direct Taxes Code is set to replace the existing income tax laws (the parliamentary paralysis at the time of writing notwithstanding) but is expected to include the current 200 per cent super deduction.

2. Output based:
   Waiver of excise duty for three years on goods produced, based on indigenously-developed technologies and patented in any two of India, the EU, the USA or Japan.

Sources: Adapted from Global Survey of R&D Tax Incentives. Deloitte, 2011.

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84. These are currently being developed in Pune (as above), Kolkata, Mohali, Bhopal, and Thiruvananthapuram/Trivandrum. The NISER is being set in Bhubaneswar.
85. Fourteen RECs were started between 1959 and 1965, with three more added in 1967, 1986 and 1987. In 2003 the Engineering Colleges were converted to NITs. In 2006 three further engineering colleges were converted. While all are up and running, some are on temporary campuses. In 2010 the Government announced the creation of ten new institutes, all of which are functioning from permanent campuses with limited intakes.
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87. Five IISERs and one National IISER.
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90. Author's calculation Data: Evidence, Thomson Reuters.
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92. That is those subjects where India has a higher share of world research output compared to its world share overall, and a higher citation impact compared to its citation impact overall. Evidence, 2011. Data and Analysis: Evidence. Thomson Reuters.
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