Transforming Science and Technology in India

08
CHAPTER

We need a spirit of victory, a spirit that will carry us to our rightful place under the sun, a spirit which can recognize that we, as inheritors of a proud civilization, are entitled to our rightful place on this planet. If that indomitable spirit were to arise, nothing can hold us from achieving our rightful destiny

C. V. Raman

Innovations in science and technology are integral to the long-term growth and dynamism of any nation. The pursuit of science also creates a spirit of enquiry and discourse which are critical to modern, open, democratic societies. Historically, India can point to many contributions to global scientific knowledge and technological achievement. However, India under-spends on research and development (R&D), even relative to its level of development. A doubling of R&D spending is necessary and much of the increase should come from the private sector and universities. To recapture the spirit of innovation that can propel it to a global science and technology leader—from net consumer to net producer of knowledge—India should invest in educating its youth in science and mathematics, reform the way R&D is conducted, engage the private sector and the Indian diaspora, and take a more mission-driven approach in areas such as dark matter, genomics, energy storage, agriculture, and mathematics and cyber physical systems. Vigorous efforts to improve the "ease of doing business" need to be matched by similar ones to boost the "ease of doing science."

WHY SCIENCE

8.1 Science, technology, and innovation have instrumental and intrinsic value for society. They are key drivers of economic performance and social well-being. But they are also important for deeper reasons: a scientific temper, with its spirit of enquiry, the primacy accorded to facts and evidence, the ability to challenge the status quo, the adherence to norms of discourse and the elevation of doubt and openness. The open spirit of inquiry that is fundamental to science can provide a bulwark against the darker forces of dogma, religious obscurantism, and nativism that are threateningly resurfacing around the world.

8.2 As India emerges as one of the world's largest economies, it needs to gradually move from being a net consumer of knowledge to becoming a net producer. Its historical contributions to science have been many, ranging from one of the most important innovations in the history of mathematics – the first use of zero – as revealed in the Bakhshali manuscript (carbon dated to AD 200–400), to important contributions made (amongst others) by Aryabhata, Brahmagupta, Bhaskara, Madhava of Sangamagrama, and to the stellar contributions made by names such as CV Raman, S. N. Bose, Srinivasa Ramanujan in the last century.

8.3 And, independent India has chalked up many accomplishments: from the nuclear energy program, the hybrid seeds program that underpinned the Green Revolution to the space program, including the *Mangalyaan* mission which highlighted India's niche of doing cost-effective, high-technology research. Most recently, India's important participation (involving three major Indian research institutions) in the Laser Interferometer Gravitational-wave Observatory (LIGO) experiment successfully detected the existence of gravitational waves. And India's vaccines and generic-drugs have saved millions of lives the world over.

8.4 However, a country cannot rest on its past laurels. Given the dizzying pace and expansion of scientific research and knowledge on the one hand, and a generally higher importance given to careers in engineering, medicine, management and government jobs amongst India's youth on the other, India needs to rekindle the excitement and purpose that would attract more young people to the scientific enterprise. Doing so would lay the knowledge foundations to address some of India's most pressing development challenges in addition to maintaining a decent, open society. Investing in science is also fundamental to India's security: the human security of its populations; the resilience needed to address the multiple uncertainties stemming from climate change; and the national security challenges stemming from new emerging threats, ranging from cyberwarfare to autonomous military systems such as drones.

INPUTS AND OUTPUTS: SOME EVIDENCE

Research and Development Expenditures

8.5 Investments in Indian science, measured in terms of Gross Expenditure on R&D (GERD), have shown a consistently increasing trend over the years. GERD has tripled in the last decade in nominal terms – from Rs. 24,117 crores in 2004-05 to Rs. 85,326 crores in 2014-15 and an estimated Rs.1,04,864 crores in 2016-17 – and double in real terms (Table 1). However, as a fraction of GDP, public expenditures on research have been stagnant – between 0.6-0.7 percent of GDP – over the past two decades. Public expenditure is dominant, although its share has come down from three-fourths of all expenditures to about three-fifths.

8.6 About three-fifths of the public investment is spread over the key government science funding agencies like Atomic Energy, Space, Earth Sciences, Science and Technology and Biotechnology (Table 2). Given the country's

Table 1. R&D Expenditure (Rs. Crores and per cent of Nominal GDP in parentheses)

Year	Public Investment in R&D	Private Investment in R&D	Total
2004-05	18078 (0.5%)	6039 (0.2%)	24117 (0.7%)
2008-09	32988 (0.5%)	14365 (0.2%)	47353 (0.7%)
2012-13	46886 (0.4%)	27097 (0.2%)	73983 (0.6%)
2016-17*	60869 (0.4%)	43995 (0.3%)	104864 (0.7%)

Source: Dept. of Science & Technology (DST); World Bank.

Note: Public Investments in R&D = Central Government Ministries/Department + Public Sector/joint sector industries+ State Government + Higher Education.

Table 2. Expenditure of Principal Science Government Agencies (Rs. Crores)

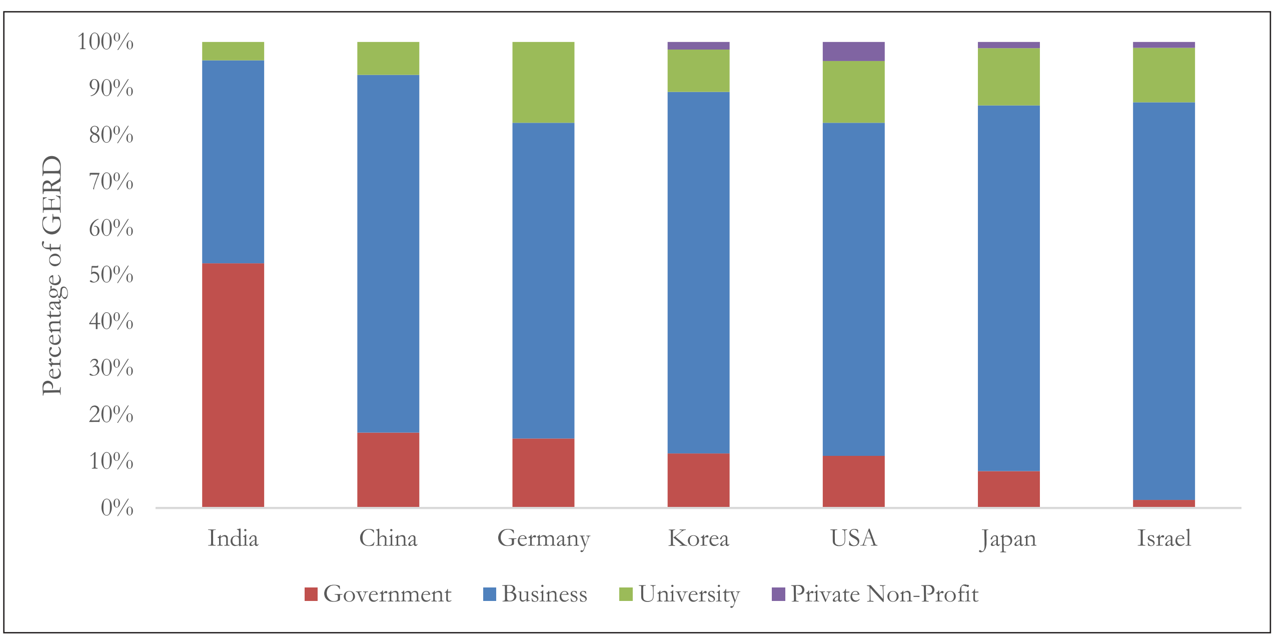
Agency	2010-11	2012-13	2014-15
1. Council of Scientific & Industrial Research (CSIR)	2929	2910	3335
2. Defense Research & Development Org. (DRDO)	10149	9895	13258
3.Department of Atomic Energy (DAE)	2855	3191	4075
4. Department of Biotechnology (DBT)	921	1031	1021
5. Department of Science & Technology (DST)	2133	2378	2701
6. Department of Space (DOS)	4482	4856	5818
7. Indian Council of Agricultural Research (ICAR)	3182	3569	3983
8. Indian Council of Medical Research (ICMR)	679	808	843
Total	**27330**	**28636**	**35034**

Source: DST.

severe health challenges, the low – and virtually stagnant in real terms – budget of the ICMR is striking.

8.7 India's spending on R&D (about 0.6 percent of GDP) is well below that in major nations such as the US (2.8), China (2.1), Israel (4.3) and Korea (4.2). It is also unique in how dominant government is in carrying out R&D. In most countries, the private sector carries out the bulk of research and development even if government must play an import funding role. However, in India, the government is not just the primary source of R&D funding but also its the primary user of these funds (Figure 1). Even more, government expenditure on R&D is undertaken almost entirely by the central government. There is a need for greater State Government spending, especially application oriented R&D aimed at problems specific to their economies and populations.

Figure 1. GERD on R&D by Performer Share in 2015



Source: United Nations Educational, Scientific, and Cultural Organization (UNESCO).

8.8 Private investments in research have severely lagged public investments in India. According to one analysis (Forbes, 2017) there are 26 Indian companies in the list of the top 2,500 global R&D spenders compared to 301 Chinese companies. 19 (of these 26) firms are in just three sectors: pharmaceuticals, automobiles and software. India has no firms in five of the top ten R&D sectors as opposed to China that has a presence in each of them.

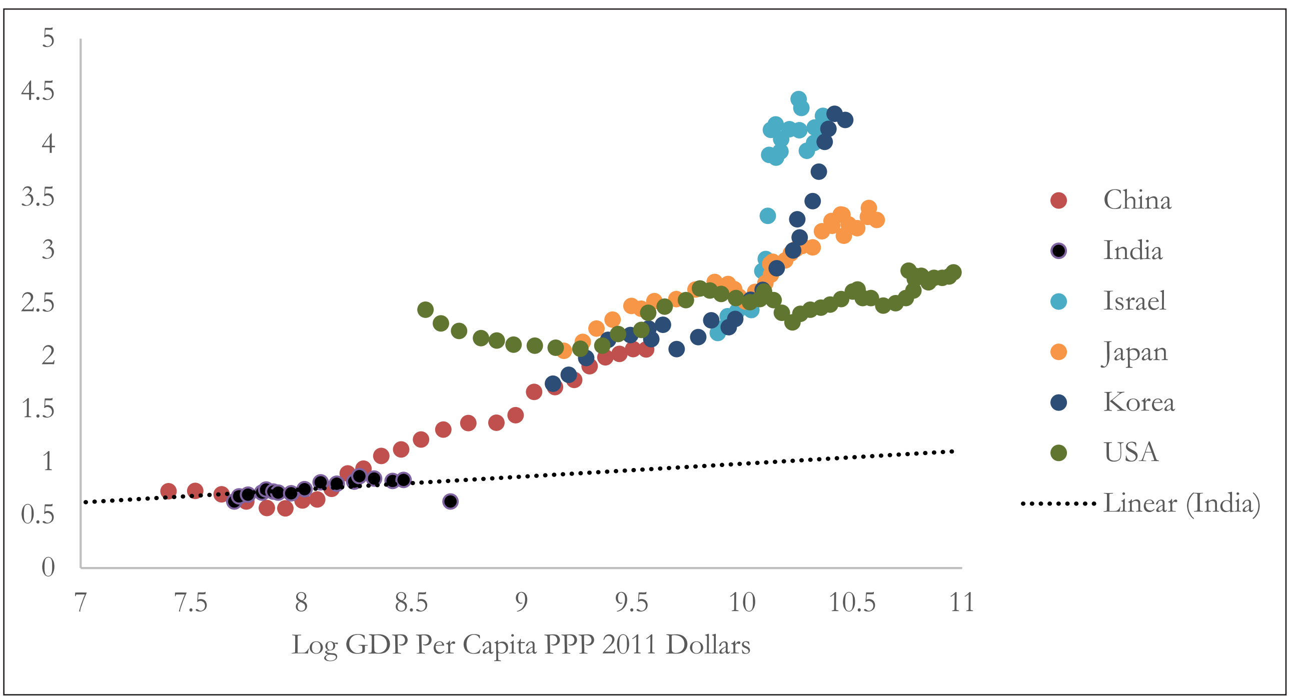
8.9 India is also distinctive in another dimension: its universities play a relatively small role in the research activities of the country. Universities in many countries play a critical role in both creating the talent pool for research as well generating high quality research output. However, publicly funded research in India concentrates in specialized research institutes under different government departments. This leaves universities to largely play a teaching role – a decision that goes back to the 1950s. It is now widely acknowledged that whatever the merits of the decision at the time, this disconnection has severely impaired both teaching as well as the research enterprise in the country.

8.10 One way of assessing if India spends enough is to compare R&D expenditures in "development time": that is, how does India fare today compared with other countries at a similar development level, and whether the Indian trajectory today will allow it to catch up with other countries.

8.11 Figure 2 plots R&D as a share of GDP against per capita GDP for a set of comparable countries. It shows that India was, at one point, spending more on R&D as percentage of GDP than countries like China at the same level of GDP per capita. As a lower middle-income country, it is not surprising that India's spending on R&D lags upper-middle income and high-income countries such as China, Israel, and the U.S. However, it currently underspends even relative to its income level.

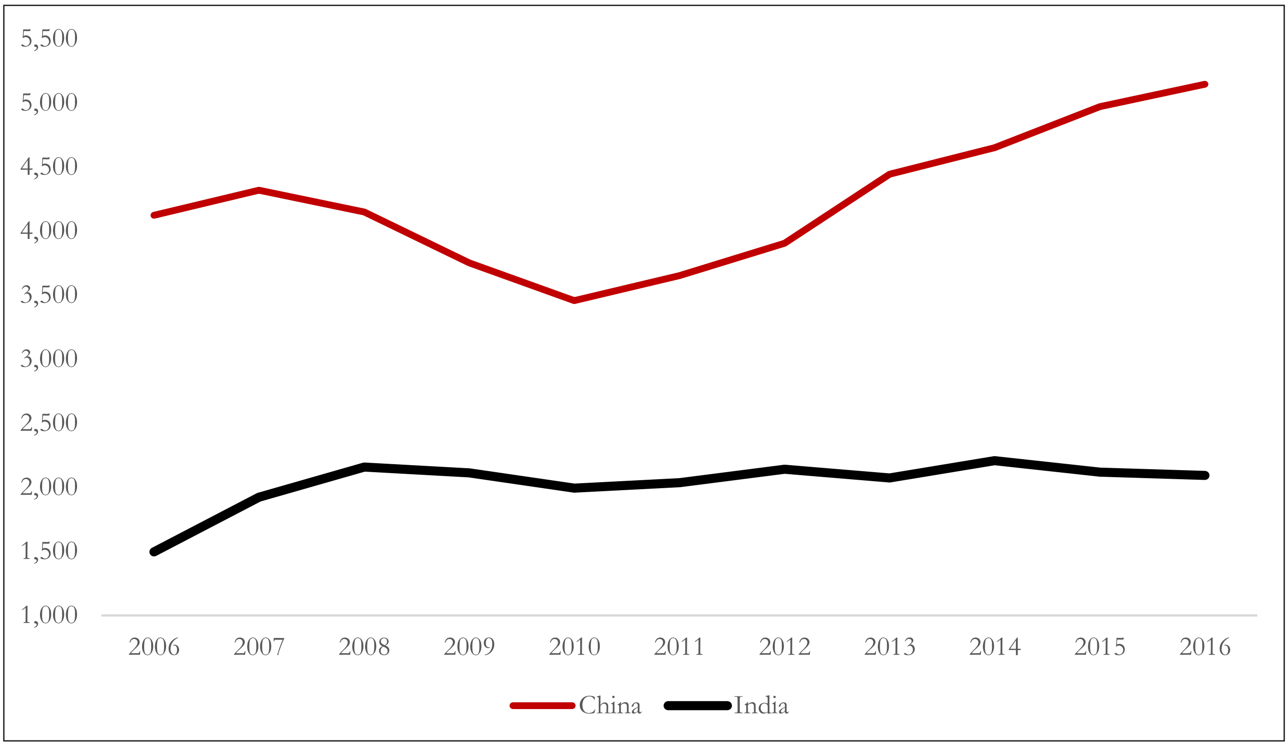
8.12 In addition, most other countries, especially East Asian countries like China, Japan, and Korea, have seen dramatic increases in R&D as a percentage of GDP as they have become richer. India, on the other hand, has only seen a slight increase. In fact, in 2015, there was a sizeable

Figure 2. R&D Expenditure as a Percentage of GDP (Development Time)



Source: UNESCO, World Economic Outlook (WEO), National Science Foundation(NSF).

Figure 3. Indian and Chinese PhDs in STEM in the US



Source: National Science Foundation

decline in R&D spending even as GDP per capita continued to rise. At its current rate, India would just barely reach GERD of 1 percent of GDP by the time it was as rich as the USA.

Ph.Ds. in Science, Technology, Engineering, and Mathematics (STEM)

8.13 The other critical input for R&D is a well-trained workforce among which Ph.D. students play an especially important role. Indian Ph.D. students obtain their degrees either within India or abroad, especially in the US. There are less than half as many Ph.D. students in STEM from India in the US as from China (figure 3). It appears that fewer Indian students have been enrolling in recent years for such degrees, whether due to more attractive options after a master's degree or rising work visa challenges.

Table 3. Investments in R&D, 2015

	U.S.A	ISRAEL	CHINA	INDIA
R&D Spending (PPP Billion Dollars)	479	12.2	371	48.1
Of which				
- Business	341	10.3	286	17
- Government	54	0.2	59	29
- Universities	64	1.5	26	2
- Private NP	20	0.1	--	--
R&D Spending (% of GDP)	2.8	4.3	2	0.8
Researchers per million population	4,231	8,255	1,113	156

Source: UNESCO

8.14 On the other hand, there has been an increase in Ph.D. enrollments in India. In 2015-16 126,451 students were enrolled in Ph.D. programs in India, of which 62 percent were in STEM fields (AISHE 2015-16). This increase is in part the result of concerted efforts by the government, including a substantial increase in the number and quantum of fellowships (such as the Prime Minister Research Fellowships at the IITs). Overall, though, India has far fewer researchers than other countries (Table 3).

OUTPUTS

Publications

8.15 Looking at publications and patents in India can help assess the productivity and quality of Indian research. In 2013, India ranked 6th in the world in scientific publications. Its ranking has been increasing as well. Between 2009-2014, annual publication growth was almost 14 percent. This increased India's share in global publications from 3.1 percent in 2009 to 4.4 percent in 2014 as per the Scopus Database.

8.16 Broadly, the publication trends reveal that India is gradually improving its performance as measured by an important metric – publications. However, there is a downside to the increase in publications. There are many journals that publish non- peer-reviewed manuscripts for a substantial fee. The major catalyst for their explosive growth is "the demand created by increasing emphasis on the number of research publications as an important determinant of the academic performance of a faculty/ scientist being considered for appointment or promotion"(Lakhotia, 2017).

8.17 But in addition to increasing publications, trends in quality (as measured by highly cited articles in table 3) are also slowly improving. The Nature Index (which publishes tables based on counts of high-quality research outputs in the previous calendar year covering the natural sciences) – ranked India at 13 in 2017. But there is still a considerable lag in levels between India and the other two large countries, and the rate of improvement in China between 2001 and 2011 is dramatically better than India's (table 4).

Patents

8.18 If journal publications reflect a country's prowess in science, patents reflect its standing in technology. According to the WIPO, India is the 7th largest Patent Filing Office in the World. In 2015, India registered 45,658 patents in comparison to China (1,101,864), USA (589,410), Japan (318,721), Republic of Korea (213,694), and Germany (91,726). However, India produces fewer patents per capita (Figure 4).

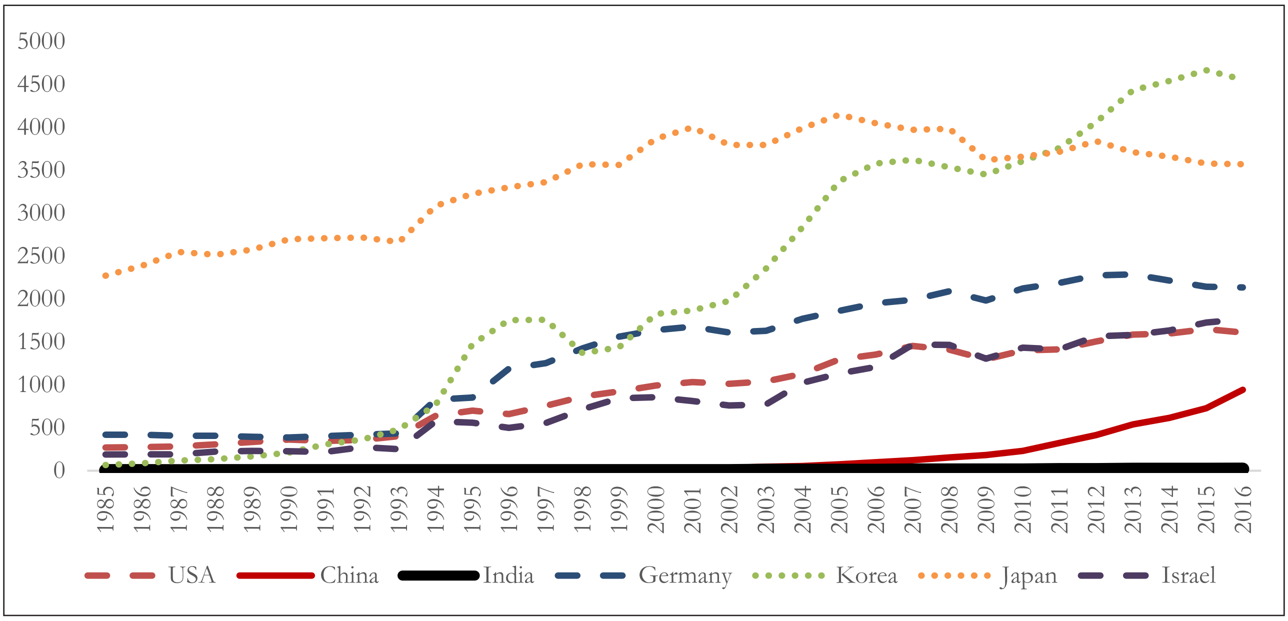
8.19 Even in development time, the story is mixed. On one hand, much of India's low patent output could be due to its lower middle-income status. However, patents have grown much faster with income in countries like China, Korea, and Japan (Figure 5). Unless there is a greater focus on R&D, rising income alone will not allow India to catch up in the near future.

Table 4. Publication Output Trends in China, India, and USA

YEAR	CHINA		INDIA		UNITED STATES	
	No. of publications	No. of highly cited articles	No. of publications	No. of highly cited articles	No. of publications	No. of highly cited articles
1990	6,104		12,346		130,559	
2001	25,730	174	15,522	103	150,817	2894
2011	122,672	980	36,456	191	184,253	3137

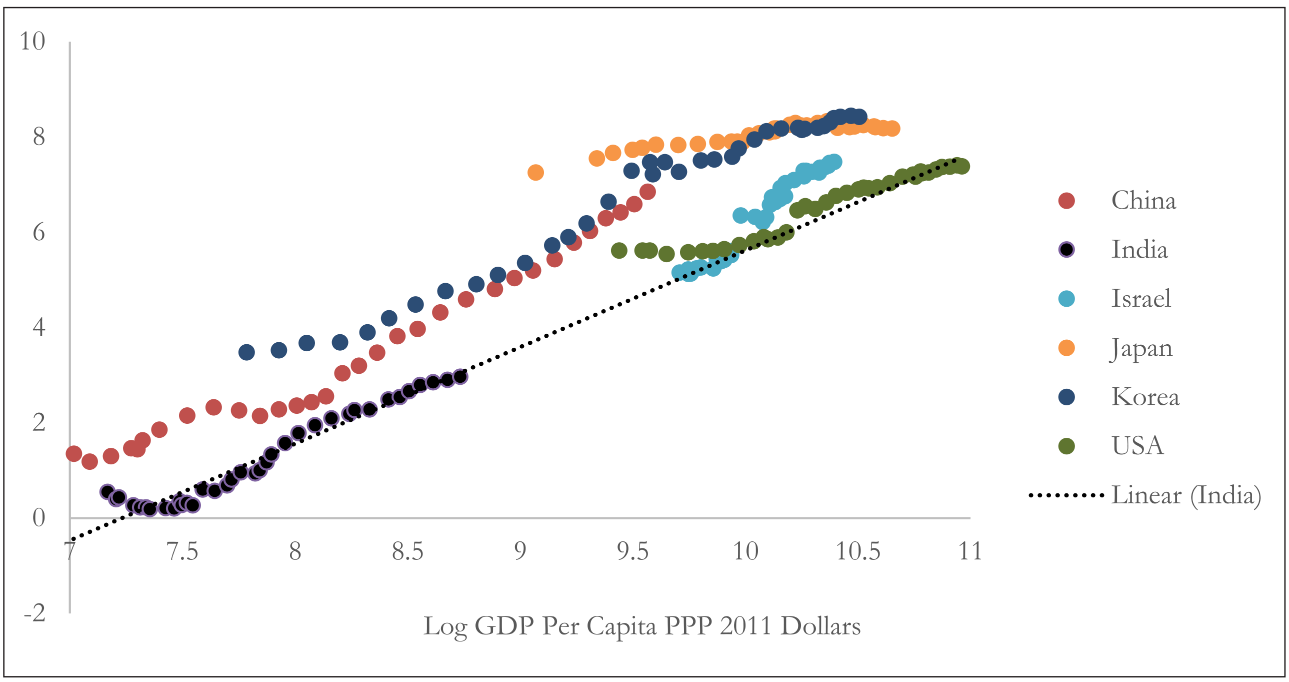
Source: Xiea (2014).

Figure 4. Patents Per 1 Million Population



Source: UNESCO

Figure 5. Log Total Patents Per 1 Million Population (Development Time)

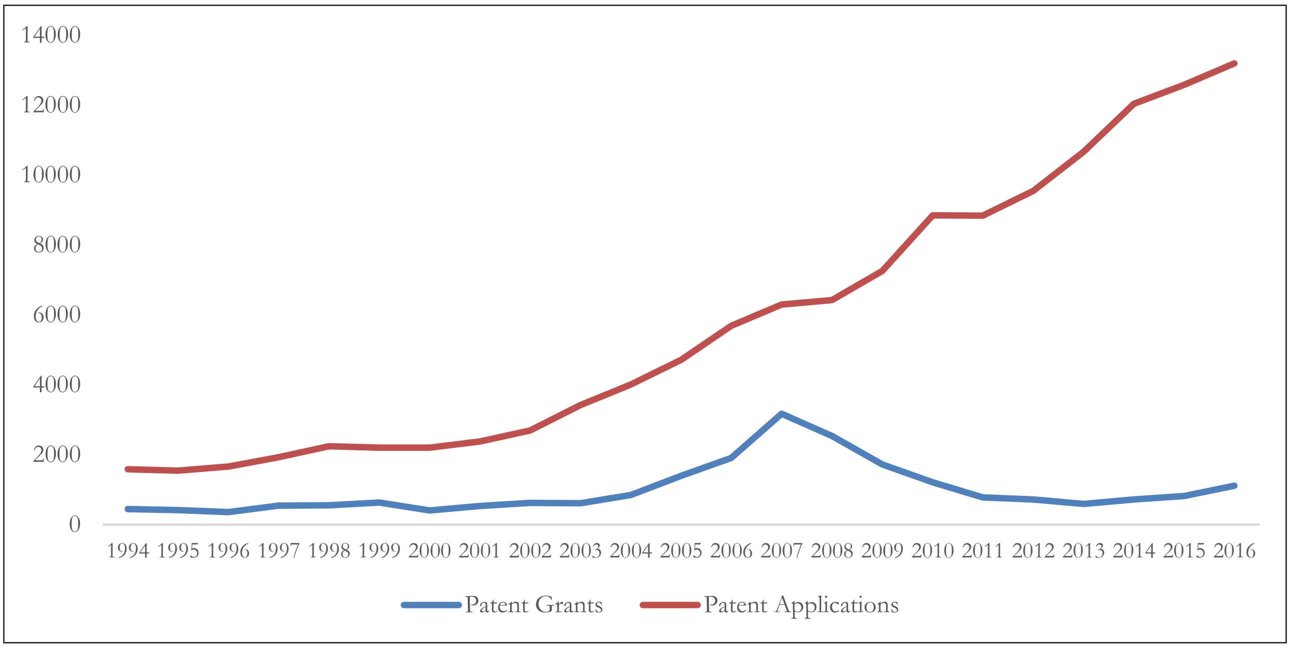


Source: WIPO; WEO

Note: Applications from country residents in both domestic and foreign jurisdictions using equivalent counts as per WIPO

8.20 One major challenge in India has been the domestic patent system. While India's patent applications and grants have grown rapidly in foreign jurisdictions, the same is not true at home. Residential applications have increased substantially since India joined the international patent regime in 2005. However, the number of patents granted fell sharply post 2008 and has remained low (Figure 6). While Indian residents were granted over 5000 patents in foreign offices in 2015, the number for resident filings in India was little over 800.

Figure 6. Resident Patents Applied vs. Granted



Source: WIPO

8.21 The decrease in grants could have been due to a stricter examination process. But evidence suggests that there is a severe backlog and high rate of pendency for domestic patent applications. Reports indicate that due to manpower shortages there is a backlog of almost 2 lakh patents pending examination. In 2016-2017, there were only 132 examiners for all patent applications in India. This has meant that patent examination and granting can take 5 or more years (Chatterjee 2017). Given the rapid rate of technological obsolescence, the inordinate delays in processing patents penalizes innovation and innovators within the country.

8.22 The government's recent hiring of over 450 additional patent examiners and creation of an expedited filing system for Indian residents in 2017 will therefore be a welcome and crucial intervention to help fix the existing patent system (Jain 2017). Chapter 9 discusses the problems that pendency in patent litigation have had on innovation and business. Having addressed issues on the patent filing side, addressing patent litigation issues will also be crucial to ensuring that the patent system effectively rewards innovation.

EXPANDING R&D IN INDIA: THE WAY FORWARD

8.23 While the data discussed above presents a mixed view, many observers point to a more troubling picture. For example, a report submitted by a group of scientists has been quoted as saying: "The stature of Indian science is a shadow of what it used to be … because of decades of misguided interventions. We have lost self-confidence and ambition and the ability to recognize excellence amongst our own. In a false sense of egalitarianism, we often chose the mediocre at every level" (Koshy 2017).

8.24 Clearly, India needs to redouble its efforts to improve science and R&D in the country first and foremost by doubling national expenditures on R&D with most of the increase coming from the private sector and universities. But the metrics also need to go beyond papers and patents to a broader contribution to providing value for society. What might these efforts entail? Some ideas are discussed below:

I. Improve math and cognitive skills at the school level

8.25 No country can create a vibrant super-structure of R&D with weak foundations of primary and secondary education for so many of its young. While India has made considerable strides in improving access to primary and secondary education, as discussed in Chapter 5, learning outcomes have been weak. This weakness denies India access to the intellect and energies of millions of young people.

II. Encourage Investigator-led Research

8.26 India needs to gradually move to have a greater share of an investigator-driven model for funding science research. A step in this direction occurred in 2008, with the establishment of the Science and Engineering Research Board (SERB), a statutory body of DST. This body has sanctioned about three and half thousand new R&D projects to individual scientists. It is a promising start that needs to expand with more resources and creative governance structures.

III. Increase funding for research from private sector as well as from state governments

8.27 The private sector should be incentivized to both undertake more R&D but to also support STEM research through CSR funds. Current tax law already favors CSR investment into R&D, but the types of R&D activities eligible can be expanded. Government can also work with the private sector to create new R&D funding opportunities which are also in line with private sector interests. Efforts like the 50:50 partnership with SERB for industry relevant research under the Ucchatar Avishkar Yojana (UAY) is a good example of what could help make such partnerships fruitful.

8.28 State governments too need to recognize the need to invest in application oriented research aimed at problems specific to their economies and populations. This would both strengthen state universities as well as provide much needed knowledge in areas such as crops, ecology and species specific to a state.

IV. Link national labs to universities and create new knowledge eco-systems

8.29 The separation of research from teaching has been an Achilles heel for Indian science. Universities have students but need additional faculty support, while research institutes have qualified faculty but are starved of bright young students brimming with energy and ideas. A closer relationship between the two in specific geographic and spatial settings would help nurture research in areas reflecting the fields of science in which the national research centers have strengths. Together they can link up with the commercial sectors and help develop industrial clusters in those areas that draw on these research strengths and lay the foundations of innovation driven "smart cities."

8.30 If success in research requires a deep commitment to excellence, commercial success requires speed and nimbleness. Government rules such as those requiring L1 for procurement are simply not geared to providing the flexibility that is needed at the frontiers of research where speed, product quality and reliability make all the difference between success and failure.

V. Take a mission driven approach to R&D

8.31 India has the potential to be a global leader outright in a number of areas if it is willing to invest. However, this will require a deliberate focus in a few key areas. The potential missions given below were chosen for their strategic importance and potential for societal impact. This is an illustrative list which should be periodically revisited by the scientific community, government and other stakeholders.

A. National Mission on Dark Matter

8.32 India needs at least one mission that is directed towards the basic sciences. India is one of the leading countries in high energy physics and relevant mathematics. The payoffs from this research will have implications on space missions of the future, quantum computing, newer solutions to energy problems etc. This mission can build on the strong foundation of astronomy and astrophysics research institutes in the country.[1] Furthermore, research in this area has some of the strongest international collaborative possibilities including those stemming from India's ongoing participation in the LIGO, Neutrino, CMS/LHC projects.

B. National Mission on Genomics

8.33 Genomic research lies at the heart of the future of the life sciences. Currently several countries have launched ambitious national genomic research projects e.g. UK Biobank Study; Finnish Birth Cohort Study; Partners HealthCare Bioban; China Kadoori Biobank. These studies are collecting detailed phenotype information, as well as blood and tissue samples, to study the determinants and life-course of biological pathways and disease. India already has a strong foundation of life science research institutes[2] which together can make significant contributions in this area.

C. National Mission on Energy Storage Systems

8.34 Renewable energy is the future and India has made a major commitment to investment in renewable energy. Energy storage technologies (e.g., batteries) help in energy management and power quality in electric power systems. India has lagged in manufacturing renewal energy generation systems. Substantial investments in energy storage systems will ensure that India can be a leader in manufacturing energy storage systems. For India, this will be especially helpful to provide round-the-clock electricity to villages using off-grid renewable energy systems.

D. National Mission on Mathematics

8.35 Mathematics has two special advantages for India: i) it is not capital intensive; ii) standards of excellence are universal. A National Mission of Mathematics will improve mathematics teaching at all levels of higher education, seek to establish five institutes of mathematical sciences within existing institutions, conduct annual district, state and national math Olympiad competitions with sizeable scholarships for all winners, with the overall goal of rapidly increasing India's human capital and research profile in mathematics within a decade.

E. National Mission on Cyber Physical Systems

8.36 The term Cyber Physical System (CPS) refers to machine based communication, analysis, inference, decision, action, and control in the context of a natural world ("Physical" aspect). This is hugely multidisciplinary area including deep mathematics used in Artificial Intelligence, Machine Learning, Big data Analytics, Block Chains, Expert Systems, Contextual Learning going to integration of all of these with intelligent materials and machines, control systems, sensors and actuators, robotics and smart manufacturing. Together these are the building blocks of future industry that will throw up both new challenges and opportunities.

F. National Mission on Agriculture

8.37 Improving Indian agricultural productivity, which still lags other countries such as China, as well as creating resilience to the looming challenges in terms of rising temperatures,

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[1] These include the Indian Institute of Astrophysics (IIA), Bangalore; Inter-University Centre for Astronomy and Astrophysics (IUCAA), Pune; Aryabhatta Research Institute of Observational Sciences (ARIES), Nainital; Tata Institute of Fundamental Research (TIFR), Mumbai; National Centre for Radio Astrophysics (NCRA-TIFR), Pune;Indian Institute of Science (IISc), Bangalore; Raman Research Institute (RRI), Bangalore; Physical Research Laboratory (PRL), Ahmedabad; Harish-Chandra Research Institute (HRI), Allahabad

[2] TIFR, IISc, IISERs, Center for Cellular and Molecular Biology, National Institute of Immunology, Institute of Genomics and Integrative Biology, National Center for Cell Science, National Center for Biological Sciences (NCBS) in Bangalore

variable precipitation, water scarcity, increase in pests and crop diseases requires a major thrust in agricultural science and technology. A national mission could help overcome the weaknesses in existing institutions of agricultural research and technology.

VI. Leverage scientific diaspora

8.38 There are today more than 100,000 people with PhDs, who were born in India but are now living and working outside India (more than 91,000 in the U.S. alone). From 2003 to 2013, while the number of scientists and engineers residing in the US rose from 21.6 million to 29 million, the number of immigrant scientists and engineers went from 3.4 million to 5.2 million. Of this, the number from India increased from just above half million in 2003 to 950,000 in 2013.

8.39 However, with the strength of India's economy and growing anti-immigrant atmosphere in some Western countries, India has an opportunity to attract back more scientists. There has been an increase in the number of Indian scientists returning to work in India during the last five years, but the numbers are still modest (from 243 during 2007-12 to 649 in 2012-17) (Press Trust of India 2017).

8.40 There are a number of government programs such as the Ramanujan Fellowship Scheme, the Innovation in Science Pursuit for Inspired Research (INSPIRE) Faculty Scheme and the Ramalingaswami Re-entry Fellowship, that provide avenues to qualified Indian researchers residing in foreign countries, to work in Indian institutes/universities, and the Visiting Advanced Joint Research Faculty Scheme (VAJRA). These schemes could be enhanced to take advantage of opportunities to recruit in a way to build whole research groups; the inducements should be such as to allow them to do good research (laboratory resources, ability to hire post-docs, housing etc.) rather than financial, to ensure that home grown talent has a level playing field.

VII. Improve the culture of research

8.41 Indian science and research institutes need to inculcate less hierarchical governance systems, that are less beholden to science administrators and encourage risk-taking and curiosity in the pursuit of excellence. While the age of peak productivity of scientists has shifted upwards over the 20th century, it is still less than fifty. Great achievements in the sciences decline after middle age, and youth, conceptual achievement, and scientific revolutions are linked (Jones et. al. 2014). Hence it is imperative that there be greater representation of younger scientists in decision-making bodies in their areas of expertise.

VIII. Greater public engagement of the science and research establishment

8.42 If science is to garner greater support from society, it will require scientists to engage more vigorously with society. Much of science is – and should be – a public good, and hence that will always require substantial public funding. But the need for publicly funded science means that national laboratories and other publicly funded R&D institutions need to make much stronger efforts to engage with the public and not make their research centers quintessential ivory towers. This will require much greater efforts at science communication whether through the media or through regular tours and lectures for school and college students as well the general public. Scientists need to create broad public support for their work and not treat it as an entitlement, given the many claims on the public purse. And if they do that, they will find a receptive and supportive public.

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