22 · India

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INTRODUCTION

Easier to do business

India remains one of the fastest-growing economies in the world (Figure 22.1). The country has recorded a respectable average growth rate of 7–8% since 2014 but the dip in savings and investment rates since 2016 may impinge on future performance (Figure 22.1).

Income inequality is high and expected to rise. The *World Inequality Report 2018* estimated that 10% of the Indian population earned 55% of the national income in 2016, compared to 37% of the population in Europe. Since 2014, the government has introduced flagship social programmes to increase public access to sanitation (*Swachh Bharat* programme), the electricity grid (*Saubhagya* programme) and financial services such as bank accounts (*Pradhan Mantri Jan-Dhan Yojana* programme) [Figure 22.1].

The elections of 2019 returned the National Democratic Alliance government led by Narendra Modi to power with a stable majority, thus improving the chances of public policies following the same trajectory in the years to come.

Since 2015, India's performance in international composite indices has varied: it climbed 14 places in a single year to rank 63rd in the World Bank's *Ease of Doing Business 2020* report and five places to 52nd position in the *Global Innovation Index 2019* but dropped ten rungs in the *Global Competitiveness Index*. There were about 9 000 start-ups in 2019. India now has the world's largest pipeline of potential 'unicorns', privately held start-ups valued at over US$ 1 billion. The number of these 'unicorns in the making' surged from 15 to 52 between 2018 and 2019 (NASSCOM, 2019).

Improving the ease of doing business was one of the objectives of the Make in India programme launched by the government in 2014, so it has been a success from this perspective. Another objective was for the manufacturing sector to contribute 25% of GDP by 2022. However, this sector is not growing fast enough (7.8% per year) to meet this target. Make in India is yet to make a tangible difference to manufacturing, for reasons that we shall explore later.

Make in India is one of a series of government strategies designed to nurture the adoption of emerging technologies across the wider economy. In May 2020, the government announced a series of measures to make India more technologically self-reliant in eight strategic sectors, as part of a comprehensive stimulus package to cope with the concurrent economic slowdown and Covid-19 epidemic. Known as *Atmanirbhar Bharat* (Make India Self-reliant), the stimulus package allows for greater private-sector participation in sectors hitherto largely reserved for state-owned bodies, namely: coal, minerals, defence manufacturing, airports and airspace management, power distribution, social infrastructure, space and nuclear energy.

The government has responded to the Covid-19 crisis with a stringent lockdown. Some states have shown that it is possible to contain a pandemic within a short period of time, provided that the government gives paramount importance to the technical advice of public health authorities and can win the trust of the general population, so that people comply fully with the measures imposed.

The hospital system has been straining to accommodate the massive influx of Covid-19 patients. In 2019, the Indian central and state governments spent INR 2.6 trillion, or 1.3% of GDP, on health. Public expenditure on health covers salaries, gross budgetary support to hospitals and other institutions, as well as budgetary transfers to states under centrally sponsored schemes like *Ayushman Bharat Yojana*. It is estimated that the private sector contributes a further 2.3% of GDP to health care (MHFW, 2019).

Manufacturing a response to Covid-19

Since the Covid-19 outbreak, India has been mobilizing its considerable capabilities to produce low-cost solutions for public health systems around the world in three areas: vaccine research and manufacturing; the manufacture of generic versions of 'game-changer' drugs; and frugal engineering of medical devices that are currently in short supply.

Six Indian firms are actively developing a vaccine for Covid-19 (Table 22.1). Among these, the Serum Institute of India has earned a reputation for being the cheapest vaccine manufacturer in the world; most of the 20 or so vaccines that it manufactures are exported to 165 countries at an average price of US$ 0.50 per dose. In June 2020, it reached a licensing agreement with pharmaceutical multinational AstraZeneca to supply one billion doses of what became known as the Oxford–AstraZeneca Covid-19 vaccine (also known as Covishield).

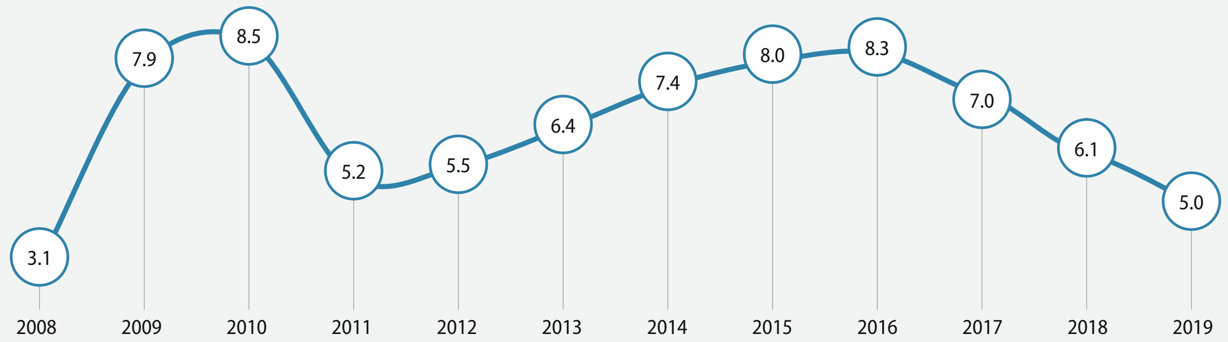
Indian pharmaceutical manufacturers are hoping that the patent-owner of remdesivir, the US-based company Gilead Sciences, will grant licensing provisions for the drug, as it did with the hepatitis C drug Sovaldi in 2014 (Chandana, 2020). According to Gilead, trials of remdesivir by the National Institute of Allergy and Infectious Diseases in the USA indicate that it may speed up recovery in Covid-19 patients (O'Day, 2020). The drug is under patent protection until 2035, with external formulation permitted strictly for research purposes.

India's manufacturing sector has been developing a number of frugal technologies. In early 2020, at least one domestic manufacturer, AgVa Healthcare was able to produce invasive ventilators which will go on sale at 20% of the standard international price.

The start-up Nocca Robotics, which is incubated by the Indian Institute of Technology Kanpur, began commercializing a low-cost ventilator in 2020 which, according to the developers, would cost about 6% of the international price.

Figure 22.1: **Socio-economic trends in India**

Rate of economic growth in India, 2008–2019 (%)



Selected socio-economic indicators for India, 2012–2018

	2012	2013	2014	2015	2016	2017	2018
Savings rate (% of GDP)	35.3	33.9	33.5	32.5	31.7	31.2	30.9
Investment rate (% of GDP)	36.7	35.6	32.6	32.6	30.6	29.1	29.7
Foreign direct investment, net inflows (% of GDP)	1.3	1.5	1.7	2.1	1.9	1.5	1.5
Foreign direct investment, net outflows (% of GDP)	0.5	0.1	0.6	0.4	0.2	0.4	0.4
Share of global exports of computer software services (%)	51	52	52	53	54	55	55
Inflation, consumer prices (%)	9.3	10.9	6.4	5.9	4.9	2.5	4.9
Growth rate of digital payments (%)	–	–	10.7	9.07	24.4	12.0	13.9
Growth rate for volume of cashless payments (%)	–	–	–	29.1	29.3	25.3	40.1
Growth rate for value of cashless payments (%)	–	–	–	9.1	24.4	12.0	14.2
Population growth (annual %)	1.3	1.2	1.2	1.2	1.1	1.1	1.0
People using at least basic sanitation services (% of population)	46.6	49.2	51.8	54.3	56.9	59.5	–
Access to electricity (% of population)	79.9	80.9	83.6	88.0	89.6	92.6	–
Access to bank accounts and other financial services (% of population)	–	–	53.0	–	–	80.0	–
Unemployment rate (% of total labour force)	5.7	5.7	5.6	5.6	5.5	5.4	5.3
Employment to population ratio (15+ years), total (%)	49.2	48.8	48.4	48.0	47.6	47.2	46.8

Share of Indian population using the Internet

34.5%
in 2017

26.0%
in 2015

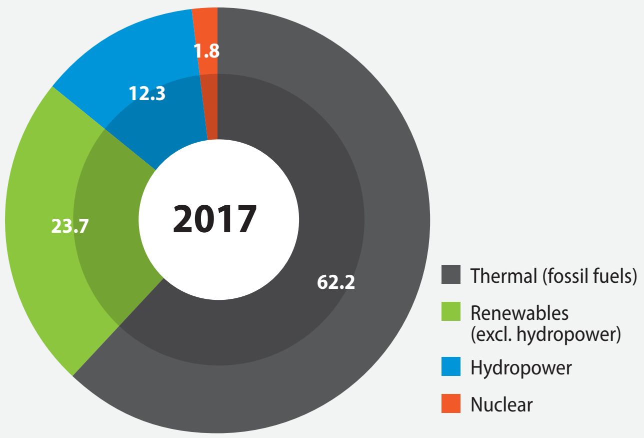
Share of Indian population with mobile cellular subscription

86.9%
in 2018

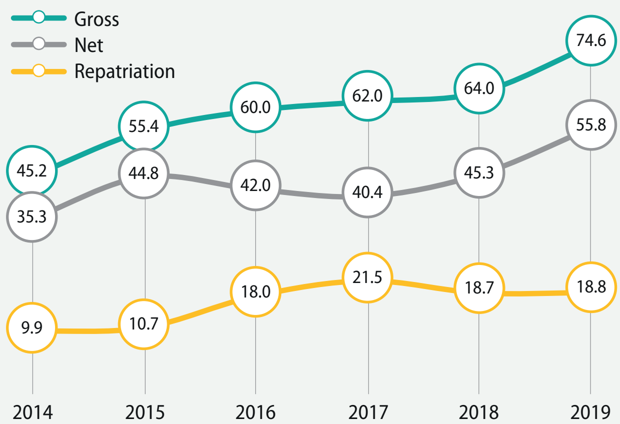
76.4%
in 2015

Electricity supplied 13% of India's final energy consumption in 2020.

India's installed capacity for electricity generation by source, 2017 (%)



Trends in gross and net FDI inflows to India, 2014–2019
In US$ billions



Note: Renewable installed capacity, as of July 2020, includes small hydro projects, biomass gasifier, biomass power, urban and industrial waste power, solar and wind energy. Coal (part of thermal) accounts for 54% of electricity generation.

Source: World Bank's World Development Indicators, October 2020, and Ministry of Statistics and Programme Implementation, Government of India; for financial inclusion: Ravi (2019); for unemployment rate: modelled estimate by International Labour Organisation; for FDI and growth rate for digital payments: computed from payment systems indicators, Reserve Bank of India; for energy: Ministry of Power, Government of India (2020) *Power Sector at a Glance*

Table 22.1: **Indian pharmaceutical companies active in Covid-19 vaccine research, 2020**

Company	Number of vaccine types	Details
Zydus Cadila	2	initiated an accelerated research programme with multiple teams in India and Europe to develop a vaccine for Covid-19
The Serum Institute of India	1	partnered with American biotechnology firm Cadagenix to develop a vaccine, expected to be ready by early 2022, and with Oxford Vaccine Group to manufacture their vaccines currently under development; aims to manufacture 4–5 million doses
Bharat Biotech	1	developing and testing a vaccine called CoroFlu alongside US-based FluGen and virologists at the University of Wisconsin-Madison
Indian Immunological	1	collaborating with Australia's Griffith University to develop a vaccine candidate using the latest codon de-optimization technology
Mynvax	1	start-up nurtured by the Indian Institute of Science, Bangalore

Source: compiled from Economic Times (2020) Seven Indian pharmaceutical companies race to develop vaccine for deadly coronavirus, 19 July; Biswas (2020) and Corum J., Grady D., Wee S.-L. and C. Zimmer (2020) Coronavirus vaccine tracker. *The New York Times*

Nocca Robotics is expected to manufacture about 30 000 ventilators by May 2020, further to an agreement with Ansys, a US-based engineering simulation company.

The Chitra GeneLamp-N test kit can confirm Covid-19 in about two hours at less than 1 000 rupees (INR, *ca* US$ 13) per test; it has been developed by a public laboratory, the Sree Chitra Tirunal Institute of Medical Sciences and Technology.

India's technological response to Covid-19 could be impeded, however, should it fail either to identify new ways of financing relevant research projects or to effect changes to international rules with respect to intellectual property rights, in general, and patents, in particular, to facilitate domestic development of technologies. Such changes could entail exempting vaccines and therapeutic drugs for Covid-19 from a product patent regime and relaxing the conditions under which a compulsory license may be issued for the manufacture of generic versions of patented Covid-19 drugs.[1]

HARNESSING EMERGING TECHNOLOGIES TO MODERNIZE INDIA

Digital India

A lot has changed since the previous edition of the *UNESCO Science Report* (Mani, 2015). Through the establishment of the National Institution for Transforming India (NITI Aayog)[2] in 2015, which serves as a think tank, the government has been attempting to modernize the country; one thrust has been to promote innovation and diffuse modern digital technologies. Another focus has been the diffusion of renewable energy technologies and electric vehicles, as we shall see later.

In July 2015, the government launched Digital India, in order to use information technology to transform the entire ecosystem of public services. Digital India has linkages to other new tech-based government schemes analysed in these pages, such as Make in India, Start-up India and the Smart Cities Mission.

India has one of the fastest-growing telecommunications networks in the world. The government has been making a conscious attempt to extend Internet access to rural areas. One in three (34.5%) Indians had access in 2017, up from just 15% four years earlier. The total number of Internet subscribers stood at 644.08 million as of 31 October 2019, 87% of whom were broadband subscribers , according to the Indian Telecom Regulatory Authority's *Yearly Performance Indicators* (2019).

In 2018, out of the 1.176 billion mobile phone subscribers in India, half (*ca* 578 million) were wireless data subscribers. This phenomenal growth in data usage has been fuelled by significant reductions in the cost of data. This, in turn, has fuelled the digital economy, boosting e-commerce and the use of app-based food-ordering and taxi-hailing services, as well as hospitality-booking services.

The digital economy is at the heart of the Fourth Industrial Revolution, also known as Industry 4.0 (Table 22.2). The digital economy is fuelled by data and closely associated with seven state-of-the-art technologies: blockchain, data analytics, artificial intelligence (AI), three-dimensional (3D) printing, the Internet of Things, automation and cloud computing (UNCTAD, 2019).

In February 2019, the prime minister inaugurated the first supercomputer to be designed through the National Supercomputing Mission. Known as PARAM Shivay, this supercomputer has been built at the Indian Institute of Technology Varanasi and will form part of a planned network of over 70 high-performance computing facilities.[3]

A drive to improve public services

The uptake of Industry 4.0 technologies has mostly occurred in the government sector. Blockchain technology is now used extensively within the central government and, in one form or another, by nearly half of state governments. It is primarily used to prepare land registry data, provide farm insurance and issue digital certificates. London-based blockchain consulting firm Dappros reports that India had 19 627 blockchain developers in 2018, second only to the USA (with 44 979) [Filatov, 2018].

In an attempt to improve public services, the government launched the direct benefit transfer scheme in 2016 to transfer subsidies directly to people through their bank accounts. By 2020, this scheme had been applied to about 439 schemes across 55 ministries. The estimated savings come to a phenomenal INR 141 677 crores (*ca* US$ 19.7 billion). In the case of the Mahatma Gandhi National Rural Employment Guarantee Scheme, the share of payments made within 15 days doubled from 43% to 90% over the two years to 2018.

Swamy and Rajendran (2019) analysed whether blockchain technology improved the efficiency of the Mahatma Gandhi National Rural Employment Guarantee Scheme. The authors found that, while it took less time for blocks to generate electronic fund-transfer orders and send them digitally to the central government, the time taken by the central government to process these transfer orders and wages for workers remained the same.

In 2014, only half of Indians had a bank account (Figure 22.1). The direct benefit transfer scheme could be implemented on a much larger scale, were this proportion to be higher. As a result of the government's *Pradhan Mantri Jan-Dhan Yojana* programme, eight out of ten Indians had a bank account by 2018.

A bold economic experiment

In 2016, the government embarked on one of the boldest economic experiments of modern times. India is a cash economy, with the vast majority of business transactions involving banknotes changing hands. To reduce the size of the informal economy, the government took the radical step of demonetizing two of the largest circulating bank notes, those for 1 000 (*ca* US$ 13) and 500 rupees, which accounted for about 86% of the notes in circulation at the time.

The scheme has been controversial abroad but there has been surprisingly little opposition in India itself. A survey of 200 families in 28 Mumbai slums showed the counterintuitive result that, despite experiencing a fall in their monthly incomes by as much as 10%, the majority welcomed the demonetization policy (Krishnan *et al*., 2017).

Although the initial objective was to limit the informal economy, the government has since shifted the aim of its demonetization policy to ushering in a fully cashless economy, which *inter alia* may promote better tax compliance and, as a result, higher government tax collection. It should also facilitate the development of a digital marketplace, now that more potential customers have access to credit cards and bank accounts.

To promote the growth of a cashless economy, a number of incentives have been put in place, including a Goods and Services Tax (GST). Nevertheless, there are signs that people have been reverting to using cash. The value of transactions has been much lower than that observed during the period of demonetization (Figure 22.1). Currency in circulation as a percentage of GDP reached 11% in 2018, just 1% less than prior to demonetization.

The Union Ministry of Finance has adopted the following two mandatory measures to foster cashless transactions, effective from 2019 onwards:

Table 22.2: **Indian strategies and policies for Industry 4.0 technologies**

Industry 4.0 technology	Government policies and actions
Blockchain	• The Reserve Bank of India set up a unit in 2018 to research/supervise emerging technologies for blockchain applications in a decentralized and cashless banking system.
	• NITI Aayog is exploring opportunities in the drug and fertilizer industries.
	• State governments have been supportive of blockchain technology, particularly those of Karnataka, Andhra Pradesh, Maharashtra and Kerala. The Telangana state government announced that blockchain would be used to digitize land records and upgrade other data.
Data analytics	• Big data analytics for e-governance is the subject of several funded state and national programmes.
	• Only Telengana state has a formal *Data Analytics Policy* (2016).
Artificial intelligence (AI)	• NITI Aayog published a *National Strategy for Artificial Intelligence* (2018) to leverage AI technologies to improve health care, education and agricultural yields and to enable smart cities infrastructure, smart mobility and smart transportation.
3D printing	• Low adoption, no specific policy.
Internet of Things (IoT)	There is a draft national policy on the Internet of Things with the following objectives:
	• create an IoT industry in India worth US$ 15 billion by 2020, increasing the number of connected devices from about 200 million units to over 2.7 billion by 2020.* India would have a 5–6% share of the global IoT industry; and
	• develop IoT products specific to Indian needs in agriculture, health, natural disaster management, transportation, security, supply chain management, smart cities, automated metering and monitoring of water and other utilities, waste management, oil and gas industries, etc.
Automation	• The Council for Robotics and Automation, a not-for-profit organization, is the apex body setting standards in robotics and automation and in education. It has begun providing support systems to institutions, such as quality assurance, technical backstopping, information systems and train-the-trainer academies.
	• Multipurpose industrial robots have been diffused primarily in the automotive sector.
Cloud computing	• The Department of Electronics and Information Technology published the Government of India's GI Cloud (Meghraj) Strategic Direction Paper in 2013.
	• Meghraj, the National Cloud of India, was set up by the National Informatics Centre (see: https://cloud.gov.in/). These cloud-based services are restricted to government departments.
	• The Telecom Regulatory Authority of India provided recommendations on cloud services, adopted by the government in 2018, and initiated a consultation in 2019 on a framework for registration of an industry body for cloud service providers.

*According to Deloitte & NASSCOM (2017) *The Internet of Things: Revolution in the Making*, the market value of India's IoT solutions industry would reach *ca* US$ 9 billion by 2020.
Source: compiled by author; see Telecom Regulatory Authority of India: https://trai.gov.in/

- account holders pay a 2% tax, deducted at source, on cash withdrawals exceeding INR 1 crore (*ca* US$ 139 000) in a year from a bank or post office account; and
- business establishments with an annual turnover of more than INR 50 crore (*ca* US$ 7 million) are obliged to offer customers low-cost digital modes of payment. Customers and merchants are not charged the Merchant Discount Rate.

The demonetization policy appears to have augmented the filing of income tax returns. According to data from the Income Tax Department, these surged by 20.5% in 2017 and by another 23.1% in 2019. The availability of a wide variety of cashless and contactless payments has proved a boon during the Covid-19 crisis when physical distancing has had to be observed for financial transactions, making online payments an attractive option.

Facilitator of Industry 4.0

In addition to spearheading adoption of Industry 4.0 technologies in the public sector, the government is facilitating the diffusion of the seven state-of-the art technologies listed earlier through three key measures:

- the *National Manufacturing Policy 2011*, which focuses on boosting the share of the manufacturing sector in GDP to 25% by 2022;
- the Centre of Excellence on Information Technology for Industry 4.0, established in 2017 to enable micro-, small and medium-sized enterprises to embrace Industry 4.0; and
- the National Mission on Interdisciplinary Cyber-Physical Systems, launched in 2018 to create a strong foundation and a seamless ecosystem for cyberphysical technologies by co-ordinating and integrating nationwide efforts in knowledge generation, human resource development, research, technology and product development, innovation and commercialization.

Moreover, NITI Aayog published a *National Strategy on Artificial Intelligence* in 2018 to leverage improvements in health care, education and agricultural yields. The strategy also sets out to foster smart cities, smart mobility and smart transportation. NITI Aayog is currently also exploring opportunities for deploying blockchain technology in the drug and fertilizer industries.

Despite the government's initial efforts, Industry 4.0 technologies and processes, which form part of the Fourth Industrial Revolution, are yet to be fully embraced in India for four main reasons:

- India's organized manufacturing sector is very small: it contributed just 18% of India's gross value added across all economic sectors at basic prices in 2019, according to the Reserve Bank of India's 2019 *Annual Report*.
- There are shortages of investment, infrastructure, know-how and cybersecurity norms.
- The cost of digital technologies is high, even though data have become cheaper to purchase.
- There is a persistent skills and talent gap.

Smart Cities Mission

In 2015, the government selected about 100 cities across the country with a cumulative population of 99.63 million to become the country's first smart cities.

There is no universally accepted definition of a smart city. India considers such a city to offer the following core elements, each impregnated with a sustainable environmental footprint: a satisfactory supply of water, electricity, sanitation, education and health services, safe and affordable housing, alongside efficient urban mobility and public transport systems; this ensemble must be supported by robust connectivity and digitalization and good governance, especially e-governance and citizen participation.

The implementation of the Smart Cities Mission at the municipal level is led by a Special Purpose Vehicle. There are two essential features of this mission. Firstly, the projects developed in the city are to be decided upon by the citizens of that city in a participatory way. Secondly, it is project-based and therefore does not result in the holistic development of the entire city.

Four years on, just ten cities account for 48% of the completed projects. It is likely that the practice of limiting development to small areas within cities will amplify existing inequalities because the upgraded services will not be available to all citizens (Deka, 2019).

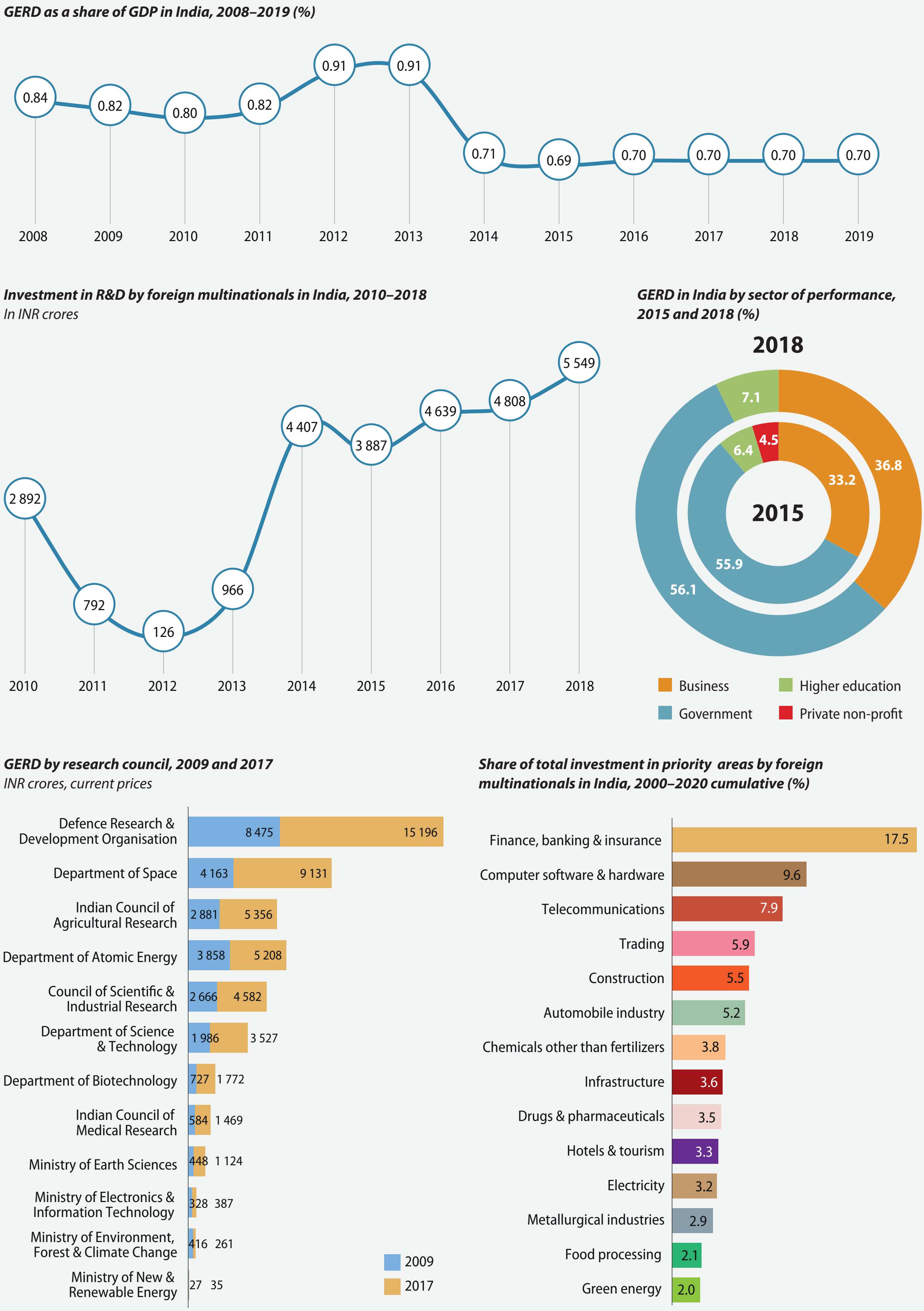
According to the Ministry of Housing and Urban Affairs (MoHUA), 80% of the Smart Mission's funding will be spent on area-based development, which benefits only part of a city's population. To speed up project implementation and monitoring, an Indian Urban Observatory has been created under MoHUA. Among the various Industry 4.0 technologies, it is the Internet of Things that is being used most by the Smart Cities Mission (Deka, 2019).

Anxiety about automation displacing jobs

Anxiety about the prospect of automation displacing jobs on a large scale dominates academic and public debate in India and abroad. These fears have been heightened by the phenomenon of 'jobless growth' that has plagued India since 1991 (Mani, 2015). In 2004, about 58% of the population entering the workforce – based on age – was absorbed but this proportion had fallen to 15% by 2011 and even to -5% by 2017, implying that some of the working age population had actually left the workforce, according to the National Statistical Office. This has happened even as India recorded a positive aggregate economic growth rate of about 7% in 2017. Worst affected have been rural women and those employed in sectors like agriculture, mining and quarrying or manufacturing. The jobless growth phenomenon has, thus, been accentuated, with job losses in the economy in 2017 for the first time since independence.

The manufacturing sector accounts for the greatest share of delivered robots in India. Within manufacturing, the majority of robots have been installed in four industries, in descending order: automotive; chemicals, rubber and plastics; metal; and electrical and electronics. On average, the number increased by 64% per year from 2000 to 2016. The booming automotive

Figure 22.2: **Trends in research expenditure in India**



Source: UNESCO Institute for Statistics; DST (2017 and 2020); Reserve Bank of India

Note: Data are restricted to selected fields representing at least 2% of the total.

industry accounts for most of the growth in robot installations in India, mimicking the international pattern. Robot usage in India is confined to two tasks: welding and soldering, as well as handling and machine tending (Mani, 2019a).

The density of robots in India is one of the lowest among robot-using countries. Total employment in all industries using industrial robots does not exceed 10% of total manufacturing employment and, within these industries, only a few tasks are automated: those that require precision and those that come with high occupational hazards.

At present, automation does not present a serious threat to manufacturing employment. However, with related technologies developing quickly, many tasks previously considered beyond the realm of automation might become automated in the near future. This could radically alter the employment landscape in India and beyond.

Make in India

Make in India sets out to stimulate investment in manufacturing and related infrastructure, foster innovation and make it easier to do business in India. Action plans for 21 key sectors have been targeted for policy initiatives, fiscal incentives, infrastructure creation, research and innovation and skills development.

The Make in India programme has sought to increase domestic manufacturing of a host of high-tech products, such as cell phones and electric locomotives. The government announced a series of strategies for 2017–2019 for new and emerging technologies such as AI and robotics, blockchain, the Internet of Things and electric vehicles, among others.

To boost economic growth and the Make in India programme, the Minister of Finance announced a scheme, in a statement on the Union Budget for 2019–2020, whereby global companies would be invited, through a transparent, competitive bidding process, to set up megamanufacturing plants in 'sunrise and advanced technology' areas, such as semiconductor fabrication, solar photovoltaic cells, lithium storage batteries, solar electric charging infrastructure, computer servers and laptops.

The mode of support envisaged in the budget is to provide investment-linked income tax exemptions under the Income Tax Act and other indirect tax benefits.

Domestic manufacture of most of these technology products involves lumpy investments that are sizeable but infrequent. As a consequence, India does not seem to have acquired the requisite technology to manufacture these products itself. Past attempts to precipitate domestic investment, especially in semiconductor fabrication, have proven inconclusive.

Moreover, incentive-induced stimulation of investment has a social cost because it involves taxing citizens and passing on the benefits to a private entrepreneur who ultimately may or may not set up a manufacturing facility in the chosen area of technology. At the same time, the very lumpiness of investments requires some sort of subsidy.

The success of the scheme announced by the Minister of Finance will depend on how the government spells out the finer details of the new budgetary policy.

The mobile phone sector is another important industry for the Make in India programme. India has become the second-largest manufacturer of mobile phones in the world, with annual production exceeding 200 million. However, the manufacturing sector is adding less value to the finished product than it did just a few years ago: the ratio of imported components to imports of mobile phones increased from 0.45 in 2014 to 7.51 in 2019 and the ratio of value added to output declined sharply from 0.30 in 2009 to 0.13 in 2017 (Mani, 2019b).

Make in India has sought to encourage both domestic and foreign firms to manufacture goods in India. Although gross inflows of foreign direct investment (FDI) have risen since 2014, multinational corporations have been repatriating about 27% of this amount (Figure 22.1). Moreover, only 26% of investment by foreign multinationals has actually gone towards the manufacturing sector, the remainder benefiting the services sector.

Over the past 20 years, one-quarter of FDI inflows has gone to finance, banking and insurance, as well as computer software and hardware. Just 2% has been invested in the green economy (Figure 22.2).

Diffusion of green energy technologies

Despite there being many legal instruments in place to deal with environmental issues, especially air and water pollution, air quality in some of the major cities remains a matter of serious concern. According to the *State of Global Air 2019* report, poor air quality is the third-leading cause of death in India, contributing to more than 1.2 million deaths per year in the country (HEI, 2019). Half of the 50 cities in the world with the worst air quality are in India and Delhi tops the list for capital cities (IQAir, 2019).[4]

In November 2019, air pollution hit record levels in Delhi, prompting the Supreme Court to warn that state governments failing to provide citizens with clean air and water would be obliged to pay them compensation. The authorities in Delhi reacted by spraying water into the air to force the pollutants to the ground. A longer-term solution under discussion is to replace fossil fuels with hydrogen-based technology.

One of the most important issues for the country's sustainable development is the effect of climate change on economic activity. India remains primarily an agricultural economy. Extreme weather and climatic events, such as drought and torrential rain, have caused enormous material damage to the economy over the past five years or so.

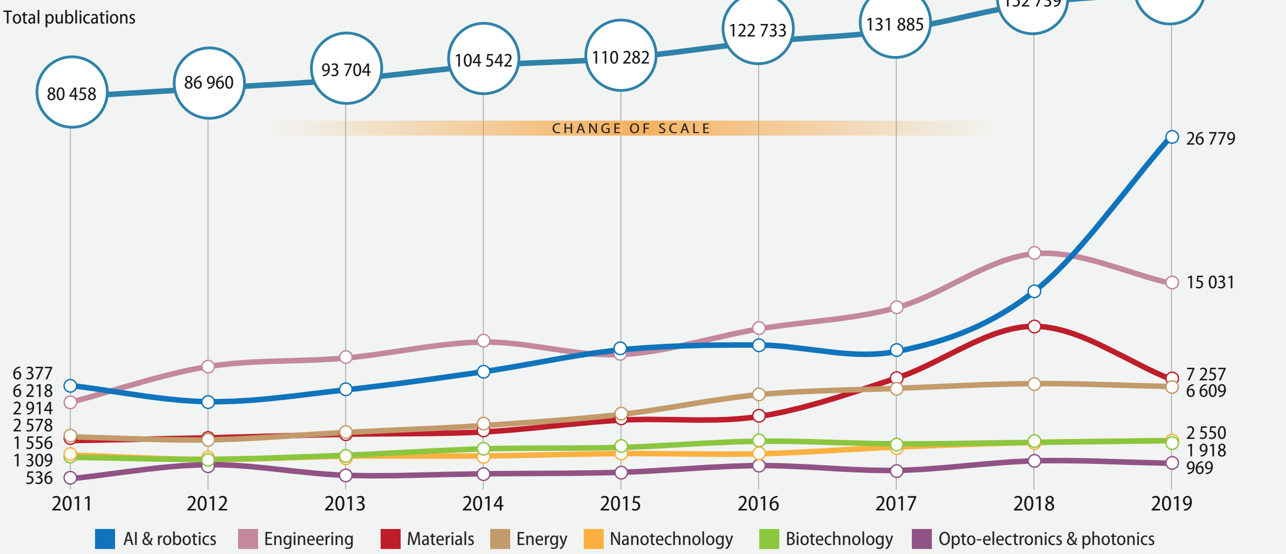
India's commitment to reducing its dependence on fossil fuels has two broad components: promoting green energy and hastening the diffusion of electric vehicles.

India's high reliance on new technologies has been accompanied by some recognition of the accompanying resource consumption and socio-environmental cost. As part of its *Paris Agreement* (2015) commitments, the government set an ambitious target of achieving 175 gigawatts (GW) of green energy capacity by 2022, increasing the current installed capacity 2.5-fold. Green energy sources are expected to meet 40% of India's electricity needs by 2030.

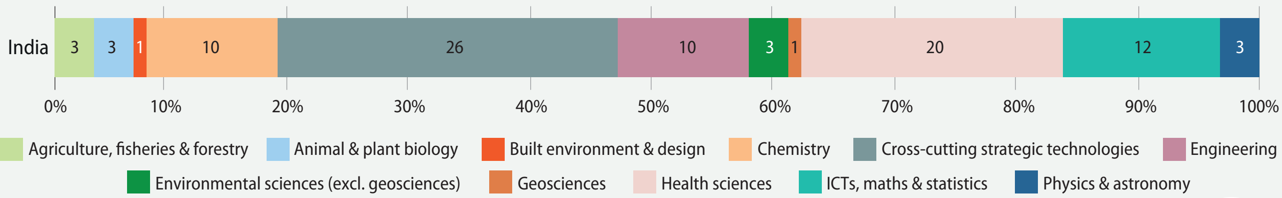
Figure 22.3: **Trends in scientific publishing in India**

Volume of scientific publications in India, 2011–2019

Total publications and output on cross-cutting strategic technologies



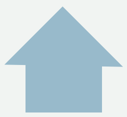
Scientific publications in India by broad field of science, 2017–2019 (%)



Engineering publications per million inhabitants in India, 2015 and 2019

11

in 2019



8

in 2015

0.86

Average citation rate for Indian scientific publications, 2013–2015; the G20 average is 1.02

18%

Share of Indian papers with foreign co-authors, 2016–2018; the G20 average is 25%

How has output on SDG-related topics evolved since 2012?

Indian researchers are publishing more than would be expected on key topics related to agricultural production, health and sustainable energy, relative to global averages. The proportion of output on climate-ready crops is even triple the global average. Output is also more than twice the global average on medicines and vaccines for tuberculosis, traditional knowledge, water harvesting, maintaining genetic diversity and pest-resistant crops.

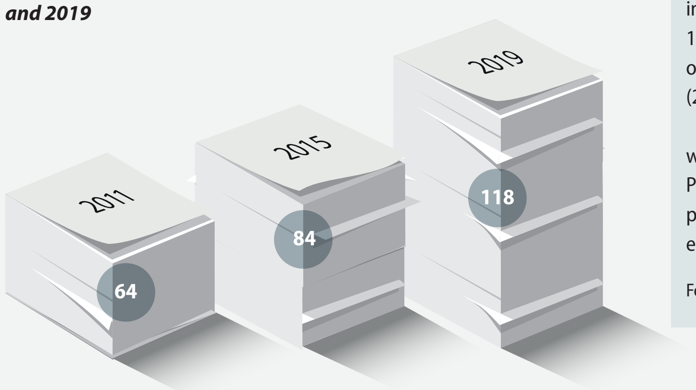
Indian researchers are publishing between 1.5 and 1.8 times the global average on smart-grid technologies, photovoltaics, biofuels and biomass and wind turbine technologies, complementing the government's push to expand green energy sources.

They are publishing no more than would be expected, however, on the impact on health of soil, freshwater and air pollution, despite counting 17 of the world's 25 most-polluted cities (IQ Air, 2019). Indian publications on this topic have, nevertheless, doubled from 893 (2012–2015) to 1 895 (2016–2019).

One of the fastest-growing topics has been sustainable transportation, with publications quadrupling from 754 (2012–2015) to 2 989 (2016–2019). Publications on greater battery efficiency almost tripled over the same period, from 1 091 to 3 188. These trends reflect the push to develop electric cars in India.

For details, see chapter 2

Scientific publications per million inhabitants in India, 2011, 2015 and 2019



India's top five partners for scientific co-authorship, 2017–2019 (number of papers)

	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator
India	USA (23 628)	UK (9 421)	China (7 244)	Germany (6 825)	Korea, Rep. (6 676)

Source: Scopus (excluding Arts, Humanities and Social Sciences); data treatment by Science-Metrix

The government's aim of achieving universal household electrification is also a boon for the power sector. India added a record 11 788 megawatts (MW) of green energy capacity in 2018 through systematic support and has one of the lowest capital costs per megawatt for solar photovoltaic plants.

For three consecutive years, investment in renewable sources has exceeded that in fossil fuels (IEA, 2019). The Union Budget for 2019–2020 allocated US$ 728.32 million to the green energy sector.

With the adoption of the *National Electricity Plan* in 2018, India's efforts are considered 2°C compatible but insufficient to meet the *Paris Agreement* target of 1.5°C. India's carbon emissions rose by 4.8% in 2018, largely driven by emissions from coal power plants. The main challenge will be to abandon further investment in such plants. The *National Electricity Plan* foresees adding 46 GW of coal-fired capacity by 2027, even though plans to build nearly 14 GW of coal-fired power plants across India were cancelled in May 2017 after being deemed uneconomical.

The total installed capacity in green energy sources (wind, solar, biofuels and small hydro-electricity generators) in 2018 was about 72.6 GW, with wind energy accounting for an estimated 48% of the installed capacity, followed by solar energy at 34%.

As a share of total installed capacity for electricity generation, green energy sources rose from 13% in 2015 to 22% in 2018. However, both total consumption and consumption per capita have also increased each year since 2015 (CSO, 2019).

Although most Indian states now have explicit policies for the installation, generation and use of green energy, only a handful have achieved substantial progress in reaching their renewable energy targets, beginning with the southern states of Karnataka (83%) and Telangana (155%) [Bhati *et al*., 2019].

In 2018, the government allocated INR 1 billion (*ca* US$ 15.8 million) to 60 cities across the country to develop projects for a combined 8.1 MW of solar panels and to install solar water heating systems covering 7 894 m^2 of collector area. The city of Chandigarh has made it mandatory to install solar water heating systems in public and industrial buildings, as well as in any new residential units (Busch *et al*., 2019). The Delhi Metro Rail Corporation, meanwhile, is gradually equipping its trains with solar photovoltaic systems.

A push for electric vehicles

Nearly 80% of all vehicles sold in India are two- and three-wheelers. The government has been considering a ban on all internal combustion engine-driven two-wheelers under 150 cc by 2025 and three-wheelers by 2023.

The *National Electric Mobility Mission Plan 2020* (2013) has sought to populate India with a fleet of 6–7 million electric and hybrid vehicles by 2020.

However, the electric vehicle industry in India is still at a nascent stage. According to the Society of Manufacturers of Electric Vehicles, 2.18 million such vehicles were sold in 2018, just 1% of total vehicle sales. At present, there are more than 400 000 electric two-wheelers and a few thousand electric cars on Indian roads. Over 95% of electric vehicles are low-speed electric scooters that do not require registration or a license.

To date, the volume of electric vehicles on the roads has fluctuated, depending on the government incentives of the moment. The government has introduced increasingly generous price subsidies, through the Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) scheme, which was launched in 2015 and moved into its second phase in 2019.

Through FAME II, the government is offering people incentives to purchase certain types of electric and hybrid vehicles between 2019 and 2022, combined with a reduction from 12% to 4% in the goods and services tax on electric vehicles. The target is to incentivize the purchase of 7 090 electric buses by State Transport Undertakings, 35 000 four-wheelers, 50 000 three-wheelers and 20 000 hybrids.

The Union Budget for 2019 provides an additional income tax deduction of INR 1.5 lakh (*ca* US$ 21 000) on the interest paid on loans taken out to purchase electric vehicles, which works out to a saving of about INR 2.5 lakh (*ca* US$ 35 000) over the loan period.

Apart from price, there are two main technological barriers to faster adoption of electric vehicles: the relative scarcity of both lithium-ion batteries and charging stations spaced at reasonable intervals. The Union Budget for 2019 addressed the domestic manufacturing of lithium storage through investment-linked exemptions from income tax; in the past, such incentive-induced promotion had not managed to generate the required investment. In parallel, the Ministry of Power delicensed Public Charging Stations in December 2018, provided they meet the standard specifications and protocols laid down. The target is to have 1 000 charging stations across the country by 2030. Charging stations at private residences are also authorized.

TRENDS AND ISSUES IN RESEARCH

A moving target for research intensity

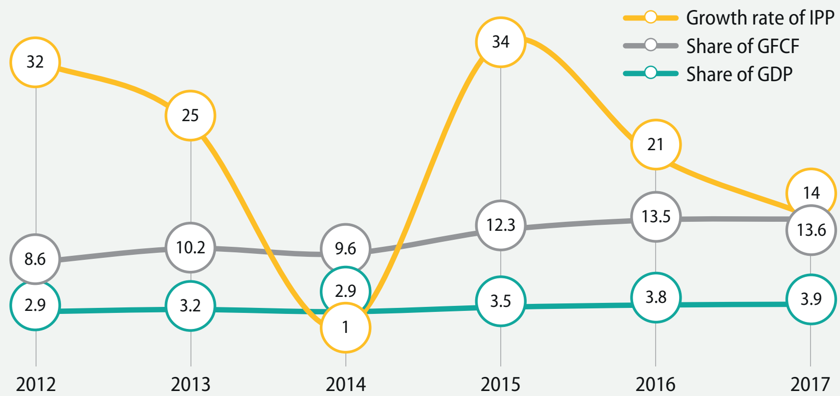
India has made solid progress towards some of its targets for the Sustainable Development Goals (SDGs), especially those under SDG9 concerning the development of industry, infrastructure and innovation.

India's research effort remains unsatisfactory, however. With an average overall gross domestic expenditure on research and development (GERD) over the past two decades of 0.75% of GDP (Figure 22.2), India has one of the lowest GERD/GDP ratios among the BRICS (Brazil, Russian Federation, India, China and South Africa), even if, in absolute terms, research expenditure has risen consistently over the past 14 years.[5]

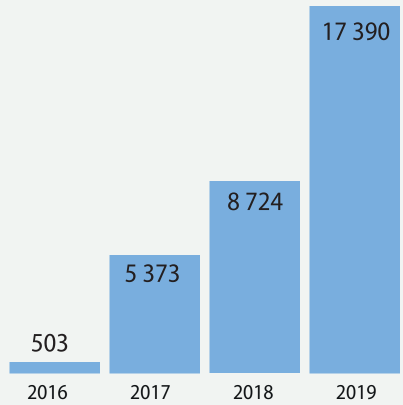
India's research intensity has been declining since 2014. The *Science and Technology Policy* of 2003 fixed the threshold of devoting 2% of GDP to research and development (R&D) by 2007. This target date was set back to 2018 in the new *Science, Technology and Innovation Policy* (2013) then again to 2022 by the Economic Advisory Council of the Prime Minister. In 2020, the task force drafting the country's new *Science and Technology Policy* recommended pushing back the target date to a more realistic 2030. As of October 2020, no date had yet been set for the policy's official release.

Figure 22.4: **Trends in Innovation in India**

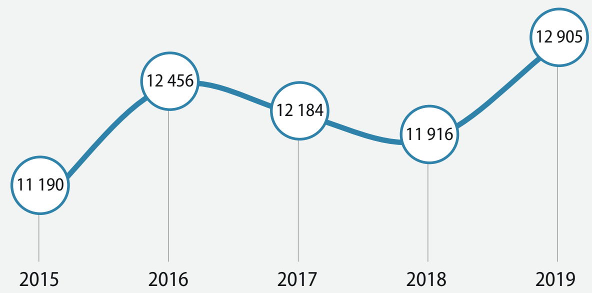
Investment in intellectual property products (IPP) as a share of India's GDP and gross fixed capital formation (GFCF), 2012–2017 (%)



Growth of start-ups in India, 2016–2019

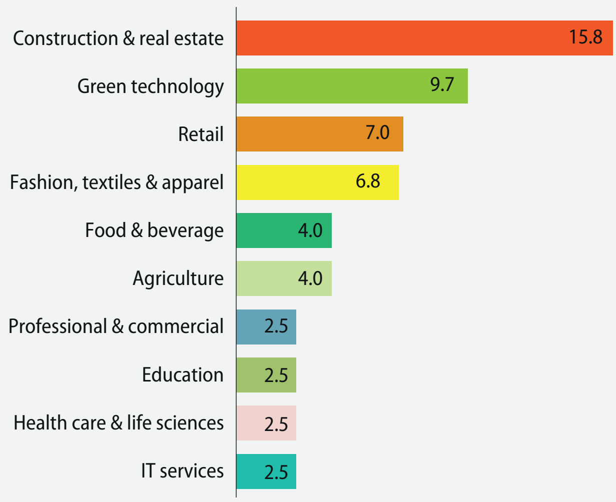


Number of IP5 patents granted to Indian inventors, 2015–2019



Note: IP5 refers to the US Patent and Trademark Office, European Patent Office, Japanese Patent Office, Korean Intellectual Property Office and State Intellectual Property Office of the People's Republic of China.

Industry-wide distribution of start-ups in India, 2018 (%)



175

Indian resident patent applications per 100 billion GDP (2011 constant US$), 2018

Indian trade balance in intangible intellectual property, 2015

US$ 67 billion

including computer software services

US$ -4 billion

excluding computer software services

Patents granted by India's national patent office to inventors residing in India and abroad, 2003–2017

Source: Central Statistical Organization (2019), trade deficit computed from UN Comtrade; DIPP (2018) Department for Promotion of Internal Trade and Industry; for IP5 patents: Science-Metrix using PATSTAT data; for resident patent applications, World Intellectual Property Organization; for India's national patent office, Office of the Controller General of Patents, Designs and Trade Marks (2018)

Whereas the new Science and Technology Policy is being piloted by the Department of Science and Technology, it is the Department of Pharmaceuticals which is overseeing preparation of an updated research policy. No mechanisms have been put in place to ensure cross-fertilization between the twin policies.

Since 2015, there has been a steady decline in share of R&D performed by the government sector (Figure 22.2). In parallel, the private business enterprise sector has raised its own contribution to 42% of the total. In theory, this is a positive trend, as it means that R&D is increasingly being performed by the same sector that has the capacity to convert research output into commercial products and processes. The challenge for India will be to ensure that the current increase in business expenditure on R&D becomes *systematic,* as has been the case for countries such as China and the Republic of Korea.

GERD remains concentrated in a handful of industries, firms and states, led by the pharmaceutical, automotive, information technology and defence sectors (Mani, 2015). According to the Economic Advisory Council of the Prime Minister, the three private companies that spent the most on R&D in 2017 all specialize in software development.

The top spenders at state level in 2017 were Maharashtra, Tamil Nadu, Karnataka, Gujarat and the Undivided Andhra Pradesh; this is primarily due to the dual presence of top firms in terms of research expenditure and leading public laboratories in these states.

Of the seven research councils in the country, the top research spenders continue to be those responsible for defence, space and atomic energy (Figure 22.2). However, the spillover effects of public research for broader civilian use, although on the increase, remain very limited. It must be added that all three agencies have been making stronger efforts to involve both public and private enterprises in their activities. In fact, the state-owned undertaking Electronics Corporation of India was initiated in 1967 as an offshoot of the research done by the Department of Atomic Energy.

Investment in R&D by foreign multinationals is on the rise (Figure 22.2). According to the most recent R&D survey (DST, 2020), they accounted for as much as 16% of private-sector investment in R&D in 2019, or 13% when public-sector enterprises were included in the calculation.

More investment in intellectual property

Scientific output has maintained an upward trajectory since 2015, despite the country's modest research intensity. Scientists have even overtaken their Japanese peers for the sheer volume of publications (Figure 22.3).

Investment in intangibles has also increased (Figure 22.4). Intangibles include intellectual property such as R&D, mineral exploration, software and databases, literary and artistic original works and so on. Investment in intangibles, which is largely done at the level of firms, spills over into other companies within the same industry and, thereby, benefits the industry as a whole. Greater investment in intangibles can, thus, lead to higher productivity and economic growth. In India, investment in intangibles now contributes about 4% of GDP and 14% of gross fixed capital formation (Figure 22.4).

Trade in intangibles has also been growing but is overreliant on software services. India has a surplus in trade in intangibles when trade in software services is included but a deficit when exports of software services are excluded (Figure 22.4). This growth was noted in the 2015 edition of the *UNESCO Science Report* and is a reflection of low investment in R&D (Mani, 2015).

The trade deficit in intangibles is concentrated in three areas: royalties and license fees, which includes charges for the use of trademarks; franchises and similar rights; and other royalties, including the license fee for patents.

India has a growing positive trade balance in R&D services but these services are largely created and exported by multinational corporations to their parent companies abroad, many of which are located in the USA.

Greater output in innovation

Inventive activity has grown tremendously, judging from trends in the number of patents issued to Indian inventors by the India Patent Office and those issued to Indian inventors by the US Patent and Trademark Office (Figure 22.4).

However, a closer look at the data shows that about 85% of the assignees of these patents are foreign inventors, commonly represented by multinational corporations. Very few patents have been granted to Indian firms, research institutions and individuals and the number of resident patent applications per 100 billion GDP has grown at a more pedestrian pace (Figure 22.4). Patents from the US Patents and Trademark Office were largely issued to inventors in just two industries: information technology services and pharmaceuticals.

The landscape for patents described in the previous edition of the *UNESCO Science Report* (Mani, 2015) has not changed:

- Indian inventors are primarily active in two industries: software development and pharmaceuticals, with the former continuing to dominate utility patents (Mani, 2015).
- The majority of software-related patents are obtained by multinational corporations operating from India, whereas almost all the pharmaceutical patents are obtained by domestic pharmaceutical companies.

India is the only country with a stringent policy on commercial exploitation of patents (Mani, 2019c). The country also sets the bar higher than any other country for the criteria used to assess inventiveness in pharmaceutical products. Patent legislation is used to effectively cull the practice of 'evergreening', whereby pharmaceutical firms extend the patent life of a drug by obtaining additional 20-year patents for minor reformulations or other iterations of the drug, without necessarily changing its therapeutic efficacy.

Pre- and post-grant opposition to patenting is another important feature of the patent system. India developed a new *National Intellectual Property Rights Policy* in 2016 but this does not fundamentally change any of the policies with which India's own patent regime had been compliant since 2005 under the Agreement on Trade-Related Aspects of Intellectual Property Rights (Mani, 2016).

A less generous tax regime for R&D

India's tax regime with respect to R&D has four important features:

- Firstly, within India, there are no requirements for the domestic use of intellectual property arising from R&D financed through tax concessions.
- Secondly, both domestic and foreign companies are eligible to seek the subsidy but their R&D must be conducted within India.
- Thirdly, if a firm is in deficit, unused benefits may be carried forward for the next eight years but not backwards to previous years.
- Fourthly, qualifying expenditure includes wages, supplies, utilities and other expenses directly related to R&D. The deduction of R&D expenditure shall be the net sum of grants, gifts, donations, etc.

The R&D tax subsidy manifests itself in terms of the amount of tax foregone, which the Ministry of Finance has been estimating on a regular basis. Over the years, the amount of tax foregone as a result of this subsidy scheme has grown at an annual rate of 14% per annum and now accounts for about 8% of all corporate subsidies (Figure 22.5).

By 2015, the Indian tax regime had become one of the most generous in the world (Mani, 2014). However, the Union Budget for 2016 reduced the tax incentive for performing R&D in business enterprises from 200% to 150% of research expenditure from 2017 onwards and to 100% from 2020 onwards. This shift follows an observation made in the 2015 *UNESCO Science Report* that India's generous tax regime '[had] not resulted in the spread of an innovation culture across firms and industries' (Mani, 2015).

Most industries seem to have taken the drop in their stride but it has come as a rude shock to the pharmaceuticals and life sciences industry, which had been lobbying the government to adopt a budget proposing a 250% tax break. Companies had also been lobbying to expand the scope of the benefit to cover expenses incurred outside research facilities, such as bio-equivalence studies, clinical studies, patent filings and product registrations.

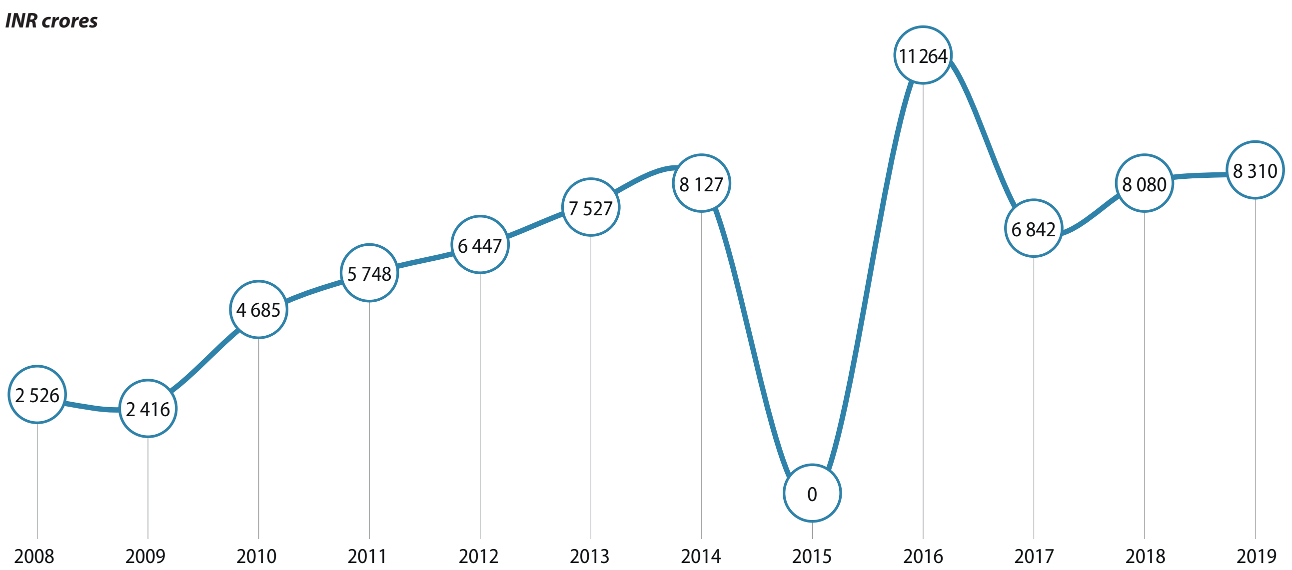
The move, thus, came as a double blow to the pharmaceuticals industry. Saumen Chakraborty, president and chief financial officer of Dr Reddy's Laboratories Ltd, reacted by saying that 'the decrease in R&D weighted deduction to 150% may have an impact on innovation, as it could de-incentivise the industry to spend more on R&D'. Venkat Jasti, CEO of Suven Life Sciences Ltd, opined that the cut in the R&D tax break goes against the government's 'Make in India' slogan (Pilla, 2016).

Simultaneously, the finance minister announced a patent-box type of incentive for the first time, wherein income received in the form of royalties and technology license fees received by Indian companies would be taxed at a reduced rate of 10% from the fiscal year 2016/2017 onwards. This move was designed to stimulate innovation by raising the revenue that companies could earn from their intellectual property. The introduction of the patent box encourages output of R&D, whereas the reduction of R&D tax incentives discourages input to innovation.

Start-up India: incentivizing tech

Innovation is promoted in two ways. In addition to the traditional avenue of tax incentives, the government has improved the ecosystem for start-ups by providing them with a range of incentives through the Startup India initiative since 2016. This incentive system ranges from 'simplification and hand-holding,' 'funding support and incentives' to 'industry–academia partnership and incubation.'

Figure 22.5: **Revenue foregone in India as a result of R&D tax incentive, 2008–2019**



Source: Ministry of Finance

One of the main barriers to the creation of start-ups has been the availability of risk capital. One source of such capital is from angel investors but there was a long-standing income tax issue known as the angel tax. This is a term used to refer to the income tax payable on capital raised by unlisted companies via the issue of shares where the share price is seen to be in excess of the fair market value of the shares sold. The excess realization is treated as income and taxed accordingly.

To resolve this issue, the Union Budget for 2019–2020 stipulated that those 'start-ups and their investors who file requisite declarations and provide information in their returns will not be subjected to any kind of scrutiny in respect of valuations of share premiums.' Furthermore, the budget extended tax breaks to investments in start-ups. In short, the proposals in the recent budget are a logical sequencing of the government's efforts to improve the ecosystem for start-ups. Consequently, the number of start-ups in the country has been increasing steadily since 2016 (Figure 22.4).

Although there has been a significant improvement to the ease with which start-ups can be established and developed in India since 2016, most start-ups are still concentrated in Maharashtra (specifically the cities of Mumbai and Pune), Karnataka (specifically Bangalore) and Delhi. Most of the start-ups are in the services sector, with software development services taking the lead (Figure 22.4). There are very few start-ups in manufacturing.

Startup India has been working with various line ministries, including those responsible for water and sanitation and agriculture, to develop start-ups that will address specific problems faced by these sectors. In this way, the emergence of new start-ups may result in innovative solutions incorporating emerging technologies.

Moreover, start-ups in the manufacturing and services sectors may manage to leapfrog over certain stages in developing their business through recourse to Industry 4.0 technologies, such as cyberphysical systems on the factory floor and the digitalization of service industries.

DEVELOPMENT OF HUMAN RESOURCES

Schemes to nurture an innovation culture

In 2018, India had 253 full-time equivalent (FTE) researchers per million inhabitants (Figure 22.6), about 11% of the researcher density of Italy. This is, nevertheless, a marked improvement on the situation in 2011 (157 per million) and 2015 (216 per million).

The density of FTE researchers per 10 000 labour force has increased very slowly, from 9 in 2005 to 11 in 2015 and 14 in 2018, the latest year for which such data are available (DST, 2020).

Since 2015, the government has put in place a range of incentive schemes to boost the scientific workforce.[6] One of the first was the Atal Innovation Mission (AIM), established by NITI Aayog in 2016, which is striving to develop an innovation culture in schools, universities and businesses. The government granted this programme US$ 24.84 million in 2016 to boost innovation by academicians, entrepreneurs and researchers.

In July 2018, AIM and MyGov launched the Innovate India Platform with the aim of providing a common entry point for information on developments in innovation across India.

As of 2020, AIM had incubated more than 620 start-ups, more than 100 of which were led by women.[7]

In parallel, the AIM programme is giving schoolchildren problem-solving and innovation skills. Atal Tinkering Labs are being established in 30 000 schools between 2018 and 2021 to familiarize pupils with hands-on technologies such as 3D printers, robotics, miniaturized electronics, the Internet of Things and computer programming. By 2020, AIM had selected 5 441 schools to host these labs; these cover 93% of the districts in India and 98% of the upcoming smart cities. By this time, more than 6 million pupils had already participated in an Atal Tinkering Lab.

In February 2018, the Union Cabinet approved implementation of the Prime Minister's Research Fellows scheme to promote innovation at university by funding PhD fellowships at a total cost of INR 1 650 crore (*ca* US$ 246 million) for seven years beginning in 2018.

The same month, the Union Government announced a grant of INR 1 000 crore (US$ 156 million) for the second phase of Impacting Research Innovation and Technology (IMPRINT), a fund created by the Department of Science and Technology and the Ministry of Human Resource and Development. In its first phase (2015–2019), IMPRINT had funded research projects worth INR 5 949 million (*ca* US$ 84 million) addressing national challenges.

Meanwhile, the Department of Biotechnology is using a scheme called Boost to University Interdisciplinary Life Science Departments for Education and Research (DBT-BUILDER) to support advanced education and promote interdisciplinary research and technological development. In practice, universities are using these funds to upgrade research infrastructure in life sciences.

Since having a critical mass of technicians will be a vital component of Industry 4.0, the Council of Scientific and Industrial Research launched the first of 30 vocational skills training programmes in 2016 in technical areas. These include: leather processing; paints and coatings; electroplating and metal finishing; industrial maintenance engineering; bioinformatics; mechatronics; and glass-beaded jewellery. The relevant teaching institutions are scattered across the country.

Plans for a National Research Foundation

The university sector performed 7.1% of GERD in 2018, up from 4.0% in 2015 (Figure 22.2) [Mani, 2015]. The *National Education Policy* (2019) envisages establishing a National Research Foundation to fund research in the education system, primarily at colleges and universities. This could provide a much-needed boost for academic research in India. It would appear that other schemes summarized in the previous edition of the *UNESCO Science Report* have not had the desired result (Mani, 2015).

The India-based Neutrino Observatory (INO) is a megaproject designed to nurture cutting-edge basic research. INO is being built in the State of Tamil Nadu, using funding approved in the government's *Twelfth Five-Year Plan* (2012–2017).

INO will ultimately consist of an underground laboratory, an iron calorimeter detector and an Inter-Institutional Centre for

High Energy Physics. More than 120 physicists, engineers and students from 25 research institutes, universities and Indian Institutes of Technology are involved in the project, which also runs a graduate training programme.

Concern over the employability of graduates

University graduates in science, technology, engineering and mathematics (STEM) still represent a little over one in four graduates (Figure 22.6). Science graduates also make up a greater share of the total than graduates in engineering and technology.

Although the government bemoans the country's low researcher density, there is actually very little quantitative evidence to show that demand for STEM graduates has increased, as investment in R&D has not kept pace with the rise in GDP (DST, 2020).

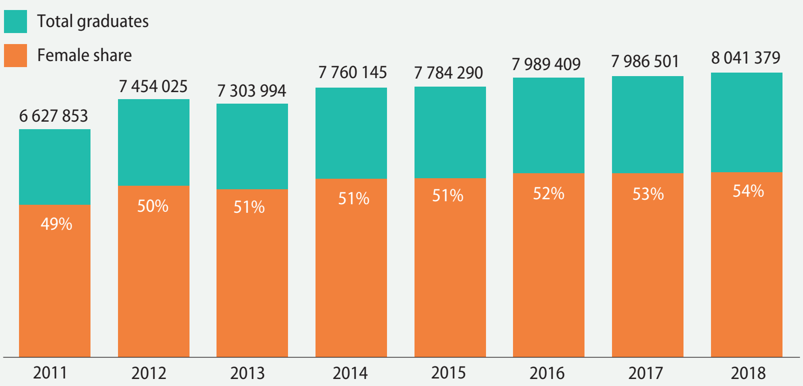
One perennial concern relates to the employability of Indian graduates, given the varying quality of education in STEM subjects, in particular. At one end of the spectrum, there are prestigious higher education institutions like the Indian Institutes of Technology. The CEOs of some of world's leading technology companies, among them Microsoft and Google, are Indians who were trained at these premier institutes. At the other end of the spectrum are a swath of provincial universities and polytechnics.

Employability increased from 34% in 2014 to almost 47% in 2019, meaning that one out of two graduates is still not employable (Figure 22.6). In technical fields, courses in electronics and communications engineering shared the highest employability rates (60.3%) with information technology (60.2%) in 2019, whereas civil engineering had the lowest.

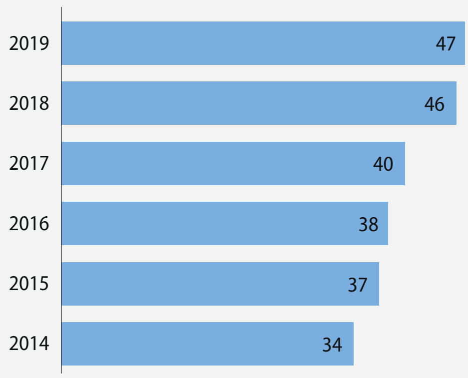
Despite the focus on improving the quality of higher education, the employability of Industrial Training Institute

Figure 22.6: **Trends in human resources in India**

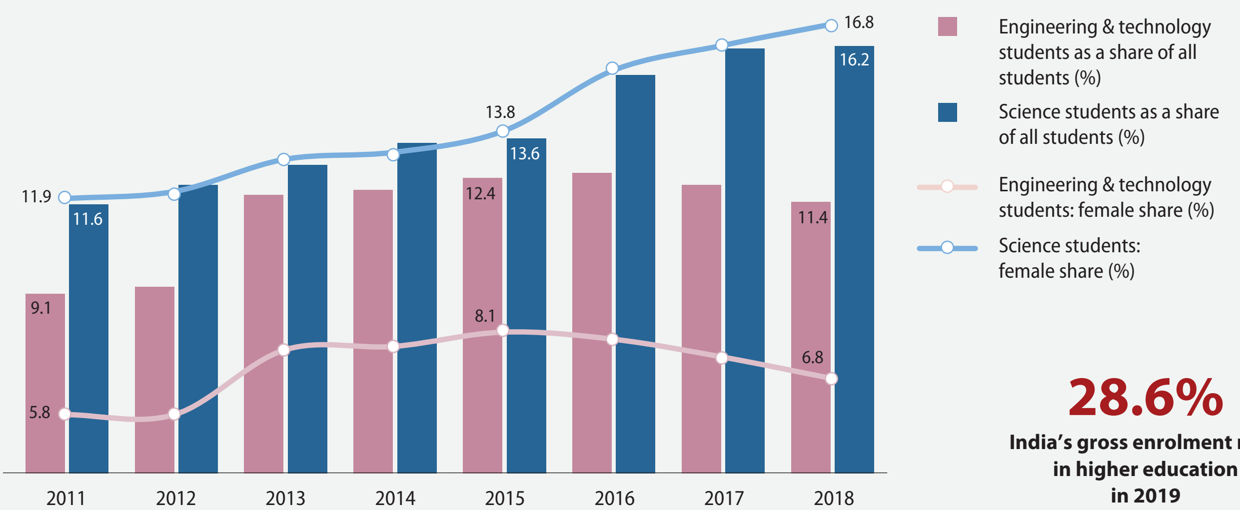
Tertiary graduates in India, 2011–2018



Employability of Indian graduates, 2014–2019 (%)



Students of science, engineering and technology as a share of total Indian students, 2011–2018 (%)



28.6%
India's gross enrolment ratio in higher education in 2019

Note: Science students include those completing undergraduate, post-graduate, MPhil and doctoral degrees in STEM subjects. The total of all students includes graduates of engineering, technology, science, medicine, humanities, social sciences and management degrees.

and polytechnic graduates has been falling, primarily due to a lesser focus on alliances with industry and core skills.

The Skills Development Mission

The prime minister officially launched the National Skills Development Mission on 7 July 2015, on the occasion of World Youth Skills Day. The aim is to create convergence across sectors and states, in terms of skills training.

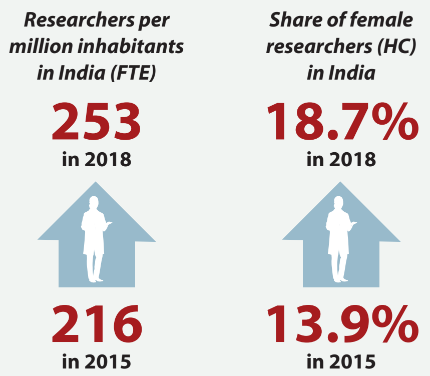
To achieve the vision of a 'skilled India', the mission is not only consolidating and co-ordinating efforts to develop skills but also expediting decision-making across sectors to achieve rapid change to a high standard.

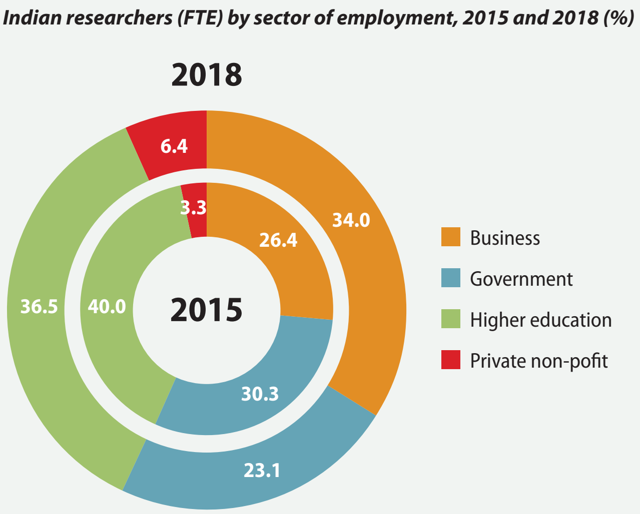
The mission is being implemented through a streamlined institutional mechanism driven by the Ministry of Skills Development and Entrepreneurship. Under the mission, about 400 million people across the country are to be trained by 2022.

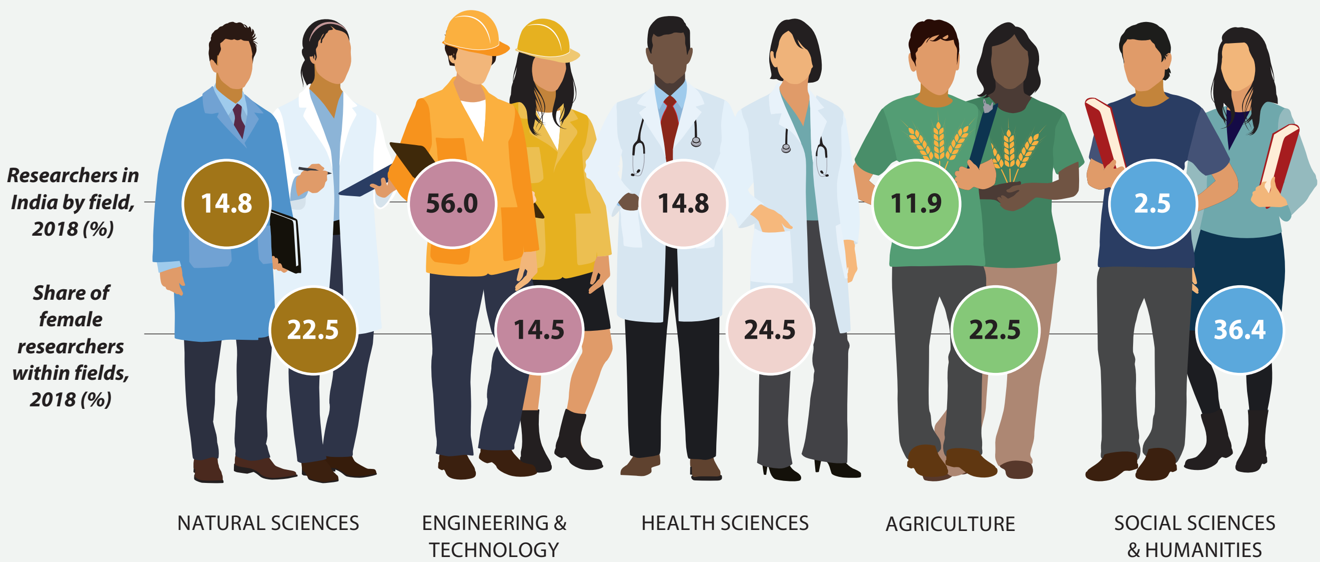
E-learning approaches galvanized by Covid-19

The Covid-19 epidemic has stimulated interest in e-learning approaches. This year, several Indian start-ups in education technology (edtech) have sprung up. The National Skill Development Corporation (NSDC) now proposes more than 450 online courses via its e-Skill India learning platform, which aligns with the Skill India Mission.

Since its inception in 2008, the NSDC has developed partnerships with the private sector to provide open access courses in a wide range of fields, including health care, electronics and English proficiency. For instance, through the company SAS, courses are available on data analytics, machine learning, predictive modelling and statistical business analytics, all of which can be applied in the retail and financial sectors, among others. The platform







Note: All researcher values are based on full-time equivalents.

Source: UNESCO Institute for Statistics; All India Survey on Higher Education Final Reports (2011 to 2018), Ministry of Human Resource Development, Government of India; for employability, Wheebox (2019); Government of India (2020) *S&T Indicator Tables 2019-20*. Ministry of Science & Technology: New Delhi has also partnered with the British Council, English Score, the Saylor Academy (USA) and UpGrad, among others.

Two schemes to address chronic brain drain

India has been losing highly skilled personnel, primarily to the USA, for some time. In 2017, half of the foreign-born individuals in the USA with a higher degree in science and engineering came from Asia, with India (23%) and China (10%) being the leading countries of origin (NSB, 2020).

The government introduced two schemes in 2017 to address this chronic brain drain. The first is the Visiting Advanced Joint Research (VAJRA) Faculty Scheme established by the Department of Science and Technology. It enables non-resident Indians and the overseas scientific community to contribute to R&D in India. The Science and Engineering Research Board, a statutory body of the Department of Science and Technology, is implementing the scheme. The VAJRA faculty undertakes collaborative research in publicly funded institutions in priority areas for India where capabilities and capacity need reinforcing.

The second scheme is the National Post-Doctoral Fellowship Programme. In order to encourage PhD recipients to stay in India, the programme offers them two-year fellowships. This, too, is administered by the Science and Engineering Research Board, which awarded 2 500 fellowships from 2017 to 2019.

Sabharwal (2018) has shown, through a field study of 83 returnees, that some reverse brain drain from the USA to India is occurring. The scientists and engineers interviewed by Sabharwal cite better career prospects in India as the reason for their decision to return home, welcoming what they perceive to be ample funding for research, less competition for grants, the ability to work on theoretical topics and the freedom to choose research objectives. However, given the small sample, there are doubts as to whether the findings of the study can be generalized.

CONCLUSION

A stronger scientific workforce is the way forward

The period from 2015 to 2020 has been a watershed moment for India. This period has been characterized notably by a stable government, especially with respect to policy-making. A large number of policies and programmes have been developed to encourage an innovation culture and absorb major emerging technologies such as artificial intelligence, blockchain and electric vehicles.

One impediment to the percolation of these technologies through the economy is the persistent shortage of well-trained scientists and engineers. As we have seen, the government has put in place a number of policies and schemes to remedy the situation.

Another impediment is the insufficient level of domestic investment in R&D. Research intensity is stagnant and patenting by domestic corporations, research institutes, universities and individuals remains low. On the positive side, intangible investments by private corporations are on the rise, as is investment in R&D by foreign multinational corporations.

A need for more 'policy' bridges

Given the large number of multinational corporations now engaged in R&D, it is imperative that the host economy benefit from this activity. The adoption of internationally accepted policy instruments could foster a more effective interaction between foreign research centres and local firms.

The eternal problem of inadequate links between public laboratories and manufacturers also demands policy attention, in order to improve technology spillovers and the commercialization of research output.

There is also a need to improve linkages between the start-up ecosystem and manufacturers, in order to push technological development in sectors in which India has a global presence, such as health care. There is potential for start-ups to develop medical devices for export, for instance.

Industry should be encouraged to mentor start-ups. One model could be the Companies Act (2013), which made it mandatory for firms to use 2% of their net profits to fund non-profit organizations, as part of their corporate social responsibility. This approach could be adapted to encourage firms to invest in start-ups in their economic sector.

Although the number of start-ups has grown steadily since 2016, these tend to be concentrated in the cities of Bangalore, Delhi, Mumbai and Pune. Good examples of institutional practises in the states hosting these start-ups, such as Kerala, Maharashtra and Telangana, could be replicated in other states. States should be encouraged to learn from one another.

Currently, every state is designing its own policies for areas such as biotechnology and information technology. They should also be encouraged to do more within the national framework, while focusing on local challenges. Moreover, rather than trying to invest across the board, states should focus on their own particular strengths. It is a positive sign that states are increasingly involving individuals from the private sector and younger talents in the development and implementation of their policies.

At the level of the union government, entrusting the co-ordination of innovation policies to a single office would avoid the current 'silo approach' to policy-making. This office would ideally be backed by a committee of experts (an epistemic community of sorts) charged with guiding policy implementation not just at the level of the union government but also between the union and the states.

Another policy challenge will be to put research programmes in place to develop the desired Industry 4.0 basket of technologies and ensure that domestic businesses have access to them, since it is these technologies which will define the nation's future competitiveness. Institutions like the Economic Advisory Council of the Prime Minister must take up the gauntlet by monitoring the country's readiness for the challenges ahead.

KEY TARGETS FOR INDIA

India plans to:

- raise GERD to 2% of GDP by 2030;
- achieve 175 GW of green energy capacity by 2022;
- meet 40% of India's electricity needs through green energy sources by 2030;
- populate India with a fleet of 6–7 million electric and hybrid vehicles by 2020;
- raise the number of charging stations for electric vehicles to 1 000 by 2030; and
- train about 400 million people by 2022 under the National Skills Development Mission.

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ENDNOTES

1 In 2020, WHO established a Solidarity Call to Action for a patent pool to ensure broad access to new treatments for Covid-19. By July 2020, 37 countries had signed up to the initiative, including the Maldives, Pakistan and Sri Lanka.
2 NITI Aayog has replaced the Planning Commission, which used to prepare five-year development plans. Consequently, the Twelfth Five-Year Plan (2012–2017) has been the last in the series. See: Mani (2015).
3 See: https://nsmindia.in/
4 This study measured the level of particulate matter of up to 2.5 microns in size (PM2.5). PM2.5 is able to penetrate deep into the human respiratory system and, from there, the entire body. The WHO recommends an annual mean exposure threshold of 10 μg m–3 to minimize the risk of health problems.
5 At current prices, GERD increased five-fold between 2004 and 2018, from INR 242 billion (ca US$ 3.4 billion) to INR 1 238 billion (ca US$ 17.82 billion). In 2016, GERD amounted to INR 1 049 billion (ca US$ 14.6 billion).
6 For details, see India Brand Equity Foundation: www.ibef.org/industry/science-and-technology.aspx
7 See the AIM brochure: https://aim.gov.in/AIM_Brochure.pdf