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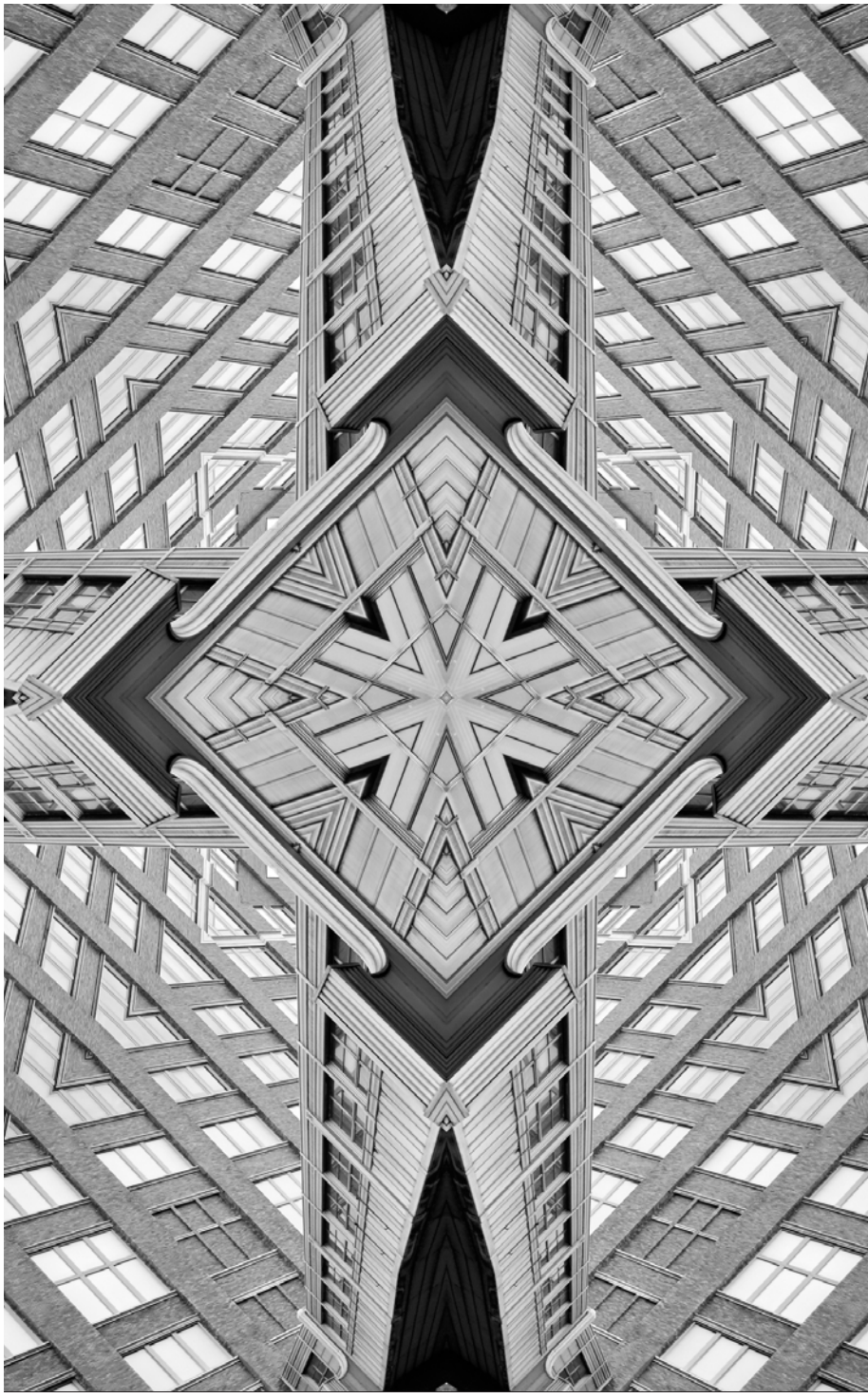

India's Innovation Ecosystem: Mapping the Trends

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Abstract

The integration of Science, Technology and Innovation goals into national policies helps achieve sustained economic and social development. This brief examines the key parameters that govern the global and Indian innovation ecosystems: research investment, education policy, researcher density, publication output, number of patents registered, and the startup environment. It finds that certain elements are crucial in developing a robust strategic innovation ecosystem, paramount of which are nurturing human resources and domestic research, reducing brain drain, synergising research activities, and increasing high-tech domestic production.

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Introduction

Advancements in technology have transformed health, transportation, communication, energy, and manufacturing industries across the globe. These transformations, in turn, have changed the organisation of economies and societies, and fostered greater cooperation within the international community through various institutions and arrangements.

As of 2018, the database of the World Intellectual Property Organization (WIPO) held more than 3 million patent filings and 12 million trademark registrations.[1] Many analysts attribute socioeconomic progress partly to these innovations, and point to the fact that the world's population living in extreme poverty has reduced from 45 percent to 10 percent over the past four decades.[2] There is no shortage of recognition that technology-driven innovation is crucial to development—Goal 9 of the UN Sustainable Development Goals (SDGs) advocates building resilient infrastructure, promoting sustainable industrialisation, and fostering innovation.[3]

So far, annual global spending on Research & Development (R&D) is pegged at around US$ 1.7 trillion. In the past decade, the world recorded a researcher intensity of 1,473 researchers per million, 2.2 million journal publications, 3 million patent filings, and nearly US$ 2 trillion in exports of hi-tech commodities.[4,5,6]

The Global Innovation Index (GII) ranked Switzerland, Sweden, the US, UK, and Netherlands, as the top five countries in R&D ecosystem in 2020. (See Table 1) In 2020, the innovation ranking was computed based on the innovation ecosystem that balances the forces that push knowledge creation, investments, technological exploitation, and the impacts of the innovation outputs.

Table 1: Innovation elements and Country rankings (2020)

Element	Global ranking		
	1	2	3
Overall rank	Switzerland	Sweden	USA
Institutions	Singapore	Finland	Norway
Human capital &Research	Korea	Denmark	Sweden
Infrastructure	Norway	Sweden	Switzerland
Market sophistication	Hong Kong (China)	USA	Canada
Business sophistication	Sweden	Switzerland	Israel
Knowledge & Tech outputs	Switzerland	Sweden	USA
Creative outputs	Hong Kong (China)	Switzerland	Luxemburg

Source: GII 2020

Globally, maturing technologies including Artificial Intelligence (AI), the Internet of Things (IOT), and robotics are expected to enter into every industry and across all societal segments with the vision of realising smart societies. AI alone could generate an additional US$ 15 trillion in economic value by 2030, globally.[7]

Table 2:
Global priority areas and technologies

Priority areas
Technology, Climate change, Ocean Resources, Biodiversity, Cyber Security, Industry & Corporate Governance, Geopolitical & Geo-economic Cooperation
Emerging technologies
Artificial Intelligence (AI), Internet of Things (IOT), Advanced Materials, Smart Grids, Autonomous Vehicles, Drones, Big Data Analysis, Precision Medicine, Genomics.

Source: Word Economic Forum 2019-20

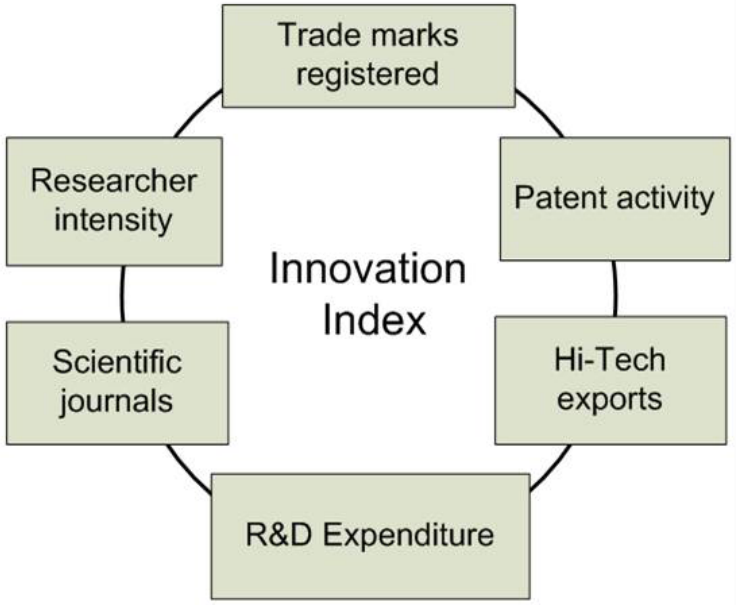
The European Union (EU) estimates that the digital markets could annually contribute US$ 0.5 trillion to the regional economy. In Southeast Asia, meanwhile, it is estimated that digital integration could result in a gain of US$ 1 trillion for those countries by 2030.[8] Global investments in clean energy systems and technologies are expected to reach US$ 2.2 trillion by 2030—all of them aimed at achieving the 1.5°C target in global temperature as set by the Paris Climate Agreement.[9]

In the financial markets, meanwhile, crypto-currencies, involving block chain and distributed ledgers technologies (DLT) have emerged as potential gateways.[a] Their use can increase global trade by more than $1 trillion in the next 10 years, according to certain estimates.[10] The number of IOT devices is expected to be more than 20 billion in 2022; and the genome editing technology will develop a market of more than US$ 10 billion by 2027. Meanwhile, autonomous underwater vehicles with swarm capabilities will be key in exploring the vast ocean resources that are estimated to have an asset value of US$ 24 trillion.[11]

a The distributed ledgers use independent computers, referred to as nodes, to record, share and synchronise transactions in their respective electronic ledgers, instead of keeping data centralised as in a traditional ledger. Blockchain organises data into blocks, which are chained together in an append-only mode.

The GII aims to capture the multi-dimensional facets of innovation and provide the tools that can assist in creating policies to promote long-term output growth, improved productivity, and job creation. The fundamental innovation components determining the GII are shown in Fig.1. The magnitude of the innovation factors in the developed and developing economies, including India, are shown in Table 3.

Figure 1: Factors in innovation ecosystem



Source: Author's own

Table 3:
Innovation factors in Select Developed & developing countries

Factor/ Country	China	France	India	Japan	USA
Researchers /million	1206	4307	216	5210	4313
Scientific and technical journal articles	426,165	69,431	110,320	96,500	408,985
R&D expenditure % of GDP	2.11	2.25	0.62	3.15	2.74
Hi-tech exports in billion US$	500 (24%)	100 (24%)	14 (7%)	83 (14%)	110 (14%)
Patents filed	1.33 million	16,000	45,000	0.32 million	0.6 million
Trademarks registered	3.7 million	0.3 million	0.3 million	0.45 million	0.55 million
Industrial design applications filed	0.65 million	15,000	10,500	30,000	45,000

Source: Word Economic Forum 2019-20

According to WIPO, the most researched areas are energy storage, new materials, biotechnology and chemicals based on the number of patents filed in those domains (See Table 4).

Table 4: Most researched areas

Segment	Theme
Energy storage	Perovskite, Li-Po batteries, Sodium-Ion batteries, Li-S, Organic thin layer solar cells, Electric double layer capacitors, Bio-fuel cells, use of carbon in capacitors.
New Materials	Nickel/ferric oxide catalysts, photo-catalysts, Hydrogen generation catalysts, Carbon quantum dots, flexible materials, photo-electrochemistry, laser melting, nano generators, cellulose nano-crystals.
Bio-tech	Zika virus infection, Genome editing, Immune therapy, Nucleic acid targeted cancer treatment, Intestinal bacteria, Intercellular signaling, Photo-thermal therapy.
Chemicals	Red-ox, neutron activation analysis, use of CO_2, organic metal structures.

Sources: World Intellectual Property Indicators 2019; World Economic Forum 2019

The Indian economy has become more market- and service-oriented, and is attracting increasing FDI through deregulation of markets and a favourable tax regime after the liberalisation of the 1990s. As seen from the experiences of developed economies, R&D can foster the growth of the present US$ 3-trillion Indian economy. In meeting the growth targets, the essential innovations are in the agriculture, manufacturing, transport, energy, digital governance, and medical sectors. The factors that could catalyse the growth of Indian R&D ecosystem include increased R&D investments, quality education, participation of private sector and universities, incentives for the startup companies, and reasonable taxes for startups.

R&D missions and spending

Investments in the R&D infrastructure and human resources are the primary requirements for any effort at innovation-driven economic development. According to 2020 statistics, the US and China contribute about 50 percent (US$ 0.85 trillion) of the global R&D spending, and eight more countries contribute 30 percent. France has spent 2.1 percent of its GDP (US$ 60 billion) consistently over the past two decades, and Japan allocates US$ 165 billion to R&D, or 3.15 percent of its GDP. China's R&D expenditure, meanwhile, witnessed an almost 30-fold increase from US$ 13 billion (0.7 percent of GDP) in 1990 to US$ 410 billion (2.8 percent of GDP) in 2018. Countries like Israel and Korea spend around 4.5 percent of their GDP for R&D.

> "R&D can foster the growth of the present US$3-trillion Indian economy."

For India, its fast-growing economy provides opportunities for capital, manpower and market to invest in scientific research and reap the socio-economic benefits. The country's R&D expenditure has tripled over the past two decades. During 2019, out of the total union budget of US$ 390 billion, the Government of India (GoI) allocated US$ 0.26, 0.74, 1.5, 1.77, 2.0 and 2.32 billion to the Ministry of Earth Sciences, Department of Science and Technology, Department of Space, Ministry of Science and Technology, Defense Research and Development Organization and the Department of Atomic Energy, respectively.[12] Table 5 shows the seven priority technology missions identified by India and the organisations involved.

Table 5: Priority technology missions of India[13,14]

Quantum Frontier
DST, DoS, DAE, DRDO, MEIT
Artificial Intelligence
DST, MEIT, DBT
Biodiversity
MoEF&CC, DBT
Bioscience for human health
DBT, DHR, DoH, DST, DAE
Deep Ocean Exploration
MoES, DBT, DoS, MNRE, ONGC, DRDO, GSI, NHO, NBA
Waste to Wealth
DST, DBT, MoEF&CC, MUD, SBA
AGNIi (Accelerating growth of New India's Innovations)
Invest India

DST- Department of Science & Technology;

DoS- Department of Space;

DAE- Department of atomic energy;

DRDO- Defense Research & Development Organization; **MEIT** – Ministry for Electronics & Information Technology; **DBT**- Department of Biotechnology;

MoEF&CC- Ministry for Env, Forest & Climate Change; **DHR**- Department of health Research;

DoH- Department of Health;

MoES- Ministry of Earth Sciences;

MNRE- Ministry for New &Renewable Energy;

ONGC- Oil &Natural Gas Corporation;

GSI- Geological Survey of India;

NHO- National Hydrographic Office;

NBA- National Biodiversity Authority;

MUD- Ministry for Urban Development,

SBA- Swatch Bharat Abhin

Source: Missions of the Indian Prime Minister's Science, Technology and Innovation Advisory Council

Education and researcher density

The measure of researcher intensity determines the number of patents filed, contribution to scientific journals, and industrial trademarks registered. According to the Times Higher Education (THE) ranking for 2020, based on 13 performance indicators—including teaching, research, citations, international outlook and industry outcome by technology transfer—the US tops the list with 60 universities in the top 200, followed by the UK with 28 and Germany, 24. The University of Oxford in the UK maintains the top position. and China has seven of its universities in the top 200. Six Indian universities occupy the top 500 list including the Indian Institute of Technology (IIT) and Indian Institute of Science (IISC). About 35 universities are in the list of the top 1,000.

India has more than 900 universities, 39,000 colleges and 10,000 standalone academic institutions. Based on the all-India survey on higher education conducted by the Ministry of Human Resource Development, after graduation only 12 percent of the students opted for post-graduation and a mere 0.5 percent of the students opted (around 0.16 million) for doctoral degrees.[15] Therefore the researcher intensity in India is only 216 per million—this is only 20 percent of that in China, and 4 percent of Japan's.

Over the years, successive governments have made efforts at improving the country's education system and, consequently, the research environment. For example, the National Policy on Education formulated in 1986 was modified in 1992 in an attempt to meet the contemporary and forward-looking needs of India's large youth population. This is in recognition of the need to improve higher education outcomes by strengthening primary school education.

The Ministry for Human Resource Development introduced in 2020 an integrated New Education Policy to try and meet the evolving dynamics in quality education, innovation and research, and to eliminate the shortage of human resources in the respective fields.[16] In 2019, the Prime Minister's Research Fellowship (PMRF) scheme was launched with an outlay of US$ 250 million—it is designed to attract the talent pool of the country to pursue doctoral programmes in top academic institutions. Meanwhile, in 2015, the Impacting Research Innovation and Technology (IMPRINT) programme was set up with an outlay of US$ 155 million aim to address the most relevant challenges in the field of engineering, technology, and self-reliance for translating research knowledge into viable technology products and processes.[12, 17]

Patents and Publications

The patents filed in China, France, Japan, USA and India classified based on resident/non-resident status is shown in Table 6. It indicates that nearly 75 percent of the patents filed by the Indians are non-residents. This can be explained by the fact that Indian universities are suffering from severe brain drain—and many researchers are leaving India to pursue careers in other countries. Indeed, a survey conducted in 2016 in five Indian universities[b] found that 65 percent of graduates aspire to move abroad, and for various reasons.[18] This shows that India must increase its R&D spending in both the government and private sectors if it is to attempt to retain the country's talent pool.

Table 6: Patents filed by residents/non-residents

Country	% of patents filed	
	Residents	Non-residents
China	90	10
France	85	15
Japan	80	20
USA	48	52
India	30	70

> "Successive governments have made efforts to improve the country's higher education and research ecosystem."

b Jawaharlal Nehru University (JNU), IIT-Delhi, Banaras Hindu University—Institute of Technology (BHU-IT), Indian Institute of Science—Bangalore (IISc), and Jammu University

Private and University participation

In 2020, the biggest contributor to R&D in India is the government (See Table 7). In developed countries, it was the business sector, followed by universities. These figures indicate that in the wealthier countries, R&D is largely market-driven—this characteristic increases the likelihood of product innovation and, consequently, their export potential. For India, because of the strains in financial resources, developing quality institutions and promoting cutting-edge research will only be possible with the active participation of the private sector. The government has initiated steps to stimulate the R&D spending of private business enterprises from the current 0.35 percent of GDP. Previously, about 42 percent of the global 500 R&D spenders have product research centres in India, a proportion that is projected to increase to 49 percent by the end of 2021. Efforts are also being undertaken to increase the total R&D expenditure in the strategic technological areas (Table 2) to 2 percent of GDP by 2022.[19]

Table 7: Role of agencies in R&D ecosystem

	China	France	India	Japan	USA
Business enterprise	78%	67%	42%	82%	78%
Government	15%	11%	53%	8%	11%
Higher education	12%	22%	5%	10%	11%

The top 10 universities in the world spend an average US$ 0.75 billion annually on research. Harvard University, for example, has an endowment fund of US$ 39 billion, followed by Yale, Texas, Stanford, Princeton, and MIT.[20] In order to cope up with the international scenario, , the GoI granted Institute of Eminence status to seven government universities and 12 private universities. The government shall provide US$ 125 million over five years to each of the 19 selected universities.[21]

Knowledge-based startups

Globally, hi-tech exports are dominated by aerospace technology, high-performance computers, pharmaceutical products, scientific instruments, and electric machinery. Monitoring the evolving nature of India's imports and exports can help identify innovation gaps. Although India's hi-tech exports increased six-fold from US$ 2 billion in 2000 to US$13 billion in 2019, the hi-tech imports[c] increased 10-fold from US$ 3.7 to 36 billion, during the same period. At the same time, the hi-tech exports of China increased 30-fold, from US$ 25 billion to US$ 654 billion. The increase in hi-tech exports was due to China's R&D expenditure, which witnessed approximately a 30-fold increase from US$13 billion in 1990 to US$$410 billion in 2018.[22] China is increasingly able to substitute defense imports with indigenous developments because of the increased spending in R&D. The increasing imports and decreasing exports in the hi-tech sector has created an impact on the overall trade profile of India. In 2020, the total defence budget of India was US$ 66 billion,[23] which almost equals the expenditure on the defence imports, including aircraft, ships, submarines, and missiles. According to data from the Stockholm International Peace Research Institute (SIPRI), nearly 10 percent of the worldwide defence exports by value are imported by India.[24]

The economic value of the Indian manufacturing sector is expected to reach US$ 1 trillion in 2025, thereby contributing to about 25 percent of GDP. The government's Foreign Trade Policy issued in 2015 for a period till 2020 was aimed to increase the value of trade to US$ 900 billion by aligning the flagship missions of Make in India, Digital India, and Skills India, to the objective of promoting exports.[25]

It is universally recognised that entrepreneurship among the young population, through the creation of startups, is considered a key element for societal change, economic expansion and innovation. India acknowledges such a link, too, and the government under the 'Start-up India' initiative aims to promote research parks, technology business incubators, and patent management companies that would promote innovative ideas until they become commercial ventures. These initiatives are based on startup policy and implementation, incubation support, seed funding, angel and venture funding, simplification of regulations, easing public procurement, and outreach.[26]

The present Indian R&D ecosystem is the world's third largest, having received a total funding of US$ 4 billion, comprising some 20,000 startups, 280 incubation and business acceleration programmes,[d] 200 global and domestic

c Aerospace, computers, scientific instruments, electrical machinery and advanced electronics

d Incubators are organisations that nurture disruptive business ideas with the intent of building a business model or a new company through their Indian mentoring and structured services. Incubator organizations directly work with startups in developing their entrepreneurial skills, such as creating and testing a prototype and understanding the market.

venture capital firms supporting home grown startups, and a fast-growing community of 231 angel investors and eight angel networks. Out of 20,000 startups, around 5,000 are tech-led startups, in which about 15 percent are in involved in AI, blockchain, storage, computing as a service, and robotics. The government has targeted to increase the number of incubators to 1,000, for which US$ 37 billion is allocated.[27]

The R&D industry in India is regulated by the Department of Scientific and Industrial Research (DSIR), which is under the Ministry of Science and Technology. Organisations part of DSIR include the Council of Scientific and Industrial research (CSIR), Consultancy Development Centre (CDC), Central Electronics Limited (CEL), National Research Development Corporation (NRDC) and the Asian and Pacific Centre for Transfer of Technology (APCTT). Mechanisms such as Transfer of Technology were introduced to accelerate R&D across industry segments and increase the operating efficiency, product development, competitive advantage and technological advancement. The Department of Industrial Policy and Promotion (DIPP) provides a framework to reduce the processing time for Intellectual Property Rights to encourage innovation and entrepreneurship in the country. The organisation, Accelerating the Growth of New India's Innovations (AGNIi), supports ongoing efforts to boost the innovation ecosystem by connecting innovators across industry, individuals and the grassroots to the market and to help commercialise their innovative solutions. The Biotechnology Industry Research Assistance Council (BIRAC) supports high-risk, early starters from academia, startups, or incubators that have exciting ideas in the nascent or planning stage. The government think-tank, NITI Aayog and the Institute of Competiveness have released the India Innovation Index 2020—it reports that the top three states in innovation environment are Karnataka, Maharashtra and Tamil Nadu.[28]

The Israel-India Innovation Bridge, India-Singapore Entrepreneurship Bridge, India-Portugal Start-up Hub, and India-Sweden Start-up Sambandh have been formulated to facilitate bilateral cooperation in the innovation domain with other countries. To accelerate the startup ecosystem in India, initiatives, such as reduction of corporate tax by 25 percent for companies with turnover of US$ 33 million, US$ 27 million allocation to Atal Innovation Mission with a target of setting 600 new Atal Tinkering Labs in 1500 schools across India, US$ 100 million to 70 technology incubators and about US$ 13 million for the entrepreneurship schemes.[29] India is also an active member in the Mission Innovation, a global initiative comprising 24 countries and the European Union working to accelerate the clean energy innovation, including smart grids and off-grid access to electricity, energy generation, transmission and energy storage.[30]

Conclusion

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The experiences of successful countries show that science, technology and innovation policies that are integrated into national development strategies can help raise productivity, improve competitiveness, and foster economic growth. For India, various initiatives have pushed the country up in the global innovation index from 57th position in 2018 to 48th in 2020. Strategic efforts are required for stimulating the innovation ecosystem for encouraging ambidextrous, multipolar and disruptive innovations to meet the dynamic market conditions, urbanisation needs, and environmental sustainability. Sustained increase in the research and development spending from the current level of 0.62 percent of GDP to the level spent by developed countries is essential if India is to aim to create world-class research facilities, improve the quality of education, increase the participation of the private sector and universities, and encourage startup companies.

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