TARUN KHANNA*
Harvard University

Science-based Entrepreneurship in India: A Policy Glass (as yet) Quarter-Full§

ABSTRACT India is celebrated for a resurgence of de novo entrepreneurship in recent decades. Entrants have engaged in creative risk-taking to provide market-based solutions for private or social needs despite not being scions of wealthy industrial or business families. In this policy piece, I first document and celebrate this rise of entrepreneurship. I then turn to the inconvenient fact that this entrepreneurship is heavily circumscribed in a handful of sectors, even more so than the similarly skewed incidence that one sees in the US ecosystem (as an imperfect benchmark). A gaping lacuna is the lack of what I refer to as science-based entrepreneurship, increasingly understood as perhaps the key source of long-run dynamism of mature economies.

The academic evidence is compelling. Science, through the recombination of past insights, provides the fuel for innovative entrepreneurial economic output. This requires universities that are not ossified into traditional silos, as well as vibrant local ecosystems that allow the translation of science into entrepreneurship.

Then, I turn to relevant policy efforts underway in India within the last decade to address this lacuna. Preliminary data indicate that these experiments are likely on successful trajectories. They are, however, deeply insufficient in the magnitude of investment and policy ambition. The rhetoric and reality must be rethought if India is to capitalize on its deep talent reservoirs and move on from what I see as a glass yet only quarter-full.

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* *tkhanna@hbs.edu*

§ This paper draws on the author's academic work and, more importantly, that of dozens of his colleagues in the US, Europe, and India. It is also informed by his experiences as an entrepreneur across the developing world and by his policy advocacy in India since 2015 through the good offices of NITI Aayog and the Office of the Principal Scientific Adviser (PSA) to the Government of India. Recent conversations with individuals from the Atal Innovation Mission (AIM); Office of the PSA to the Government of India; Ministry of Defence, Government of India; Delhi Science and Technology Cluster; and Indian Institute of Technology, Madras, were very helpful, as were discussions with Lee Fleming (Berkeley), Ramana Nanda (Imperial College, UK), Jasjit Singh (INSEAD, Singapore), and Chintan Vaishnav (NITI Aayog, AIM). Radhika Kak, Mansoor Masood, and Vidhya Muthuraman of the Harvard Business School, India Research Center, supported the writing of this paper.

1. Growth in Indian Entrepreneurship

As of 2022, India has the third largest startup ecosystem in the world after the US and China, with over 65,861 recognized startups that have cumulatively created over 700,000 jobs (Press Trust of India 2022) India's startup ecosystem development has been driven by a confluence of factors internal to the country (particularly the creation of a digital public infrastructure and the recognition by the State of the importance of entrepreneurship) and the vagaries of geopolitics and global capital flows.

There has been a 32 percent per annum growth in funding over the last decade. Venture Capital (VC) and Private Equity (PE) funding increased from

$3.1 billion in 2012 to a record $38.5 billion in 2021 (Bain & Company, and Indian Venture and Alternate Capital Association 2022) (see Table 1), with VC funding accounting for more than half of this. Both the number of deals and average deal size increased. Deal activity increased particularly in Series A, indicative of greater risk appetite for early-stage startups, and Series C and beyond, driven by multiple follow-on rounds by existing investors and an increased number of late-stage companies, both characteristics of a maturing startup ecosystem. More investors are participating in the startup ecosystem. The number of VC investors increased from 327 in 2012 to 455 in 2021 (see Table 1) (Statista 2022a). New members at angel investment firms rose ~7.5x between 2019–21 (Hariharan 2021).

TABLE 1. Startup Funding and Number of VC Funds in India

Year	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*	*2021*
Number of VC funds in India	327	341	355	370	374	381	402	418	431	455
Total funding (US $ billion)	3.1	2.9	4.6	6.3	4.8	4.7	6.6	11.1	10	38.5
Average deal size (US $ million)	6.8	4.9	6.7	6.4	5.6	8.1	11.5	14.7	12.4	24.9
Number of deals	458	593	684	987	854	589	571	756	809	1,545
Number of deals by- deal size										
< US $10 million	N.A.	N.A.	N.A.	N.A.	728	485	410	543	637	1,135
US $10–US $50 million	N.A.	N.A.	N.A.	N.A.	115	89	136	171	128	270
US $50–US $100 million	N.A.	N.A.	N.A.	N.A.	4	3	8	20	24	48
> US $100 million	N.A.	N.A.	N.A.	N.A.	7	12	17	22	20	92

Source: India Venture Capital Report 2022 (Bain & Company, and Indian Venture and Alternate Capital Association 2022), SEBI 2018.

Note: The number of funds registered includes Registered Venture Capital Funds and Registered Foreign Venture Capital Investors.

Foreign investors are increasingly investing in Indian startups. Several factors have contributed to this. The Chinese startup ecosystem, India's biggest competitor, is highly saturated with too much capital chasing too few assets, while India's is relatively underpenetrated. US-China geopolitical tensions and the Chinese Communist Party's regulatory action against the country's tech ecosystem have also played a role. SoftBank, one of China's most prominent foreign investors, said it intended to take a 'more cautious approach' to back the country's startups' while it has continued to build its India portfolio (Rascouet and Pavel 2021). US-based Tiger Global, also a big investor in China, increased investment activity in India. In 2021, it was the second-largest investor by deal volume (Bain & Company, and Indian Venture and Alternate Capital Association 2022; Bhattacharya 2021).

Better prospects for secondary sales have also driven greater institutional investor participation in startups. The value of VC exits was a robust $14.3 billion in 2021, a far cry from scant exits in recent decades. The robustness was accentuated by this being a mix of secondary market strategic sales (60 percent of total VC exits) and primary capital raises through IPOs (40 percent) (Bain & Company, and Indian Venture and Alternate Capital Association 2022).[1]

The SEBI's 2022 regulatory framework, which proposed disclosure requirements for loss-making companies, has alleviated some of the capital constraints faced by startups and increased the number of VC-funded companies listing on Indian exchanges. The new framework made it possible for loss-making companies to release Key Performance Indicators (KPIs), along with the disclosure of the standard financial ratios, during the listing process. Companies had the discretion to determine the specific KPIs and justify their use (Securities and Exchange Board of India 2018).

SEBI's Innovators Growth Platform, launched the same year, and aimed at relaxing listing requirements for issuers in technology or IP intensive fields such as IT, bio-technology and data analytics, has also helped. The platform relaxes restrictions on pre-issue capital, allows discretionary placements of an issue and listing of shares with differential voting rights, and simplifies delisting requirements. Arguably, these are signs of somewhat greater investor sophistication and greater regulatory comfort with earlier stage and riskier assets becoming available in the market.

Higher valuations, too, have encouraged investors. In May 2022, India became the third country to produce 100 unicorns after the US (559 unicorns) and China (173 unicorns). India has seen an acceleration in unicorn generation; 44 unicorns emerged in 2021 versus 42 in China. In Q1 2022, India added 14

1. There was much exuberance around the recent IPOs of Zomato (a restaurant aggregator and food delivery app that raised approx. $1.25 billion), and Nykaa (an omnichannel retailer of beauty and related products that raised approximately $715 million). The resilience of these business models will become clear over time.

unicorns compared with 5 in Q1 2021. India's 100 unicorns have raised $90 billion and are valued at over $333 billion. They have acquired 326 companies and created employment for 380,000 people (Inc42. 2022).

The promulgation of government initiatives to nurture entrepreneurship has helped particularly by signaling the support of the State for the phenomenon. For example, the "Startup India" initiative, launched in 2016 under the Ministry of Commerce and Industry, is an important such endeavor (Government of India 2020c). The Atal Innovation Mission (AIM), also launched in 2016 under the NITI Aayog, and therefore equidistant from all ministries, is another. The AIM seeks to improve educational opportunities for school-aged children, promote R&D, and connect various stakeholders through a network of incubators.

A maturing digital infrastructure has been a catalyst, and is itself in a sense a result of an encouraging symbiosis between the State and private sector entrepreneurs. India is one of the few countries that has built digital public goods at scale. Unlike the US and China, where private companies and the government facilitated the creation of digital infrastructural assets, in India, a combination of public-private partnerships and volunteer-driven initiatives has contributed to the creation of digital platforms and technologies. An example of this is India Stack, a series of platforms that have emerged to solve constraints to financial inclusion and support the government's Digital India initiative. Through digital identification (Aadhaar), interoperable payments (the Unified Payment Interface), and data management, India Stack has led transformations in digital and financial inclusion. Aadhaar provided digital IDs to more than 95 percent[2] of the population and lowered the cost of verifying IDs, making it easier to deliver banking and other services (International Monetary Fund 2021). The Unified Payment Interface (UPI) has made bank-to-bank transfers free and seamless via mobile phone, accelerating the adoption of digital payments. This has helped digital services startups increase market penetration and e-commerce companies reduce cash on delivery orders. Over 22.3 billion transactions worth $547 billion were made through UPI in 2020–21, signifying a 78 percent increase in volume and a 93 percent increase in value from a year earlier (Reserve Bank of India 2021; Inc42. 2022). Furthermore, low data prices,[3] pushed down by market competition (Cable.co.uk 2022), increased internet penetration from 4 percent in 2007 to 45 percent in 2021, and monthly data consumption per user from 805 MB in 2015 to 17 GB in 2021 (Statista 2022b; Nokia 2022). The Aadhaar-driven electronic Know Your Customer (e-KYC) has enabled companies to evaluate credit histories more efficiently and offer financial products in a paperless format. Through all this, Bangalore has emerged as the startup hub of India, being listed in the top 10 startups cities in the world (StartupBlink 2022) and the third-best in Asia, behind Beijing and

2. Aadhaar enrolment data from UIDAI Annual Report 2020–21.

3. The cheapest GB of data in India is as low as $0.05.

Shanghai (StartupBlink 2022). In 2021, it accounted for half of all VC funds raised, 40 percent of all deals (Inc42. 2022), and was home to 14 of the 25 most funded startups (Entrackr 2021).

2. Weaknesses in the Indian Startup Ecosystem

Notwithstanding the progress, India's emerging entrepreneurial ecosystem continues to face considerable challenges.

Early-stage investments are disproportionately channeled into a few sectors. Over the last decade, investors predominantly invested in the e-commerce, technology, and financial services sectors, in that order, while other sectors like healthcare, agriculture, and ideas emanating from the natural sciences, received limited funding (see Table 2) (Indian Venture and Alternate Capital Association, Ernst & Young 2022; Entrackr 2021).[4] The fact that 65 of India's 100 unicorns are in the e-commerce, fin-tech, and IT-services sectors and not a single unicorn is based on advances in the natural sciences is a testament to this (Inc42. 2022).

TABLE 2. Startup Investments Split by Sector: 2011–20

Industry	*Number of Deals*	*Funds raised (US $ million)*	*% of Total*	
			Number of Deals (%)	*Funding (%)*
E-commerce	805	13,311	23.9	39.2
Technology	738	5,183	22.0	15.2
Financial Services	397	5,052	11.8	14.9
Logistics	209	2,044	6.2	6.0
Infrastructure	190	1,455	5.7	4.3
Healthcare	178	1,297	5.3	3.8
Media & Entertainment	174	915	5.2	2.7
Education	132	901	3.9	2.7
Real Estate	128	828	3.8	2.4
Food and Agriculture	126	746	3.7	2.2
Others	285	2,264	8.5	6.7

Source: India Trend Book 2021 (Indian Venture and Alternate Capital Association, Ernst & Young 2021).

A recent study of India's deep-tech startup ecosystem claimed that 12 percent (or approximately 3,000+) of India's startups in 2021 were deep-tech startups, i.e., startups that created, deployed, or utilized advanced technology like AI,

4. Between 2011 and 2020, there were 805 deals in technology, 738 in e-commerce, and 397 in financial services, but only 178 in healthcare.

machine learning, internet of things, drones, etc., in their products or services, and only a small pool of these startups (about 500) created products or solutions that were backed by fundamental research (NASSCOM and Zinnov 2022). The study classified these as 'inventive deep-tech' startups. These classifications are, to some degree, subjective, but it appears true that very few startups in India involve deep scientific advance (some sectors, like life sciences, are almost entirely absent) (NASSCOM and Zinnov 2022).

Gender parity in funding is also an issue. Between 2018 and 2022, startups with women co-founders accounted for 17 percent of the number of fundraising deals and 6.4 percent of funds raised. Solo female founders accounted for an even smaller share; 3.4 percent of all deals and 0.78 percent of funding value (YourStory Media 2022). Various government, corporate, and investor-led programs, like the NITI Aayog Women Entrepreneurship Platform,[5] the Telangana government's WE Hub,[6] and the Godrej group's Beauty-prenuer program,[7] have targeted boosting female entrepreneurship. Still, these initiatives are few and far between.

The competition and incentive-based innovation infrastructure is also anemic. Developed countries use incentives to boost innovation, particularly in science and technology. Some examples are the UK "Grand Challenges",[8] the US federal government platform, challenges.gov, and the competitions run by the Chinese government. In contrast, in India, competition-driven innovation is still emerging. While the AIM has launched a few competitions to promote innovation, and India recently began hosting a local version of Shark Tank, a US reality show that has inspired entrepreneurship in young adults (Roy and Aziz 2022), to rally support among the public for this kind of approach, these efforts to broad-base incentives are at an early stage.

Though incubators have been growing, their number and quality is as yet inadequate. In 2019, there were only 0.4 incubators and accelerators per million people in India, compared with 4.5 in the US and 2.1 in China. Further, many incubators are housed within academic institutions and operate in silos with insufficient interaction and partnership with the outside world. Hence, many early-stage startups miss out on the networking, mentoring, and funding opportunities most critical for success.

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5. A platform to provide women entrepreneurs funding assistance, mentorship, and other support. It currently has over 26,000 women and 200 partner organizations.

6. The Telangana Government's initiative to incubate women entrepreneurs by providing access to technical, financial, and mentoring support.

7. A program that supports small-scale women-led beauty enterprises by building technical and business management competencies, and creating a community of women to network, share and learn.

8. Part of the UK Government's endeavor to put UK at the forefront of the industries of the future. The first four challenges are AI and data, ageing society, clean growth, and the future of mobility.

Well-known gaps exist in the Indian education system. Its rigid emphasis on rote learning impedes students' creative and analytical thinking, practical learning, and communication skills. These skills are vital for entrepreneurship. A recent study found that despite consistent talent shortages in the IT industry, less than 20 percent of engineers are employable for software jobs and only 3.5 percent for core IT product roles (SHL 2019).[9]

Finally, notwithstanding the progress made to streamline regulatory processes by the introduction of the Goods and Service Tax, and self-certification for compliance with labor law under Startup India, the regulatory environment remains complex. Entrepreneurs have to deal with numerous agencies to obtain the permits required to start a business. Weak enforcement of intellectual property rights is an issue. Further, due to a backlog of cases and insufficient judicial capacity resolving disputes in Indian courts is a lengthy process. Early-stage startups spend considerable time and resources on regulatory issues, which diverts attention away from core business building.

3. Specific Institutional Voids Relevant to Science and Tech Entrepreneurship

In earlier writings, I co-developed (with Krishna Palepu) a simple taxonomy for thinking about the structural inadequacies that bedevil the bringing together of buyers and sellers to consummate transactions in so-called emerging markets. In other words, what particular combinations of information or contracting problems make a market 'emerging' rather than one that has matured or 'emerged' (Khanna and Palepu, 1997; Khanna et al. 2010)?

Relative to more mature economies, entrepreneurs in emerging markets find it difficult to access information about each other, evaluate credit histories, and credibly ascertain the quality of products and services. When disputes arise, contractual or arbitration mechanisms to resolve these are limited or inefficient. Mature economies rely on a network of specialized intermediaries such as independent auditors, financial and other analysts, media agencies, headhunters, a government to promulgate rules, and a judiciary to enforce them (see Table 3). We refer to the absence or paucity of such intermediaries as institutional voids.

With regards to science and deep-tech entrepreneurship in India, woeful informational and contracting voids in talent and capital factor markets manifest in several arenas, such as these below.

9. SHL's "National Employability Report: Engineers Annual Report 2019." Such reports were first published by the company acquired by SHL, based in New Delhi, called Aspiring Minds.

TABLE 3. Institutional Infrastructure in a Developed Market

Type of Market Institution	*Function that it Performs*	*Examples in Capital Markets*	*Examples in Product Markets*	*Examples in Talent Markets*
Credibility enhancers	Third-party certification of the claims by suppliers or customers	Audit committees; Auditors	ISO certification; CMM level certification	AACSB certification; ETS admission tests
Information analyzers and advisors	Collect and analyze information on producers and consumers in a given market	Financial analysts; Credit rating agencies for companies and individuals; Financial press; Financial planners; Investment bankers	Consumer reports magazine; J.D. Power ratings; Press; Industry analysts (Gartner Group); Market research firms; Autobytel; Management consultants; Audit Bureau of Circulation	Publications ranking universities and professional schools; Career counsellors; HR consultants
Aggregators and distributors	Provide low-cost matching and other value added services for suppliers and customers through expertise and economies of scale	Banks; Insurance companies; Mutual funds; Venture capital; Private equity funds	Trading companies; Mass retailers	Universities; Professional training institutions; Labor unions
Transaction facilitators	Provide a platform for exchange of information, goods and services, provide support functions for consummating transactions	Stock, Bond, and Futures exchanges; Brokerage houses	eBay; Commodities exchanges; Credit card issuers; PayPal	Executive recruiters; Job announcement websites
Adjudicators	Resolve disputes regarding law and private contracts	Courts and arbitrators; Bankruptcy specialists	Courts and arbitrators	Courts and arbitrators; Union arbitration specialists
Regulators and other public institutions	Create the appropriate regulatory and policy framework, and enforce it	SEC; FASB; NASD	FDA; EPA; Consumer Product Safety Commission; FCC; FTC; FAA	OSHA; Equal Employment Opportunity Commission; Unemployment Insurance Agencies

Source: Khanna, and Krishna Palepu (with R. Bullock) 2010.

3.1. The State of Education in India

India has the world's largest school-aged population[10] of ~370 million (Population Pyramid 2022). Unfortunately, only about 260 million kids are in school (British Council 2019). In 2020, the higher secondary enrolment ratio in India was 52 percent (Government of India 2020e), compared with 88 percent in China and 99 percent in the US (World DataBank 2022). The quality of school education is also poor and appears even to be deteriorating by some measures. A recent survey of over 20,000 government school students found that the proportion of Grade 3 students who can read Grade 1 text and recognize double-digit numbers decreased from 41 percent and 75 percent in 2014 to 24 percent and 60 percent in 2020 (ASER Centre 2021).

India also lags on tertiary education (TE) enrollments.[11] Its TE enrollment ratio was 29.4 percent in 2020, versus China's 58.4 percent, EU's 73 percent, and USA's 87 percent (World DataBank 2022). India's education policy targets reaching a ratio of 50 percent by 2035 (Government of India 2020e).

In 2019, 38.5 million students (Government of India 2020e) were enrolled in higher education studies. Of these, 30.6 million are enrolled in undergraduate programs. Around 25 percent of undergraduates are enrolled in science-based programs; including 4.7 million in B.Sc., 2.1 million in BTech, 1.5 million in engineering (Government of India 2020e), and 1.3 million in medical sciences.[12] Of the 6.7 million students who complete their undergraduate degree yearly (Government of India 2020e), 12.5 percent receive engineering and tech degrees (Government of India 2020e; University Grants Commission 2022).[13]

Besides enrollment, the scarcity of high-quality science-based undergraduate programs is another limitation of the current tertiary education system. Over 2.2 million students (Blume Venture Capital 2022) sit for the IIT entrance exams for 16,000 seats, equating to an acceptance ratio of 0.72 percent (Blume Venture Capital 2022). The effective acceptance ratio plummets to 0.3 percent if one accounts for the reservation of over 60 percent of seats for students from backward classes and economically weaker backgrounds. The reservations are warranted as a matter of attempting to level the playing field, but they come at the cost of short-run reduction of scarce seats for currently prepared-talent that might otherwise have been accommodated. This is, of course, a conundrum

10. Children between the ages of 5 and 19 years.

11. Tertiary education refers to all higher education after 12 years of schooling.

12. Medical sciences include nursing, pharmacy, pathology, physiotherapy, homeopathy, and Ayurveda.

13. While the Ministry of Education includes dairy technology, urban planning and transportation planning in its definition of "Engineering & Technology," students receiving an undergraduate degree in these courses represent less than 0.5 percent of all graduates. Engineering graduates account for ~90 percent, while IT and architecture account for 5 percent and 1.7 percent, respectively.

common to all societies, not just India, as the Harvard historian and China scholar, Michael Szonyi, and I explore in a recent co-edited volume, Making Meritocracy (Khanna and Szonyi 2022).

In comparison to the selection rates of elite Indian institutions, top-quality undergraduate engineering programs at US universities such as Stanford, Cornell, MIT, and Princeton, which attract global talent, have acceptance rates of between 5 percent and 10 percent. Consequently, many high-caliber students in India are forced to settle for second-rung colleges or go to foreign educational institutes. The number of students attending overseas universities increased from 56,000 in 1999 to 589,000 in 2019 (Blume Venture Capital 2022). While ed-tech companies and other open-source digital resources are enabling access to top-quality resources online, the absence of adequate high-quality physical educational institutions is a systemic void.

As the average STEM student receives a low-quality education, they are not readily employable after graduation. The educational system's emphasis on rote learning deprives students of sufficient practical learning opportunities. There is little interaction between academia and business; consequently, students are offered few opportunities to understand how science and technology can be applied in real-world situations. By the time students reach higher education levels, they lack the creativity, critical thinking skills, and open-mindedness required to become successful innovators and entrepreneurs (Government of India 2020b). Furthermore, Indian educational institutes provide little training on soft skills like communication and negotiation, among others, a disadvantage that persists over time. Indian entrepreneurs tend to under-network, possibly because they lack the necessary social skills (Dimitriadis and Koning 2021). Entrepreneurial education, including training on spotting trends, evaluating product-market fit, and so on, represents another gap in the education ecosystem.

Given the inadequacies of the education system, the findings of a 2019 Aspiring Minds study pointing to the unemployability of graduates should come as no surprise. The study found that less than 20 percent of engineering graduates are employable for software jobs, less than 8 percent for core engineering jobs, and only 4 percent for core IT product jobs (see Table 4) (Statista 2019a). The founder of one of India's largest IT services companies, Infosys, commented, "Engineering colleges in India are churning out only 25 percent quality engineers and nearly 80–85 percent of youngsters are not suitably trained for any job (India Today Web Desk 2021)." India is currently short of 500,000 workers in tech. By 2026, this gap is estimated to widen to 1.4 – 1.9 million workers (Malik 2022). Deficits are particularly pronounced in new-age digital skills like AI, big data analytics, the Internet of things, and cloud computing, where there is a current shortage of 140,000 workers, up from 62,000 in 2018 (Malik 2022).

Not many students continue education beyond the undergraduate level. Of every 100 undergraduates, 23 receive a graduate degree, and 0.6 a Ph.D. degree

(Government of India 2020a). India has half the number of graduating doctoral students compared to China and the US (Aggarwal 2018). These figures are partly representative of an inadequate number of higher education programs. A 2019–20 report found that only 35 percent of Indian higher education institutions run post-graduate level programs, and only 2.7 percent, Ph.D. programs (Government of India 2020a). Of the 200,000 students enrolled in Ph.D. programs, around half go into engineering, technology, and science-based programs, showing clear interest in these fields (Government of India 2020a).

TABLE 4. Employability of Engineering Graduates in India

Particulars	*2020 (%)*
Employability of engineering graduates in India – by job role	
IT Engineers:	
Associate – ITeS operations (hardware and networking)	36
Software engineer – IT services	16
Startup ready – IT services	4
Software engineer – IT product	3
Chemical design engineer	8
Mechanical design engineer	7
Electronics design engineer	7
Design engineer – non-IT	7
Electrical design engineer	6
Civil design engineer	5

Source: All India Survey on Higher Education 2019-20 (Government of India 2020a), "National Employability Report".

As low numbers of students receive graduate degrees, academic research in India lags behind that in other countries. The ecosystem for research as a career path is largely missing, with insufficient rewards and recognition for those who enter the field. Indian higher education institutions also underspend on research, spending US $3 billion on average, versus US $24 billion and US $62 billion by institutes in China and the US, respectively. As of 2018, India had 156 researchers per million citizens, versus 4,205 and 1,089 in the US and China, respectively, and a global average of 1,500 (UNESCO Institute for Statistics 2022). Between 1996 and 2020, India ranked seventh globally in the number of science and tech research publications, with 2 million published articles, while the US and China, the leading countries, published 14 million and 7 million articles, respectively (Scimago Journal & Country Rank 2020). By 2018, India's cumulative contribution to global scientific research was merely 5 percent, compared with China's 21 percent and the US's 17 percent (National

TABLE 5. R&D Spend as a percent of GDP, Patents, Research and International Co-authorship

Year	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
Percentage of GDP spent on R&D								
United States	2.8	2.7	2.7	2.7	2.7	2.8	2.8	2.8
China	1.8	1.9	2.0	2.0	2.1	2.1	2.1	2.1
India	0.8	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Number of patent applications to the US Patent and Trademarks Office								
China	10,545	13,273	15,093	18,040	21,386	N.A.	N.A.	N.A.
India	4,548	5,663	6,600	7,127	7,976	N.A.	N.A.	N.A.
Percentage of patents granted by the US Patent and Trademarks Office								
China	1.5	1.9	2.2	2.4	2.8	N.A.	N.A.	N.A.
India	0.5	0.6	0.8	0.9	1.0	N.A.	N.A.	N.A.
Percentage of patents granted by the Indian Patent Office								
Indians	17.0	16.0	17.4	15.0	11.4	14.5	13.4	14.8
Foreigners	83.0	84.0	82.6	85.0	88.6	85.5	86.6	85.2
Number and percent of total, science & engineering articles published- by country								
United States								4,22,808 (17%)
China								5,28,263 (21%)
India								1,35,788 (5%)
Percentage of papers with international co-authorship (2019)								
United States								40.9
China								23.0
India								18.9

Source: Research and Development Statistics 2019–20 (Ministry of Science & Technology, Government of India 2020d), World Bank, Economics of Industrial Research & Innovation–European Commission, National Science Foundation, UNESCO Science Report 2021.

Science Foundation 2019). A survey of highly cited papers by country showed India lagged China by a factor of six (Aggarwal 2018).

3.2. Lack of Funding for Scientific Research and Entrepreneurship

A bedrock of independent, inquiry-based research is a sine qua non for scientific progress, innovation, and ultimately long-term growth. The US research ecosystem is fueled by government spending. Over decades, about a third of US patents rely on federally funded research, and these tend to be the patents that are more cited, and more commercially valuable (Fleming et al. 2019).

India's persistent underfunding of basic research represents perhaps the most significant headwind to science-based entrepreneurship. India spends less than 1 percent of GDP on R&D, a ratio that has, in fact, been declining over time (see Table 5). In contrast, Germany allocates nearly 3 percent of GDP to R&D, the US spends 2.5 percent, and China, more than 2 percent. Global leaders like Israel and South Korea dedicate over 4 percent of GDP to R&D, while advanced European economies, between 3 percent and 4 percent. Other BRICS countries also spend more on R&D as a percent of GDP. Even after adjusting for PPP, the US spends ten times more, and China seven times more than India, on R&D (see Table 6). Further, funding models for R&D are not always linked to performance metrics such as research publications, patents, or number of researchers.

TABLE 6. R&D Spend Percentage, by Segment of the Economy and PPP Adjusted Spending, US $ billion

Country	*Government (%)*	*Business (%)*	*Universities (%)*	*Private Non-profit (%)*	*Total Spend (US$ billion)*
US	11	72	13	4	476
China	16	77	7	N.A.	346
India	56	37	6	N.A.	47

Source: UNESCO Institute for Statistics 2022.

Low R&D spending limits India's technological advancements. Patent filings, for example, are one rough indicator of a country's technological progress. In 2002, both China and India filed close to 800 patent applications at the US Patent and Trademark Office (USPTO), of which 390 were granted to China, and 267 to India. In 2015, China filed over 21,300 applications while India filed less than 8,000 (U.S. Patent and Trademark Office 2022a). From 2002 to 2015, the share of foreign patents issued by the USPTO to China increased from 0.4 percent to 5.3 percent, while India's share increased only from 0.3 percent to 2 percent (U.S. Patent and Trademark Office 2022b). Even within India, only 15 percent of patents issued by the Indian patent office accrue to Indians and Indian companies, while the remaining are issued to foreign nationals and corporations (see Table 5). Streamlining of patent processes, and greater education of entrepreneurs regarding intellectual property rights (IPR) can help. The government has also experimented with subsidizing patent fees for startups and providing free counselling to navigate the filing possibilities (Press Information Bureau, Government of India 2023). These are sensible steps. Yet, despite improvements, India's patenting in 2020 is still roughly only a tenth that of the US, and lags China even further (Sanyal and Arora 2022). Given the general paucity of funds, it is unsurprising that ideas emanating from untested science find it difficult to attract funding. Science and deep-tech startups typically have a limited sense of commercial viability when they apply for funding. Investments in such ventures present a higher risk of failure than in more traditional segments. Furthermore, it can often be challenging for VC executives to accurately assess the research or technology proposed by such startups. VC firms also find it challenging to match entrepreneurs' needs for capital over long-term horizons, as they operate under finite time frames for returning capital to their own investors.

These factors make it imperative for society—including but not limited to the government—to find ways to fund science-based startups that emanate from novel science, initially by using funds of the sort not available through VCs for de-risking this science. The Biotechnology Industry Research Assistance Council (BIRAC) under the Department of Biotechnology of the Ministry of Science and Technology represents a small but encouraging start. BIRAC has funded nearly 500 med-tech companies, helping bring more than 50 products to the market (Rajan et al. 2021). On the whole, however, government spending on R&D remains grossly insufficient (see Table 5). One reason for this is the belief that R&D spending is a 'luxury that India cannot afford (Kumar 2019).' With a GDP per capita of US $6,500 in PPP terms (World DataBank 2022), India is still a relatively poor country. There is enormous pressure to spend constrained resources on building critical infrastructure rather than on categories viewed as non-essential, including research. The concentration of government spending on R&D is also a problem. More than 50 percent of government R&D funds are allocated to two agencies, the Defence Research & Development Organization (DRDO) and the Department of Space (DOS) (Government of India 2020d). Other agencies, such as the Indian Council for Medical Research and the Ministry of Environment, Forest and Climate Change, receive little funding, limiting their research output.

Although the private sector's contribution to total R&D spend is increasing, from 25 percent in 1991 to 37 percent in 2018, it lags behind other countries. In the US and Germany, the share of private sector funding of R&D is ~70 percent (UNESCO Institute for Statistics 2022). While profit as a percent of GDP at Indian firms has increased from 0.8 percent in 2003 to 2.2 percent in 2018 (Statista 2019b), there has not been a proportional increase in R&D

investment. In 2020-21, Indian listed companies spent 0.9 percent (Oberoi 2020) of revenues on R&D, versus S&P 500 companies, which on average spent 4 percent. Only one Indian company, Tata Motors, featured in the list of top 100 global spenders on R&D, while the list featured 38 companies from the US, 14 from Japan, 12 from Germany, and 8 from China. Average R&D spend across the top 100 spenders was a whopping 7.5 percent of total revenue. Of the top 2,500 spenders on R&D, only 29 companies were Indian. Of these, 21 operate in just three sectors: pharmaceuticals, automobiles, and software. Even within the pharmaceutical industry, an area of strength for India, firms spend only 8 percent of revenues (India Brand Equity Foundation 2021) on R&D, while US firms spend 21 percent on average (Statista 2021; Drug Discovery & Development 2022).

Private sector spending on R&D has languished for many reasons. One reason is the scarcity of basic publicly-funded research that the private sector can build upon. Indeed, the roots of many commercially used products can be traced back to research funded by universities or the government. In the 1970s, the US Department of Defense (DoD) funded research to develop the 'Global Positioning System' (GPS), a satellite navigation system. This technology was later made available for public use and is now an invaluable facet of everyday consumer products such as cars and phones (NASA 2012; Comen and Suneson 2019). The Internet was developed by the Advanced Research Projects Agency, a DoD-funded computer science research project that aimed to allow scientists and researchers to share information, knowledge, and findings (Free Code Camp 2020). The Human Genome Project, publicly funded by the US Department of Energy and US National Institutes of Health, brought together scientists from across the world (Office of Science and Office of Biological and Environmental Research, US Department of Energy 2019) to discover the complete set of human genes and the sequence of DNA bases in the human genome. The findings have transformed biology (Office of Science and Office of Biological and Environmental Research, US Department of Energy 2019). Some of the most innovative products today, including the reusable rocket system developed by SpaceX, LED bulbs, the Apple iPad, and Amazon's Kindle, are the results of R&D investment by private companies (Ryan 2019) in technologies that represent the de-risking of publicly funded science. In the US, this conceptual framework—the idea that the fruits of publicly-funded research are equally accessible to all and that individuals can establish property rights on the incremental advancements atop these—was facilitated by the Bayh-Dole Act of 1980 (Latker 2000).[14] This symbiosis of individual entrepreneurial agency building upon publicly-funded science is largely missing in India.

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14. The Bayh-Dole Act permits non-profit organizations and small business firm contractors to retain ownership of inventions developed through public funding. It also authorizes federal agencies to grant exclusive licenses for inventions owned by the federal government to others.

Related to the difficulty of accessing novel science is the observation that Indian firms are often focused on low-cost imitations of western ideas. Few Indian companies aim to grow through investment in research and innovation. It is also uncommon for large corporates to invest in ideas stemming from other smaller private research entities and individuals, as happens frequently in the US. Amazon, for example, has established two funds to do this. The US $1 billion Amazon Industrial Innovation Fund is dedicated to logistics and supply chain investments (Savitz 2022), and the US $200 million Alexa Fund is dedicated to investments in voice technology innovation (Amazon 2022). Such funds play an essential role in developing the research ecosystem. In this regard, the government's decision to allow firms to count R&D grants to government-funded incubators and research institutions, as part of the mandatory 2 percent of revenue corporate social responsibility target is a positive step (Times News Network 2019). Leading Indian research institutions are reporting an increase in sponsorship. The sponsored research of IIT-Madras has seen steady growth, with funding increasing from Rs 108 crores in 2014–15 (Gohain and Rao 2019) to Rs 590 crores in 2020–21 (Indian Institute of Technology Madras 2021).

Increased Foreign Direct Investment (FDI) in R&D, currently at 0.13 percent of total FDI, also can boost R&D activity in India (Gupta 2022). FDI brings in not only funds but also training and expertise that can help propel India into a world-class research and innovation hub. There have been many examples of foreign partners accelerating the development of innovations. The rapid development of the COVID-19 vaccine is one example. Incentivizing foreign firms to establish global R&D centers in India is one proposal to boost FDI in research. Some firms like CISCO and General Electric have already done this. FDI in R&D can be boosted by fast-tracking IP granting procedures, setting up specialized courts for IP disputes, and simplifying regulatory compliance requirements.

3.3. Lack of Collaboration in Research

Innovative solutions to large-scale global problems typically require inter-disciplinary thinking, and therefore collaboration amongst researchers is crucial. A 2018 OECD report envisioned that the future of scientific knowledge will come from collaboration: "Innovation springs not from individuals thinking and working alone, but through cooperation and collaboration with others to draw on existing knowledge to create new knowledge (Jones 2009)." A fallout of the explosive growth in our cumulative amount of knowledge is increased specialization. For example, biology today has numerous branches with increasingly narrow specializations within each branch. As research moves further, the resulting silos may limit the acquisition of the broad knowledge and collaboration required to achieve transformational change. Attempts to tackle complex real-world problems from narrow fields of vision will likely result in fragmented incomplete solutions.

In India, the lack of collaboration within academia and between academia and industry presents a gap in the innovation ecosystem.

3.3.1. Lack of Collaboration Within Research

Research in India is silo-ed and fragmented. Few Indian institutes have multi-disciplinary research platforms. An example of what I have in mind, parochial to my backyard, is the Harvard University Centre for the Environment (HUCE), embracing an interdisciplinary approach to promote research and education on the environment. The center connects students and faculty at Harvard University from diverse fields, including chemistry, earth, and planetary sciences, engineering and applied sciences, history, biology, public health and medicine, government, business, economics, religion, literature, and law. We have long known that substantial scientific advance comes through what is perhaps best described as a combinatorial advancement process, mixing and matching bits and pieces of scientific and humanistic insight (Uzzi et al. 2013). By connecting scholars and practitioners from different disciplines—transcending conventional boundaries of pure science, social science and humanities—the center provides aspiring researchers, policymakers, and corporate leaders a comprehensive interdisciplinary platform for research and education (Harvard University Center for the Environment 2022). It is worth emphasizing an emerging consensus that pure science (and engineering) is more effective in addressing human needs when its insights are juxtaposed paired with those from the humanities.

3.3.2. Lack of International Collaboration in Research

India lags behind other countries on international research collaboration. In 2019, 19 percent of India's research output stemmed from international collaboration, versus 23 percent in China, and 41 percent in the US (see Table 5) (UNESCO 2021).

International collaboration in research is important as it enables access to global talent pools, and larger amounts of data and infrastructural facilities, thereby improving output. It also offers many personal benefits for researchers. It typically leads to greater recognition, as papers with multiple authors are more likely to be cited (Adams 2012). It enables skill development through mutual learning, and opens up opportunities for mobility, leading to personal and professional growth and satisfaction (Guthrie et al. 2017. These factors, in turn, make research a more attractive career path for young people.

There are many examples of successful international scientific collaborations dating back several decades. In the 1970s, the International Rice Research Institute (IRRI), which aims to enhance food security using research in agricultural science (CGIAR 2022), produced one of the first high-yielding rice varieties that helped stave off mass famine in Asia. Another well-known example is the effort that led to the International Space Station (ISS) project, a collaboration between 16 nations to build and operate a world-class research center in space. A more recent international collaboration, in which India is largely absent, is the Earth Biogenome Project, that aims to sequence genomes of the Earth's bio-diversity over a period of 10 years. Many other international collaborations continue to solve some of the world's biggest problems, such as AIDS, polio, and environmental degradation, among others (Clinton White House Archives 2022).

3.3.3. Lack of Collaboration between Research and Industry

Across the world, collaboration between industry and academia has been the critical fuel for innovation and technological progress. Industry represents the best option to translate the gains in scientific knowledge into practical applications in the form of products and services. Regions that have been able to structure collaboration into networks, such as California's Silicon Valley and Cambridge's Bio Cluster, have sustained long-term success. Research finds that the higher level of informal and formal networks between firms and between firms and academic and other research organizations has been instrumental in Silicon Valley's success.

In India, collaboration between industry and research was considered critical for innovation and success.[15] But in reality, there was a gap in collaboration, stemming from a divergence in how stakeholders view each other's roles. Researchers view their role as building foundational knowledge and tend not to focus on the translation of their research to serve practice. Industry tends to treat government-funded research institutions as part of a larger bureaucracy, which limits the free flow of information between the two and slows any iterative give-and-take and the resultant refinement of relevant scientific ideas. Private sector firms are also reluctant to invest time and resources to bring academic research to a market-ready state. This mistrust of mutual capacity and intent has resulted in limited networks of interaction and communication. In some cases, collaboration is hampered by lack of clear policies. For instance, not all institutes of higher education have clear policies for faculty entrepreneurship.

Given the extensive co-location of research institutions and industry, there is enormous scope to collaborate. The National Chemical Laboratory (NCL) is an example of a collaboration that has worked well. Under Dr Raghunath Mashelkar's leadership in the early 1990s, the NCL, one of the 37 labs of the

15. According to a recent study, more than 50 percent of the deep-tech startups surveyed believed that collaboration with academia was important in the quest for patentable technologies. See NASSCOM and Zinnov. August 2022. "India's DeepTech Startups Poised for Impact," https://community.nasscom.in/communities/productstartups/indias-deeptech-start-ups-poised-impact, accessed March 2023.

Council for Scientific and Industrial Research (CSIR)[16] across the country, collaborated extensively with firms like General Electric to develop and patent polymers. Mashelkar believed that research organizations should focus on patent creation as ‘patents are wealth creators.’ His focus on ‘patent, publish and prosper’ resulted in NCL owning 88 percent of all foreign patents granted in 1994 across all CSIR’s labs. Upon taking over as director-general of CSIR, Mashelkar endeavored to inculcate this mindset across all labs (Choudhury and Khanna 2020). Such examples of collaboration, however, remain the exception rather than the norm.

3.3.4. *Insufficiency of Business Incubators*

Business incubators are a relatively nascent phenomenon in India. There are ~0.4 incubators per million citizens, compared with 4.5 and 2.1 incubators per million citizens in the US and China, respectively (NASSCOM 2020). Incubators are concentrated in a few elite academic institutions (IITs, IIMs) and select States such as Tamil Nadu, Karnataka, Maharashtra, and Delhi, and not widely accessible to aspiring entrepreneurs (Rajan et al. 2021).

There is also scope to improve the quality of incubators. Indian incubators are criticized for being primarily providers of physical infrastructure rather than technical know-how, domain expertise, and relevant commercialization advice. In a 2019 NASSCOM survey, about 60 percent of startup respondents[17] said that Indian incubators underperform vis-à-vis their global peers, half said that they could find alternative investors more capable of enabling genuine value creation, and a third said that the Indian incubator model is outdated (NASSCOM 2020). India is yet to witness a startup from an incubator achieve unicorn status (NASSCOM 2020). A study of Chilean incubators found that providing basic services like funding and infrastructure does not tangibly impact new venture performance but training and mentorship can significantly help (Gonzalez-Uribe and Leatherbee 2018). With the advent of co-working spaces and other peripheral infrastructure, incubators must offer differentiated services. It is essential to design and track KPIs to assess the progress and impact of incubators. Without such frameworks, inefficient incubators may continue to operate indefinitely without generating adequate value, diminishing impact, and experience (Rajan et al. 2021).

Some academic institutions have established successful incubators. The Indian Institute of Madras’s Incubation Cell (IIMIC), for example, has incubated 233 startups, which have raised over US $296 million, filed for 100+ patents,

16. CSIR is a network of labs, outreach centers, and innovation complexes under the Ministry of Science & Technology, focusing on areas such as environment, farm, food, drinking water, housing, and energy.

17. This NASSCOM survey was part of the report ‘Startup Catalysts - Incubators and Accelerators, 2020’. Participants n=24.

and created over 4,000 jobs (Indian Institute of Technology Madras 2022). One of the cell's most successful ventures is Ather Energy, a firm that pioneered the manufacturing of smart electric scooters and the setting up of electric vehicle charging infrastructure in India. A key reason for the cell's success is its strategic location within India's first Science and Technology Research Park, designed on the lines of the Stanford Research Park. The Park houses over 70 research organizations across 17 sectors, and 200 labs and testing facilities. It has generated 1,300 patents.

4. Current Public Policy Initiatives

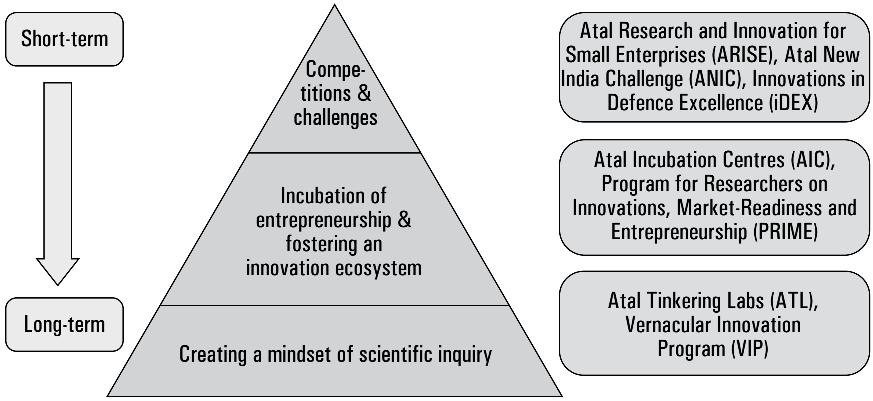
Institutional voids bedeviling science-based entrepreneurship cannot be mandated away through deregulation and liberalization; it takes both significant time and expertise and, frankly, institutional entrepreneurship here itself, to eliminate these voids or ameliorate their effects. In the following section, I elaborate on distinct policy initiatives introduced by the government to boost innovation and entrepreneurship in the science and deep-tech sector, and how these initiatives are bridging the existing institutional voids in this space.

The first, the Atal Innovation Mission (AIM), set up under the NITI Aayog, has demonstrated considerable traction in the innovation ecosystem through its programs. The second, the Science and Technology Clusters project under the Office of the Principal Scientific Advisor (PSA), is described below but it is still too early to offer an assessment. Another program at the confluence of these two policy initiatives is the AIM Program for Researchers in Innovation, Market Readiness, and Entrepreneurship (PRIME), which aims specifically to promote entrepreneurship in science.

4.1. Atal Innovation Mission

The AIM was launched in 2016 to provide an umbrella under which a wide variety of programs to catalyze the innovation ecosystem could find an institutional home. The report resulted from an approximately year-long consultative process in 2015 launched by the Government of India under NITI Aayog auspices that I had the privilege of chairing. The underlying conceptual framework sought to suggest ways to ameliorate the effects of institutional voids over the short, medium, and longer-term (see Figure 1). Table 7 presents a summary of how programs of the AIM (Atal Tinkering Labs and Atal Incubation Centres) address broad categories of relevant voids. I have also made some back of the envelope calculations on the value generated at the ATLs and AICs between 2016 and 2021 (see Table 8).

FIGURE 1. Programs under the Atal Innovation Mission



Source: Report of the Expert Committee on Innovation and Entrepreneurship, NITI Aayog, August 2015.

TABLE 7. Current Initiatives Bridging Institutional Voids

Role	*ATL*	*AIC*	*PRIME*
Transaction Facilitator	–	Bring together providers and users of risk capital	Bring together investors to enable participants to raise money and create awareness about opportunities in science and technology
Credibility Enhancer	–	Validate entrepreneurial projects that have passed muster in typically a 3–6-month period	Validate commercial potential of scientific research, new technologies, products, and services
Information Analyzer	Identify high school students with a science interest and aptitude	Convert tacit information about quality of entrepreneurial teams and/or their ideas to make these available to transaction partners	
Aggregator	Facilitate distribution of training materials for high school science teachers, Aggregate mentoring services (complement to efforts of teachers) associated with formal organizations	Provide a means to aggregate pools of capital so as to facilitate access to these for decentralized entrepreneurs	Aggregate content on a public YouTube channel, and the PRIME playbook which is used for broader dissemination within the community

Source: The author.

TABLE 8. Back-of-the-envelope Calculation on Value Generated under AIM, 2016–21, Rs in crores

Particulars	*Amount (Rs crores)*
AIM Expenditures	1,511
Of which, investment in startups	252
AIM Benefits	
Benefit (A): Value Created by Startups and Incubators	
Benefit (B): Value Created by Atal Tinkering Labs	
Elaborating Benefit (A):	
Mark-to-Market Value based on 2,729 startups' capital raises	6,835
Money raised (Rs 1367 crores), assume 20% dilution on average	
(excludes social spillovers from companies' 467 patents)	
(Pessimistic) Accounting value of 14,556 new jobs @Rs 30,000 /month salary	524/year
(Less Pessimistic) Capitalized value of new jobs	7,486
(capitalizing Rs 524 crores/year at 7% social cost of capital)	
AICs capital raise in matching funds	58
Valuation of infrastructure	
Benefit (A) Total	
Conservative: ~30x return	7,417
Less Conservative: >50x return	14,379
Elaborating Benefit (B):	
75 lakh students sensitized to ideas of innovation and entrepreneurship	
Conservative value: Accounting cost of such exposure	750
(assuming it costs students Rs 1000 for an equivalent course)	
Less Conservative: Capitalized value of such exposure	10,714
Rs 750 crores at 7 percent social cost of capital	
Student 'mindset' earns perpetuity value of incremental earnings attributable to creativity	
Total Benefits (A + B)	
Conservative: (5x return)	8,167
Less Conservative: (17x return)	25,093

Source: Author computations and Dr Chintan Vaishnav, Atal Innovation Mission.

4.1.1. Atal Tinkering Labs

The Atal Tinkering Labs (ATL) project is one such longer-term initiative that seeks to bridge institutional voids by aggregating and providing educational resources, equipment and mentorship services to school students.

The program entails the setting up of physical laboratories in schools, equipped with scientific kits and apparatus for students between the sixth and twelfth grades. The hope is that the opportunity to "tinker," and learn by doing, will sow the seeds of a scientific mindset and an entrepreneurial spirit amongst children from an early age. The program's vision is to create one million innovators with complex problem solving, critical thinking, adaptative learning, and computational skills.

The AIM provides a grant of up to Rs 20 lakhs over five years for the setting up of each ATL. Schools must apply to be admitted into the program—de minimis physical facilities are needed as is the identification of a school teacher who is the ATL in-charge—and selected schools then receive the grant. Up to Rs 10 lakhs is to be spent on capital expenditures, including machinery, equipment, and tools, and the remaining Rs 10 lakhs may be used for operational and maintenance expenses. The AIM has a mandate to fund 10,000 ATLs in the first phase. As of May 2022, it has funded 9,600 spaces in 34 States and Union Territories. These have been rolled out in implementation waves over recent years, with attention to locating ATLs across States with varying levels of economic and social development, and across some aspects of the urban-rural divide. The labs have been equitably distributed across the country, with 53 percent of the labs in States with a GDP per capita above the national median, and 47 percent in States with a GDP per capita below the median. The AIM has also given particular importance to States typically ignored such as Jammu & Kashmir, where it plans to set up 1,000 labs, and the north-eastern States, some of which currently have the highest number of labs per million residents. Further, more than 70 percent of ATLs have been set up at government schools. The labs have engaged over 7.5 million students who have created over 2.1 lakh projects (Atal Innovation Mission 2022e).

Through various programs, the ATLs offer students an array of opportunities. ATL schools are encouraged to engage with stakeholders in their communities to better understand and address their challenges. ATLs also leverage their communities through the Mentors of Change (MoC) initiative. Mentors are selected and trained volunteers who support the ATL-in-charge teacher by helping students with technical know-how and advice on commercial aspects of innovation; some also offer internships in the organizations with which they are affiliated. The MoC initiative has connected more than 5,100 mentors with over 4,600 schools. While this program is a step in the right direction, its scale is still small. Today, less than half of existing ATLs have even one mentor and the per-ATL mentor count is very low.

The ATLs also address voids by serving as credibility enhancers to students who participate in its events and challenges. These include the 'Student Innovator Program' (SIP)[18] and the 'Student Entrepreneurship Program' (SEP).[19] Winners of these challenges are offered opportunities such as internships and access to international programs[20] and additional resources and mentorship.

To motivate participants, the AIM regularly celebrates high-performing ATL participants through initiatives like the Exemplary Teachers of Change[21] and the ATL of the Month initiative.[22] The AIM also organizes a mentor roundtable bi-annually, where exemplary mentors are invited to spend time with senior officials from the NITI Aayog (Atal Innovation Mission 2022f). While such recognition is helpful, a lot more can be done. Teachers at ATL schools are typically on low salaries with few opportunities and platforms for recognition. Non-financial incentives including more opportunities to travel, learn, and connect with a national and international community could motivate them. Likewise, small financial incentives for achieving key outcomes could also incentivize better performance.

Notwithstanding initial successes, the program faces several challenges. For starters, there is a wide gap between the pre-existing educational level of a vast majority of students at ATL schools and the skills required to "tinker" at the labs. Bridging this gap requires cultural change, and will take time. The quality of teacher and mentor engagement across ATLs also varies significantly. Given the high work-loads for teachers at schools, there is often little incentive for them to put in the additional work required for students to tinker and innovate effectively. Further, the infrastructural pre-requisites for setting up labs and the single language of instruction (English) curtail the reach of the program. Many schools have also reported the compliance procedures to be cumbersome. Another limitation of the ATLs is the lack of outreach to a critical stakeholder in the child's innovation journey, the parents. Finally, an obvious challenge is that the AIM cuts off funding to ATLs five years after their initiation. While the AIM encourages labs to become financially self-sufficient through self-funding and corporate partnerships, this approach will inevitably lead to some labs being discontinued, especially in rural areas, possibly stymieing the momentum of the program.

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18. A program in collaboration with AICs to train students on business and entrepreneurial skills.

19. A 10-month program where top teams from the SIP work with corporate and industrial partners and receive further mentorship and training on product design and commercialization.

20. An example is the Indo-Singapore Innovation Festival-Inspreneur, organized by the High Commission of India in Singapore. In 2018, 30 top-performing ATL teams were invited to present their innovations to the Prime Minister of Singapore, Lee Hsien Loong, and the Prime Minister of India, Narendra Modi.

21. An initiative to recognize high-performing teachers in charge of the tinkering labs.

22. An initiative to recognize students and teachers at high-performing labs by means of an award.

The AIM is attempting to address some of these challenges. To simplify compliance and improve engagement, the AIM is creating regional clusters that will decentralize monitoring. To improve accessibility, the ATL is piloting mobile and virtual ATLs, and designing resources in vernacular languages through the Vernacular Innovation Program (VIP). Further, the AIM is also collaborating with the Ministry of Education (MoE), Central Board of Secondary Education (CBSE),[23] National Council of Educational Research and Training (NCERT),[24] and the State governments, to integrate the ATL pedagogy into the school curriculum. This initiative should help scale the program to 50,000 schools, the newly adopted AIM target for its ATL program.

4.1.2. Atal Incubation Centres

Through the Atal Incubation Centres (AIC) program, the AIM aims to build an ecosystem of business incubators where entrepreneurs can gain access to a variety of facilities, including physical infrastructure, training and education, and access to key stakeholders including investors (AIC seed funding, and also a network of venture capitalists, corporate funding, family offices), other innovators, and mentors.

The AICs act as transaction facilitators by bringing together providers and users of risk capital. They serve as aggregators by consolidating pools of capital and facilitating entrepreneurs' access to these pools. Finally, they are information analyzers by converting and making available to possible partners otherwise-tacit information about the quality of entrepreneurial teams and their ideas.

The AIM provides a grant of up to Rs 10 crores over five years for the setting up of an AIC (Atal Innovation Mission 2022d) or to support investments at 'Established Incubation Centers' (EICs) (Atal Innovation Mission 2022d).[25] Subsequent tranches of the grant are conditional on meeting minimum performance metrics. The AIM has also raised Rs 58 crores in matching contributions from participating institutions for infrastructural investment at the AICs.

Academic institutions, research labs, and corporates are eligible to apply for an AIC. The applicant institution is responsible for hiring a full time-CEO and supporting team within 30 days of receiving the grant. The AIM requires that the CEO has experience in entrepreneurship, fund raising, technology, or incubation. The CEO of one of the bio-incubators in Bangalore, for example, has a PhD in brain research from a university in Germany, and postdoctoral

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23. A national level educational governing body set up to raise the standard of education in India.

24. A government body that conducts research, and prepares and publishes materials for school education.

25. EICs are existing incubators which have already been in operation for a minimum of three years.

training from the University of California, San Francisco, and has completed a biotech management program for executives from the Wharton School. He previously worked at a biotech consulting company and has also been an adviser to many biotech firms in the US.

An example worth highlighting is Phool.co, a startup that recycles floral waste into incense sticks and oils. This venture received a seed grant of Rs 30 lakhs from the Indian Institute of Information Technology Hyderabad AIC, and raised Rs 60 crores in its Series A in May 2022 from other investors (Tripathi 2022).[26] Another is Bugworks, a clinical-stage bio-pharmaceutical company which aims to develop affordable, accessible, novel therapies to combat anti-microbial resistance and cancer. It was set up in 2014 and incubated at an EIC, the Centre for Cellular and Molecular Platforms (C-CAMP). C-CAMP is a bio-incubator set up by the Department of Biotechnology and receives support from the AIM. Bugworks is also a part of the Combating Antibiotics-Resistant Bacteria Accelerator (CARB-X), a non-profit accelerator at Boston University, where it raised Rs 20 crores in 2017 (CARB-X 2022). It raised an additional Rs 135 crores in its Series B in February 2022 (Rekhi 2022).[27]

The AIC program faces several challenges in practice. Many centers have struggled to build market connections, particularly with investors, where the landscape is highly fragmented. Few have successfully scaled manufacturing-based ventures or backed ventures that are able to supply the government. To achieve success, centers need to have clear targets, and progress needs to be monitored.

The AIM is addressing some of these challenges. In collaboration with IIT Delhi, it is piloting a framework of 23-input, process, and output indicators to strengthen evaluation. Some of these indicators include number of startups incubated per year, active network partners, external funding raised, patents filed, and jobs created. The framework classifies incubators based on characteristics such as age and focus areas to measure impact more accurately. For example, for research-focused incubators, the framework places greater emphasis on parameters like patents filed and external funds raised, while for social incubators, it emphasizes job creation. AIM is also creating virtual platforms to connect startups with investors, and other key stakeholders like mentors, manufacturers, and the government. While these are steps in the right direction, significant effort is still required to improve incubator performance. An acid test will be whether underperforming AIM incubators have their support withdrawn if and when they fail to meet pre-specified performance targets.

26. Investors include Sixth Sense Venture, Indian Angel Network Fund, and actor Alia Bhatt.

27. Investors include Lightrock India, The University of Tokyo Edge Capital (UTEC), Japan, Global Brain Corporation, 3ONE4Capital, Acquipharma Holdings, IM Holdings and Featherlite Group India.

4.1.3. Working with Ministries

In addition to independent initiatives such as the ATLs and AICs, the AIM also engages with several ministries through various programs and competitions. These initiatives are aimed at synergizing the efforts of various ministries in promoting innovation and entrepreneurship in their sectors. For instance, the AIM has launched the Applied Research and Innovation in Small Enterprises (ARISE), Atal New India Challenge (ANIC), and the ed-tech demo day competitions in collaboration with partner ministries (see Table 9). Another collaboration, which falls under the aegis of the Ministry of Defence, is the Defence Innovation Organisation (DIO). The DIO has had significant impact in fostering innovation, entrepreneurship, and self-reliance in the defense sector, in line with the government's Aatmanirbhar Bharat vision.

TABLE 9. Other Initiatives and Programs of the AIM

Program Name	*Description*
Atal Community Innovation Centres (ACICs)	The ACICs are physical centers which aim to promote the benefits of technology-led innovation in the underserved regions of India. These include Tier 2, Tier 3 cities, aspirational districts,* tribal, hilly, and coastal areas. There are currently 12 ACICs in operation, and the AIM gives each center a grant of up to Rs 2.5 crores over five years (Atal Innovation Mission 2022c). Along with the physical infrastructure, the ACICs provide innovators in the centers with mentoring, networking, incubation, and funding support. These centers enable members from the local community to convert grassroots innovation into products and services.
Applied Research and Innovation in Small Enterprises (ARISE)	ARISE is an initiative of AIM in collaboration with partner ministries,[#] and some organizations including ISRO, launched to promote research and innovation at MSMEs and promote self-reliance. Through this program, partner ministries set out specific problem statements for which MSMEs conduct research and develop products. A grant of up to Rs 50 lakhs is made to winners to develop a prototype. For example, under ARISE 1.0, launched in 2020, the Ministry of Defence invited applications for AI-based predictive models for the maintenance of plant and machinery, and for the development of a modem for high-definition data communication. Similarly, other participating ministries invited applications for projects within their areas. The AIM has approved over Rs 11.6 crores in grants for winners of ARISE 1.0, which will be disbursed over 9–12 months.
Atal New India Challenge (ANIC)	The ANIC is a competition launched by the AIM to promote technology-based innovation in sectors of national importance. ANIC 1.0 was launched in 2018 in partnership with five ministries, Railways, Housing and Urban Affairs, Agriculture, Road Transport and Highways, and Jal Shakti.[†] The competition had 24 challenge areas and received over 900 applications. Ultimately, the ministries selected 30 innovations from 12 challenge areas to receive grants of up to Rs 1 crore each over 12–18 months. A total amount of Rs 22.85 crores was approved, of which Rs 6.85 crores has been disbursed (Atal Innovation Mission 2022b). ANIC 2.0 was launched in April 2022 with 18 challenges from seven sectors; EV charging infrastructure, smart mobility, AI and machine learning for space applications, medical devices, sanitation, waste management, and smart agriculture (Press Information Bureau, Government of India 2022).

(Table 9 continued)

(Table 9 continued)

Program Name	*Description*
India-Australia Circular Economy (I-ACE) Hackathon	I-ACE is a competition jointly organized by the AIM and the Commonwealth Scientific and Industrial Research Organization (CSIRO) of Australia. The program seeks to foster innovative solutions in developing a circular economy within the food system value chain. Such international collaborations are an opportunity for Indian startups to learn from the best practices of startups in other regions and to collaborate on research by sharing resources.
AIM-iCrest	iCrest is a program jointly developed by the AIM, Bill and Melinda Gates Foundation and the Wadhwani Foundation. The program is a structured capacity-building effort to enable incubators in India to implement world-class entrepreneurship programs, build credibility, and become financially sustainable. The program uses the best practices from over 200 accelerators and incubators globally to bridge existing gaps at the AICs and EICs (Atal Innovation Mission 2022a).
AIM iLEAP	AIM launched the iLEAP program with Startup Réseau,[‡] with the objective of overcoming two significant bottlenecks startups face: market and investor access. This program provides AIM-backed startups access to Startup Réseau's global network of mentors, and investors. Five verticals of the program are fin-tech, cyber security, med-tech for home-based solutions, climate-tech for fighting air pollution, and audio-tech.
Demo Day for Ed-Tech	Demo Day is a competition organized by the Ministry of Education (MoE) in collaboration with the AIM for companies working on educational solutions for children with special needs. This competition provides a national level platform for companies to showcase latest innovations such as assistive teaching technologies and adaptive equipment. Such programs help innovators and entrepreneurs get exposure to potential customers, mentors and investors.
Agri-Tech Challenge 2021	The Agri-Tech competition is an international collaboration of the AIM with by the UN Capital Development Fund (UNCDF), the Bill and Melinda Gates Foundation, Rabo Foundation, International Fund for Agricultural Development (IFAD), and Bayer. The competition aims at supporting startups that are finding solutions to three large obstacles that small farmers face; low productivity, climate risk and inefficient supply chains. Selected participants receive support in the form of industry and sector linkages, investor connects and financial grants to enable international expansion in Asia and Africa.
AIM Youth Co:Lab India	Youth Co:Lab was co-created by the UNDP Asia Pacific and the Citi Foundation in 2017 and is a program that aims to strengthen youth-led innovation and social entrepreneurship. The AIM launched the Youth Co:Lab program in India. The fourth edition of the event was held in 2021 and focused on identifying and supporting young entrepreneurs across certain themes, including, the circular economy, waste management, sustainable transportation, e-mobility, sustainable tourism, and sustainable food tech.
Climate Entrepreneurship Hub (CEH)	The CEH is a program launched by the UNDP India and the AIM to promote a multi-stakeholder alliance for green innovation and climate entrepreneurship in India. The CEH creates an enabling ecosystem through access to specialized business support and mentorship that are not available at other, more traditional incubators.

(Table 9 continued)

(Table 9 continued)

Program Name	*Description*
Vernacular Innovation Program (VIP)	The VIP is an initiative of the AIM designed to lower language barriers by translating design thinking and entrepreneurship resources into 22 local languages. AIM has created a Vernacular Task Force (VTF) for each language, comprising of vernacular language teachers, subject experts, writers, and members of the regional AIC. The AIM has also partnered with the design department of the IIT Delhi to train all VTFs in design thinking and entrepreneurship concepts to enable them to contextualize and translate these resources to their respective languages. By making educational resources on design thinking and entrepreneurship available in 22 languages, the accessibility of these resources will significantly increase to include previously underserved sections of the population. This will help local communities innovate to find grassroot solutions to their own challenges independently. This initiative will help to improve the accessibility of all programs under the AIM ecosystem including ATLs, AICs, and ACICs.

Source: Atal Innovation Mission.

Notes: *: Aspirational districts is a program launched under NITI Aayog in 2018 with the objective of transforming 112 of the most backward districts across 28 States. The program aims to expedite transformation of these districts through the convergence of central and State schemes, collaboration between all levels of government and competition between aspirational districts. The program focuses on five main themes, health & nutrition, education, agriculture & water resources, financial inclusion, skill development and basic infrastructure; #: Ministries of Defence, Food Processing, Health and Family Welfare, and Housing and Urban Affairs; †: The Ministry of Jal Shakti includes the Department of Water Resources, the Department of River Development and Ganga Rejuvenation; ‡: Startup Réseau is a network of Startups, Enterprises, Capital, Markets, and Services, designed to bring in a structured interface for enabling collaboration in the ecosystem. It was founded in 2019 by Ajay Ramasubramanium in Mumbai and operates across India and Africa. Startup Reseau has conceptualized and operated accelerator programs for various corporates and also actions CSR-driven mandates for the promotion of entrepreneurship and startups.

While these initiatives have made considerable impact, they face some challenges. For starters, startups operate in a fast-paced environment, vastly different from the government bodies that finance them. Lengthy and complicated documentation, cumbersome audit requirements, and an unhurried disbursement of grants slows down their funding. Another challenge is the lack of an integrated inter-ministerial platform to invite innovations that solve national challenges and long-term technological transitions. The AIM is working on addressing these challenges. To fast-track the pace of grant approvals and disbursements, it is trying to transition from a milestone-based to a venture capital-based financing model. The AIM also plans to create ‘innovation sandboxes,’ forums to bring together academics, innovators, and policymakers on a project basis. These sandboxes will enable a multi-disciplinary approach to solve national challenges like farm productivity, and healthcare delivery, among others.

4.1.4. Deep Dive into the Defence Innovation Organisation (DIO)

The DIO was launched by the Ministry of Defence in 2017 to fund and support innovations in the defense and aerospace sectors (Press Information Bureau, Government of India 2017). The DIO is a non-profit company set up under the Department of Defence Production (DPP) and seed-funded by Bharat Electronics Limited (BEL) and Hindustan Aeronautics Limited (HAL). BEL and HAL provide the DIO support with technical knowhow and R&D infrastructure. Though the DIO does not fall under the AIM, the AIM supports the DIO via advice on commercial aspects of product development, and through supervisory services by virtue of being represented on the DIO's board.

In 2021, the Ministry of Defence granted the DIO budgetary support of Rs 500 crores over five years, up to FY26 (Press Information Bureau, Government of India 2021).[28] Of this, Rs 450 crores is to be used towards grants to winners of various iDEX (explained below) competitions, Rs 30 crores to develop programs at partner incubators, and Rs 20 crores towards internal operations at the DIO (Government of India 2021f). An additional Rs 1,000 crores has been allotted by the Ministry of Defence for procurement from companies supported by the iDEX in FY 2023 (Government of India 2022g).

The DIO is operationalized through its platform iDEX that supports innovation through two competitions; the Defence India Startup Challenge (DISC), where proposals for predetermined problem statements are invited and the Open Challenge (OC), where companies are invited to present open-ended innovations. Winners of these competitions receive a grant of up to Rs 1.5 crore each (Government of India 2021f). In 2021, the iDEX launched DISC 5 across 35 problem statements, and OC 2. These competitions saw 41 and 4 winners, respectively. In 2022, in addition to launching DISC 6 with 38 problem statements, iDEX also launched iDEX Prime, a competition with 6 problem statements and funding of up to Rs 10 crores for each winner. Saif Automation Services is the first winner of an iDEX competition to secure a procurement order from the Indian defense forces in October 2021. The startup created a battery-operated self-propelled vehicle for water bodies, which can be controlled remotely. This vehicle can be used for search and rescue operations and for disaster relief in flooded areas.

In addition to providing grants to the winners of its competitions, the DIO also bolsters the development of prototypes in numerous ways. The DIO has partnered with 14 incubators at key institutions such as the Indian Institutes of Technology (IITs) and the Indian Institutes of Management (IIMs), through which it supports winners of the competitions from the prototyping stage through to commercialization and procurement. Partner incubators also run programs to mentor entrepreneurs attempting to create defense technologies. The DIO gives partner incubators up to Rs 40 lakhs to run each such program. The DIO aims to increase its number of partner incubators to 50 by 2023. Working with incubators allows the DIO to identify high-potential startups and build a pipeline for its competitions.

28. Financial Year (FY) refers to the 12 months ending March 31.

DIO also provides iDEX winners with technical support by facilitating their access to testing and research facilities, and to the expertise of various defense public sector undertakings. It also facilitates access to senior officials in the defense forces to enable fast-tracked testing, commercialization, and procurement. Winners of the competitions enjoy significant national and international exposure to other participants in the ecosystem, including manufacturers, increasing the potential for collaboration and therefore, the probability of successful commercialization.

4.2. Science & Technology Clusters

An important government initiative to promote innovation in science is the Science & Technology (S&T) clusters project. Set up in 2020 at the behest of the Prime Minister's Science, Technology, and Innovation Advisory Council (PM-STIAC), under the Office of the PSA, the clusters project aims to bridge institutional voids by bringing together academia, the corporate sector, and the local administration in a collaborative ecosystem (see Table 10). The hope is that aggregating stakeholders in an erstwhile siloed and fragmented marketplace will lead to scale economies, trigger synergies in the research and development process, and facilitate transactions between providers and users of research. Robust research universities, anchored in vibrant innovation ecosystems, are key to both absorbing from and contributing to the global flow of idea. S&T clusters have a tri-layered structure of objectives. The foundational layer consists of building an ecosystem of collaboration between participating institutions, for example, in the form of sharing course content across institutes, working on joint R&D projects, etc. The intermediate layer comprises problem-solving in the local community and for the local and State administrations. Clusters may collaborate with external partners such as local incubators to do this. The final layer consists of building sectoral capabilities and expertise to enhance competitiveness, with the ultimate goal of contributing to the strategic objectives of the Government of India (Office of the Principal Scientific Adviser to the Government of India 2022).

One successful example of collaboration between academia and industry in India is the IIT-Madras Research Park. The research park has over 70 partner companies across 17 sectors, has filed over 1,300 patents, and incubated over 230 startups, of which 40 percent have IIT Madras faculty as founders or minority shareholders. Many large companies, such as Saint-Gobain and Mahindra, have set up or relocated their research facilities from elsewhere in the country to Chennai, citing the IIT Madras Research Park ecosystem as the reason. In May 2022, Pfizer invested over Rs 150 crores to set up the company's first global drug development center in Asia at the Park (Business Standard Reporter 2022). Similar instances of collaboration in the West also have a track record of generating tangible results. Geographic clusters such as Silicon Valley, North

Carolina's Research Triangle Park, and Cambridge's bio-cluster, for instance, have attained international prominence for research and innovation.

TABLE 10. Pilot Clusters: Lead Institutions, Focus Sectors, and Funding Raised

Cluster	*Lead Institution*	*Focus Sectors*	*Funding Raised*
Hyderabad	Research and Innovation Circle of Hyderabad	Life Sciences, Food & Agriculture and Sustainability	Rs 4.15 crores from Foundation for Innovative New Diagnostics (FIND), Bill and Melinda Gates Foundation, and Ministry of Agriculture & Farmer's Welfare
Pune	Inter-University Centre for Astronomy and Astrophysics	Sustainability & Environment, Health, Big Data & AI and Sustainable Mobility	Rs 4.19 crores from Schlumberger, Hindustan Unilever, Rockefeller Foundation and Cummins India Foundation
Delhi-NCR	Indian Institute of Technology, Delhi	Solid Waste Management, Water Security, Air Pollution AI/ML in Healthcare, Sustainable Mobility and Effective Education	–
Bhubaneswar	Kalinga Institute of Industrial Technology	Quantum Engineered Advanced Materials, Waste to Value, Wetland Management, Biosciences and Polymer based Interventions	Rs 3.38 crores from industrialist Mr Subroto Bagchi
Jodhpur	Indian Institute of Technology, Jodhpur	Medical Technologies, Handicraft & Handlooms, i-governance, Thar Designs, Water & Environment and IoT Innovation	Rs 15.53 crores from Department of Biotechnology (DBT), Jal Jeevan Mission, Ministry of Jal Shakti, Siemens and Canara Bank
Bangalore	Indian Institute of Science, Bangalore	Health & Wellness, Urban Life and Futuristic Technologies & Solutions	–

Source: The Office of the Principal Scientific Adviser to the Government of India.

So far, the PSA has granted seed funding to six S&T clusters, which function autonomously. The current framework for clusters aims to leverage skills and resources at existing institutions rather than the setting up of new multi-disciplinary institutions and centers. Each of the six clusters is centered on select themes, with the goal of building expertise and capabilities in specific areas. Clusters also operate virtual platforms to bring in domain knowledge from other domestic and international organizations that share a similar mission. Enabling virtual participation allows clusters to collaborate efficiently with non-local actors, improving outcomes.

The S&T Cluster Apex Committee (ST-CAC) is the apex body for the S&T clusters project and is chaired by the Vice-Chairman of the NITI Aayog. The committee formulates guidelines on clusters' selection, operation, and performance evaluation. It is responsible for enabling inter-cluster collaboration, and coordination between clusters, ministries, State governments, and international institutions. It nominates a lead institution for each cluster and lays down principles for the selection of cluster CEOs. The lead institution is responsible for enabling and ensuring collaboration within the cluster, hiring a CEO and other full-time staff, and other activities required to commence operations. For instance, IIT Delhi is the lead institution for the Delhi Cluster, while the Indian Institute of Science Bangalore leads the Bengaluru Cluster. Cluster CEOs typically come with a diverse range of experience from the private sector, academia, and the government.

An important objective of the ST-CAC is to monitor cluster performance through tracking measurable outcomes. Some of these outcomes include the number of solutions commercially deployed, the number of partnerships, patents, and industry-sponsored R&D projects created, and monetary value of FDI brought in. While a structure for accountability is critical, it is also important that reporting requirements are not overly onerous, particularly at initial stages. Each cluster must have the flexibility to explore problems and opportunities in their selected themes freely without being weighed down by the need for approvals, committee reviews, and other bureaucratic impediments.

Clusters are not a recent phenomenon in India. The Department of Biotechnology, for example, established four bio-clusters in 2014 to promote research, development, and entrepreneurship in the sector. The Ministry of Commerce set up the Auto Cluster Development and Research Institute in Pune in 2007. However, possibly as a consequence of being set up within specific ministries, these clusters have not adequately been able to break through existing siloes and collaborate effectively with other institutions. As such the ecosystem of formal and informal networks is still nascent.

4.2.1. Deep-dive into the Delhi S&T Cluster

The Delhi S&T Cluster located at IIT Delhi and founded in 2021 is an example of a cluster that has made tangible progress in shaping the science and deep-tech ecosystem. The cluster currently has over 40 partners across academia, industry, research labs, and the government. Each partner gets access to a platform for collaboration, fundraising opportunities, industry connections, and strategic advisory services (see Table 11).

Currently, the cluster works on six themes,[29] each of which is led by a Principal Investigator (PI) working alongside a multi-disciplinary team of participants.

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29. Themes include solid waste management, water security, air pollution, artificial intelligence and machine learning in healthcare, sustainable mobility, and effective education.

TABLE 11. Example of a Cluster's Constituents, Select Participants of the Delhi S&T Cluster

Academic Institutions	• Indian Institute of Technology (IIT), Delhi (Lead Institution) • Indian Institute of Technology (IIT), Dhanbad • Jawaharlal Nehru University (JNU) • Delhi Technological University (DTU) • University of Delhi • Netaji Subhas University of Technology (NSUT) • All India Institute of Medical Sciences (AIIMS, New Delhi) • Indraprastha Institute of Information Technology (IIIT, Delhi) • Ashoka University • BML Munjal University
Government Labs	• CSIR-Central Road Research Institute (CRRI) • CSIR-Institute of Genomics and Integrative Biology (IGIB) • ICAR-Indian Agricultural Research Institute (IARI)
Government Agencies	• Delhi Transport Corporation (DTC) • Delhi Metro Rail Corporation (DMRC) • Delhi Pollution Control Committee (DPCC)
Private Companies	• Tata Power • Mahindra Power • BSES-Rajdhani Power Limited • BSES-Yamuna Power Limited • Google • PhonePe • Panasonic Batteries • Tata Steel • Hyundai • Swiggy • Zomato • BASF • Central Square Foundation
International Organizations	• World Economic Forum (WEF) • United Nations Development Program (UNDP)

Source: The Office of the Principal Scientific Adviser to the Government of India, Delhi Research Implementation, and Innovation (Delhi S&T Cluster).

For each theme there is a stated goal. For instance, the social mobility theme aims to create charging, power distribution, and battery swapping infrastructure. Partners for this theme include IIT Delhi, Tata Power, Mahindra Electric, Maruti Suzuki, Google, Delhi Metro, Delhi Transport Corporation, and CSIR, and it is led by Dr. B.K. Panigrahi of IIT Delhi. A research project in one of the themes led to the development of a technology for recycling e-waste[30] through

30. E-waste signifies electronic products that are unwanted, not working, or at the end of their useful life.

pyrolysis.[31] E-waste constitutes a significant source of waste generated today and can be dangerous if not processed appropriately. The method developed has been patented and published in leading academic journals and was awarded the SRISTI-GYTI[32] in 2020.

Apart from working on the theme's objectives, the cluster also undertakes specific research projects with industry partners. The cluster's development of advanced battery and energy storage solutions, such as battery packs for EVs, in collaboration with Log9 Materials and the Centre for Automotive Research and Tribology (CART), is one example. Another is the collaboration between the Delhi Cluster and a leading Indian two-wheeler manufacturer to set up a center of excellence (CoE) for mobility-based projects. The manufacturer will fund the CoE and work with the cluster on R&D projects, on training and skill development programs, and on exploring potential collaborations with startups.

The cluster also runs an educational and commercialization platform to enable growth and development of entrepreneurial ventures. Its skill development platform, PERKS (Platform for Entrepreneurship, Research, Knowledge and Skill Development), offers participants access to skill development and training programs, and other research infrastructure. Its online course on electrical engineering deployed in EV charging infrastructure, in collaboration with the CART, is accessible to all, enabling broad dissemination of knowledge generated at the cluster. In addition, the cluster is working on a startup and innovation platform that will support companies between Technology Readiness Levels (TRL)[33] 4-7 with technology development and demonstration.

While the cluster's progress has been appreciable, it still faces numerous challenges. For one, the governance structure and reporting requirements are convoluted. Also, there remains a lingering apprehension amongst cluster participants about collaborating openly with partners, and moving away from the existing model of clear institutional silos. Finally, finances are also a challenge. It will be important for the cluster to raise funds from industry partners to ensure continued support for R&D projects and entrepreneurial ideas.

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31. Pyrolysis is the heating of a material, such as biomass, in the absence of oxygen.

32. The Gandhian Young Technological Innovation (GYTI) award is given in collaboration with the Society for Research and Initiatives for Sustainable Technologies and Institutions (SRISTI), to individuals in the field of engineering, science, technology, and design.

33. Originally introduced by NASA, the TRL is a scale with nine levels for describing the maturity of a technology from the idea stage (TRL1) to the highest degree of application, commercial readiness (TRL9).

4.3. AIM – Program for Researchers on Innovations, Market-Readiness and Entrepreneurship (PRIME)

AIM-PRIME was launched in 2021 by the AIM in collaboration with Venture Center Pune,[34] Pune Knowledge Cluster,[35] Office of the Principal Scientific Adviser, and Bill and Melinda Gates Foundation. The program brings together three key stakeholders: entrepreneurs at science-based startups, managers of incubators, and academicians, with the goal of taking research from labs to the market. It is a program to expedite the scaling of science-based startups over a period of nine months.

The PRIME program is a nine-month virtual education program which comprises three months of instructional sessions followed by six months of mentorship. The program is focused on four themes; energy and the environment, health and rehabilitation, industrial automation and IoT, and nutrition and agriculture, and offers resources across five scientific disciplines: chemicals and materials, biological sciences, electronics, mechanical engineering and design, and data analytics and computing. During the program, startups and academicians are paired with an incubator where they concurrently work on their ideas while completing the program. The instructional sessions cover broad topics of entrepreneurship such as marketing and funding as well as topics more pertinent to science-based innovation such as an intellectual property management and regulatory strategy. The sessions consist of a combination of lectures, class exercises, panel discussions, and milestone presentations. To increase the accessibility of these sessions, they are recorded and posted on the program's public YouTube channel.

The classroom module is followed by six months of mentoring from experts from leading academic institutions, corporates and the Venture Centre, Pune. The program also leverages global experts to enable international collaborations and partnerships. Mentorship sessions cover topics including business model development, lab to market strategy, IP and regulatory strategy, and funding opportunities. During the first cohort, teams cumulatively received over 635 hours of mentorship over the six-month period with the highest team receiving over 70 hours. Providing mentorship at early stages can significantly benefit startup progress.

The program's first cohort was launched in 2021. Applicants were screened based on their educational background, professional experience and IP holdings. Applicants' product proposals were also screened on parameters including novelty, knowledge intensity,[36] and progress on commercialization. AIC

34. An incubator focused on science and technology startups that was established by the CSIR's National Chemical Laboratory (NCL), Pune, and is supported by the Department of Science and Technology.

35. A S&T cluster hosted by Inter-University Center for Astronomy and Astrophysics.

36. The extent to which a firm depends on its knowledge as a source of competitive advantage.

members were screened on the number of science and deep-tech incubatees at their centers. The cohort had 64 participants from 16 incubators, 8 academic institutions, and 16 startups. Participants were divided in 25 teams, with each team consisting of a minimum of one entrepreneur or faculty member, and one member from an incubator.

Participants demonstrated tangible progress through the course of the program. Progress towards commercialization, measured by Technology Readiness Levels (TRLs), increased by up to two levels during the program. TRLs are a method for understanding the maturity of a technology with TRL 1 representing the idea stage, and TRL 9 representing a product/service with proven operational success. The readiness of proposed technology was also measured on five other metrics including, team, customer, business, IP, and funding. For instance, under the Customer Readiness Level (CRL) evaluation, ideas were assessed on commercial and market viability. While CRL 1 represents hypothesizing on possible customer needs, CRL 9 represents widespread deployment of a scalable product. By the end of the program, participants saw a 22.6 percent rise in performance across all five parameters, with funding readiness increasing the most, by 30.1 percent. Participants also filed for 24 patents, of which 6 were granted, and won over 22 awards and competitions, including the iDEX, Dassault Systems 3D Experience Global Pitch- Paris,[37] Ministry of Electronics and Information Technology (MEITY) Grand Challenge, and Social Alpha's SBI Techtonic Program.[38] This enhanced their visibility within the science and tech ecosystem.

Another initiative under AIM-PRIME is the PRIME investor panel, which brings together investors to mentor participants, to raise funds for proposed ventures, and to increase awareness amongst the investor community on investment opportunities in science. This initiative brings together angel investment networks, VCs, incubators, and the government, at various forums, including, panel discussions, lectures, mentorship programs, and demo-day evaluation dates. It includes investors from organizations like Venture Centre Pune, Indian Angel Network, Social Alpha, Kotak Investment Advisors and Centre for Innovation, Incubation and Entrepreneurship (CIIE) at the IIM Ahmedabad. This, amongst other initiatives, has helped AIM PRIME participants raise Rs 20 crores. While this initiative is a step in the right direction towards building a funding ecosystem for science and deep-tech startups, funding has so far been highly concentrated with just one company attracting over 50 percent of total funds raised. Over time, as this program is scaled up to include more investors and good quality startups, we can expect to see greater allocation and diversification of funding.

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37. A platform that connects people and business to promote sustainable innovations.

38. A program that supports innovations rooted in science and deep technology in the fields of health, education, climate change and agriculture.

AIM-PRIME is also building an ecosystem to support graduates of the program. It runs PRIME services, through which it provides mentoring and related support to graduates. It also hosts road shows and demo-days for graduates to promote their ideas, and to build investor awareness for funding opportunities in science and deep-tech.

The PRIME Playbook and the PRIME library were launched as outcomes of the first cohort. These programs aim to increase accessibility of educational materials to the broader public. The PRIME playbook is a guide for science-based entrepreneurs and faculty on how to bring research from labs to the market. It covers important concepts such as regulatory and IP management, funding and financial management, networking, and negotiation. It also contains templates for capital structure, evaluation of commercialization potential of R&D, and innovation opportunity maps. The PRIME library compliments the playbook and is a collection of curated links of books, articles, reports, videos, and websites across various business and tech focused topics.

The PRIME program is positive in intent. Many ventures emanating from the first cohort of the program have seen early signs of commercialization and funding success, and have won various awards. The fact that the entire program was run virtually is encouraging for future scalability. Though still too early to reliably measure impact, PRIME has significant potential to positively impact the science and technology ecosystem in India.

5. Summary

India should reinvest in the science-entrepreneurship nexus.

Of course, this must start with a recommitment to investment in basic science. The American inventor and policymaker Vannevar Bush's description of Science as the Endless Frontier in 1945 rings more true today than ever with the explosion of scientific insight (Bush 1945).

Equally, we need entrepreneurs to feed at the trough of this scientific cornucopia. This requires alleviating the mistrust that bedevils collaboration across scientific fields and between scientists and entrepreneurs. It also requires the creation of public goods that remove the informational and contracting voids that prevent consummation of transactions between scientists and entrepreneurs (the sell-side and the buy-side of scientific ideas).

The institutional experiments that I have highlighted in this note (and many others, such as Startup India, UIDAI, Unified Payments Interface, and several at individual States) show the feasibility of the needed policy entrepreneurship. But our rhetoric needs to be even more aspirational rather than self-congratulatory, with the policy will to match.

References

Adams, Jonathan. 2012. "Collaborations: The Rise of Research Networks," Nature, 490(7420): 335–336.

Aggarwal, Varun. 2018. Leading Science and Technology: India Next?, p. 312. New Delhi: SAGE Publishing India.

Amazon. 2022. "The Alexa Fund," https://developer.amazon.com/en-US/alexa/alexa-startups/alexa-fund, accessed on May 13, 2022.

ASER Centre. 2021. "Annual Status of Education Report (ASER) 2021," accessed on June 10, 2022.

Atal Innovation Mission. 2022a. "AIM iCrest," https://aim.gov.in-/aim-icrest.php, accessed on May 11, 2022.

——. 2022b. "ANIC Overview," https://aim.gov.in/anic-overview.php, accessed on May 20, 2022.

——. 2022c. "Atal Community Innovation Centre," https://aim.gov.in/acic-overview.php, accessed on May 20, 2022.

——. 2022d. "Atal Incubation Centres," https://aim.gov.in/atal-incubation-centres.php, accessed on May 11, 2022.

——. 2022e. "Atal Tinkering Labs," https://aim.gov.in/atl.php, accessed on May 6, 2022.

——. 2022f. "Mentor India Round Table," https://aim.gov.in/mentor-round-table.php, accessed on May 20, 2022.

Bain & Company, and Indian Venture and Alternate Capital Association. 2022. "India Venture Capital Report 2022," https://www.bain.com/insights/india-venture-capital-report-2022, accessed on April 25, 2022.

Bhattacharya, Ananya. 2021. "China has invested a lot less in Indian startups than you think it did," Scroll.in, November 19, https://scroll.in/article/1010783/china-has-invested-a-lot-less-in-indian-startups-than-you-thought-it-did, accessed on May 16, 2022.

Blume Venture Capital. 2022. "Understanding India: The Indus Valley Annual Report 2022," https://blume.vc/understanding-india-the-indus-valley-annual-report-2022/, accessed on May 10, 2022.

British Council. 2019. "The School Education System in India". New Delhi: British Council, India.

Bush, Vannevar. 1945. "Science, the Endless Frontier". Washington: United States Government Printing Office.

Business Standard Reporter. 2022. "Pfizer sets up drug development centre at Chennai's IIT Research Park," *Business Standard*, May 5, https://www.business-standard.com/article/companies/pfizer-sets-up-drug-development-centre-at-chennai-s-iit-research-park-122050500197_1.html, accessed on June 12, 2022.

Cable.co.uk. 2022. "Worldwide Mobile Data Pricing 2021,"
https://www.cable.co.uk/mobiles/worldwide-data-pricing/, accessed on April 27, 2022.

CARB-X. 2022. "Portfolio Company, Bugworks," https://carb-x.org/gallery/bugworks/, accessed on June 8, 2022.

CGIAR. 2022. "Impact," https://www.cgiar.org/food-security-impact/, accessed on June 18, 2022.

Choudhury, Prithwiraj and Tarun Khanna. 2020. "Do Managers Matter? A Natural Experiment from 42 R&D Labs in India," *The Journal of Law, Economics, and Organization*, 36(1): 47–83.

Clinton White House Archives. 2022. "Examples of International Scientific Collaboration," https://clintonwhitehouse4.archives.gov/WH/EOP/OSTP/html/00426_7.html, accessed on May 5, 2022.

Comen, Evan and Grant Suneson. 2019. "The Internet and Jeeps are Among 15 Commercial Products Invented by the Military," *USA Today*, December 17, https://www.usatoday.com/story/money/2019/12/17/internet-among-15-commercial-products-invented-by-the-military/40789191/, accessed on May 4, 2022.

Dimitriadis, Stefan and Rembrand Koning. 2022. "Social Skills Improve Business Performance: Evidence from a Randomized Control Trial with Entrepreneurs in Togo," *Working Paper*.

Drug Discovery & Development. 2022. "Pharma's Top 20 R&D Spenders in 2021," https://www.drugdiscoverytrends.com/pharmas-top-20-rd-spenders-in-2021/, accessed on May 10, 2022.

Entrackr. 2021. "Startups Funding Report 2021," https://entrackr-bucket.s3.ap-south-1.amazonaws.com/wp-content/uploads/2022/01/08095803/2021-Funding.pdf, accessed on May 5, 2022.

Fleming, L., Greene, H., Li, G., Marx, M., and Yao, D. 2019. "Government-funded Research Increasingly Fuels Innovation," Science, 364(6446): 1139–1141.

Free Code Camp. 2020. "A Brief History of the Internet – Who Invented It, How it Works, and How it Became the Web We Use Today," https://www.freecodecamp.org/news/brief-history-of-the-internet/, accessed on May 4, 2022.

Gohain, Manash Pritam and Yogita Rao. 2019. "Top IIT's See Surge in Sponsored research, IIT Madras First Ever to Cross Rs 500 cr Mark in a Financial year," *The Times of India*, October 10, https://timesofindia.indiatimes.com/city/chennai/rs-536-54-crore-via-sponsored-research-puts-iit-madras-on-top/articleshow/71497351.cms, accessed on May 13, 2022.

Gonzalez-Uribe, Juanita and Michael Leatherbee. 2018. "The Effects of Business Accelerators on Venture Performance: Evidence from Start-Up Chile," *The Review of Financial Studies*, 31(4): 1566–1603.

Government of India. 2020a. "All India Survey on Higher Education 2019–20." New Delhi: Department of Higher Education, Ministry of Education, Government of India.

——. 2020b. *Report of the High Level Committee on Developing Science and Technology Clusters in India* (Chairman: Dr Rajiv Kumar). New Delhi: Office of the Principal Scientific Adviser to the Government of India and NITI Aayog, Government of India.

——. 2020c. "Report on the Evolution of Startup India. Capturing the 5-Year Story." New Delhi: Department of Promotion of Industry and Internal Trade, Ministry of Commerce and Industry, Government of India.

——. 2020d. "Research and Development Statistics 2019–20." New Delhi: Ministry of Science and Technology, Government of India.

——. 2020e. *"Unified District Information System for Education Plus (UDISE +) 2019–20*. New Delhi: Department of School Education and Literacy, Ministry of Education, Government of India.

——. 2021. "Scheme for Innovations for Defence Excellence (iDEX)." New Delhi: Department of Defence Production, Ministry of Defence, Government of India.

——. 2022. “Innovations for Defence Excellence. A Runway for Innovations.” New Delhi: Department of Defence Production, Ministry of Defence, Government of India.

Gupta, Raj L. 2022. “The Private Sector Can Transform India’s Science, Innovation and R&D Landscape,” *Hindustan Times*, April 3, https://www.hindustantimes.com/opinion/the-private-sector-can-transform-india-s-science-innovation-and-r-d-landscape-101648970964497.html, accessed on May 10, 2022.

Guthrie, Susan, Catherine Lichten, Jennie Corbett, and Steven Wooding. 2017. *International mobility of researchers: A review of the literature*. Cambridge: RAND Europe.

Hariharan, Sindhu. 2021. “More Indians Turn Angels in Startup Funding Boom,” *Times of India*, November 18, https://timesofindia.indiatimes.com/business/india-business/more-indians-turn-angels-in-startup-funding-boom/articleshow/87767006.cms, accessed on April 25, 2022.

Harvard University Center for the Environment. 2022. “Mission,” https://environment.harvard.edu/mission, accessed on May 15, 2022.

Inc42. 2022. “Unicorns of India: Decoding India’s 100 Unicorns Report 2022,” https://inc42.com/reports/unicorns-of-india-decoding-indias-100-unicorns-report-2022/, accessed on May 13, 2022.

India Brand Equity Foundation. 2021. “Report on Pharmaceuticals: May 2021,” https://www.ibef.org/download/Pharmaceuticals-May-2021.pdf, accessed on May 17, 2022.

India Today Web Desk. 2021. “Employers Want Advanced Skills in Engineers, not Just Knowledge,” *India Today*, November 22, https://www.indiatoday.in/education-today/jobs-and-careers/story/employers-want-advanced-skills-in-engineers-not-just-knowledge-1879684-2021-11-22, accessed on May 13, 2022.

Indian Institute of Technology Madras. 2021. “Annual Report 2020–21.” Chennai: Indian Institute of Technology Madras.

——. 2022. “Incubation Cell,” https://www.iitm.ac.in/research-park/incubation-cell, accessed on May 2, 2022.

Indian Venture and Alternate Capital Association, Ernst & Young. 2022. “PE/VC Agenda: India Trend Book 2021,” https://ivca.in/ivca-ey-pe-vc-agenda-india-trend-book-2021/, accessed on May 17, 2022.

International Monetary Fund. 2021. “Stacking up Financial Inclusion Gains in India,” https://www.imf.org/external/pubs/ft/fandd/2021/07/india-stack-financial-access-and-digital-inclusion.htm, accessed on March 15, 2023.

Jones, Benjamin F. 2009. "The Burden of Knowledge and the ‘Death of the Renaissance Man’: Is Innovation Getting Harder?" *The Review of Economic Studies*, 76(1): 283–317.

Khanna, Tarun and Krishna G. Palepu, 1997. "Why Focused Strategies May Be Wrong for Emerging Markets," *Harvard Business Review*, 75(4): 41–51.

Khanna, Tarun, Krishna G. Palepu, and Bullock, Richard. 2010. *Winning in Emerging Markets: A Road Map for Strategy and Execution*. Boston: Harvard Business Press.

Khanna, Tarun, and Michael Szonyi. (eds.), 2022. *Making Meritocracy: Lessons from China and India, from Antiquity to the Present*. New York, NY: Oxford University Press.

Kumar, Rakesh. 2019. “India’s science and technology funding: time to rethink?” *Nature India*, 29 June, https://www.nature.com/articles/nindia.2019.83, accessed on May 12, 2022.

Latker, Norman J. 2000. “Brief history of federal technology transfer” https://ipmall.law.unh.edu/sites/default/files/BAYHDOLE/latkinPDF/Brief_History_of_Federal_Technology_Transfer_by_Norman_J._Latker,_9-24-2000.pdf, accessed on May 15, 2022.

Malik, Bismah. 2022. “India could face shortage of 14–19 lakh techies by 2026: Nasscom-Nizzov report,” *Business Today*, February 17, https://www.businesstoday.in/big-story/story/india-could-face-a-shortage-of-14-19-lakh-techies-by-2026-nasscom-zinnov-report-323019-2022-02-17, accessed on May 12, 2022.

NASA. 2012. “Global Positioning System History,” https://www.nasa.gov/directorates/heo/scan/communications/policy/GPS_History.htmlhttps://nces.ed.gov/fastfacts/display.asp?id=372, accessed on May 4, 2022.

National Science Foundation. 2019. “S&E articles in all fields, for 15 largest producing regions, countries, or economies: 2008 and 2018,” https://ncses.nsf.gov/pubs/nsb20206/publication-output-by-region-country-or-economy, accessed on May 19, 2022.

NASSCOM. 2020. “Startup Catalysts - Incubators and Accelerators 2020,” https://nasscom.in/system/files/secure-pdf/start-up-catalysts-incubators-and-accelerators.pdf, accessed May on 4, 2022.

NASSCOM and Zinnov. August 2022. “India’s DeepTech Startups Poised for Impact,” https://community.nasscom.in/communities/productstartups/indias-deeptech-start-ups-poised-impact, accessed on March 15, 2023.

Nokia. 2022. “India Mobile Broadband Index 2022,” https://www.nokia.com/sites/default/files/2022-03/nokia-mbit-2022.pdf, accessed on May 19, 2022.

Oberoi, Rahul. 2020. “How stocks of largest spenders on R&D have performed during the last 10 years,” *Economic Times*, October 19, https://economictimes.indiatimes.com/markets/stocks/news/how-stocks-of-largest-spenders-on-rd-have-performed-during-the-last-10-years/articleshow/78744539.cms, accessed on May 10, 2022.

Office of the Principal Scientific Adviser to the Government of India. 2022. *Science & Technology Clusters- One Year on the Ground*. New Delhi: Office of the Principal Scientific Adviser to the Government of India.

Office of Science and Office of Biological and Environmental Research, US Department of Energy. 2019. “Human Genome Project Information Archive 1990–2003,” https://web.ornl.gov/sci/techresources/Human_Genome/index.shtml, accessed on May 15, 2020.

Population Pyramid. 2022 “Population Pyramids of the World 1950 to 2100,” https://www.populationpyramid.net/india/2020/, accessed on June 14, 2022

Press Information Bureau, Government of India. 2017. “Ministry of Defence, Defence Innovation Organisation,” https://pib.gov.in/PressReleasePage.aspx?PRID=1496637, accessed on June 11, 2022.

—. 2021. “Ministry of Defence, Innovations for Defence Excellence (iDEX),” https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1739954, accessed on May 24, 2022.

—. 2022. “NITI Aayog - Atal New India Challenge 2.0 (ANIC 2.0) Launch,” https://pib.gov.in/PressReleasePage.aspx?PRID=1821302, accessed on May 31, 2022.

—. 2023. “Sustained Government e orts result in increasing the number of recognized Startups from 452 in 2016 to 84,012 in 2022.” https://pib.gov.in/PressReleasePage.aspx?PRID=1881495, accessed on March 15, 2023.

Press Trust of India. 2022. "Number of recognised startups in India rises to 65,861, says govt," *Business Standard*, March 25, https://www.business-standard.com/article/current-affairs/number-of-recognised-startups-in-india-rises-to-65-861-says-govt-122032500790_1.html, accessed on April 25, 2022.

Rajan, Thillai A., Srivardhini K. Jha, Joffi Thomas, and Rohan Chinchwadkar. 2021. *Shifting Orbits: Decoding the Trajectory of the Indian Start-up Ecosystem*, Hyderabad: Universities Press India.

Rascouet, Angelina, and Pavel Alpeyev. 2021. "SoftBank to take more cautious tack as it cuts deals in China," *Bloomberg*, September 22, https://www.bloomberg.com/news/articles/2021-09-22/softbank-to-take-more-cautious-tack-as-it-cuts-deals-in-china, accessed on May 13, 2022.

Rekhi, Dia. 2022. "Bugworks Research bags US $18 million in funding round led by Lightrock India, others," *Economic Times*, February 8, https://economictimes.indiatimes.com/tech/funding/bugworks-research-bags-18-million-in-funding-round-led-by-lightrock-india-others/articleshow/89431416.cms, accessed on June 18, 2022.

Reserve Bank of India. 2021. *Annual Report 2020–21*. New Delhi: Reserve Bank of India.

Roy, Suha and Natasa Aziz. 2022. "Here's why Shark Tank India is a hit with youngsters," *Telegraph India*, March 6, https://www.telegraphindia.com/edugraph/campus/heres-why-shark-tank-india-is-a-hit-with-youngsters/cid/1854765, accessed on May 15, 2022.

Ryan, Kevin J. 2019. "The 10 Greatest Inventions of the Past Decade," *Inc.*, December 16, https://www.inc.com/kevin-j-ryan/greatest-inventions-decade-2010-2019.html, accessed on May 13, 2022.

Sanyal, Sanjeev and Aakanksha Arora. 2022. "Why India Needs to Urgently Invest in its Patent Ecosystem," https://www.ies.gov.in/pdfs/why-India-needs-to-urgently-invest-in-its-IPR-ecosystem-16th-Aug-2022.pdf, accessed on March 2023.

Savitz, Eric J. 2022, "Amazon Launches US $1 Billion Venture Fund to Invest in Logistics Startups," *Barron's*, April 21, https://www.barrons.com/articles/amazon-launches-1-billion-venture-fund-51650493559, accessed on May 13, 2022.

Scimago Journal & Country Rank. 2020. "Scimagojr country rank 2020," https://www.scimagojr.com/countryrank.php?order=itp&ord=desc&year=2020, accessed on June 17, 2022.

Securities and Exchange Board of India, "Disclosures for 'Basis of Issue Price' section in offer document under SEBI (Issue of Capital and Disclosure Requirements) Regulations, 2018," *Consultation Paper*, February 18, 2022, p. 2.

SHL. 2019. "National Employability Report – Engineers Annual Report 2019," https://www.shl.com/en-in/resources/by-type/whitepapers-and-reports/national-employability-report-engineers-2019/, accessed on March 31, 2023.

StartupBlink. 2022. "Global Startup Ecosystem Index 2021," https://www.startupblink.com/startupecosystemreport.pdf, accessed on June 17, 2022.

Statista. 2019a. "Employability of engineering graduates by role in India," https://www-statista-com.ezp-prod1.hul.harvard.edu/statistics/1017322/employability-it-engineering-graduates-by-job-role-india/, accessed on May 12, 2022.

—. 2019b. "Share of private corporate sector profits to GDP in India from 2003 to 2018," https://www-statista-com.ezp-prod1.hul.harvard.edu/statistics/1051721/india-private-sector-corporate-profit-to-gdp-share/, accessed on May, 17 2022.

—. 2021. "Spending of U.S. pharmaceutical industry for research and development as a percentage of total revenues from 1990 to 2020," https://www.statista.com/statistics/265100/us-pharmaceutical-industry-spending-on-research-and-development-since-1990/, accessed on May 9, 2022.

—. 2022a. "Number of registered alternative investment funds (AIFs) across India from 2014 to 2020," https://www-statista-com.ezp-prod1.hul.harvard.edu/statistics/881640/india-number-of-registered-aifs/, accessed on May 5, 2022.

—. 2022b. "Internet Usage in India," https://www-statista-com.ezp-prod1.hul.harvard.edu/study/22628/internet-usage-in-india-statista-dossier/, accessed on May 14, 2022.

Times News Network. 2019. "Government widens scope of CSR spend to include R&D," *Times of India*, September 21, https://timesofindia.indiatimes.com/business/india-business/govt-widens-scope-of-csr-spend-to-include-rd/articleshow/71228027.cms, accessed on June 14, 2022.

Tripathi, Naandika. 2022. "India's first biomaterial startup Phool.co raises US $8 million in Series A funding," *Forbes India*, April 5, https://www.forbesindia.com/article/startups/exclusive-indias-first-biomaterial-startup-phoolco-raises-8-million-in-series-a-funding/75005/1, accessed on May 20, 2022.

University Grants Commission. 2022. "Total number of universities in the country as on March 4, 2022," https://www.ugc.ac.in/oldpdf/consolidated%20list%20of%20all%20universities.pdf, accessed on May 16, 2022.

UNESCO. 2021. *UNESCO Science Report, The race against time for smarter development*. Paris: UNESCO.

UNESCO Institute for Statistics. 2022. "How much does your country Invest in R&D?", http://uis.unesco.org/apps/visualisations/research-and-development-spending/, accessed on April 27, 2022.

U.S. Patent and Trademark Office. 2022. "Number of Utility Patent Applications Filed in the United States, By Country of Origin, Calendar Years 1965 to Present (1)," https://www.uspto.gov/web/offices/ac/ido/oeip/taf/appl_yr.htm, accessed on June 18, 2022.

—. 2022. "Patent Counts by Country, State, and Year – All Patent Types," https://www.uspto.gov/web/offices/ac/ido/oeip/taf/cst_all.htm, accessed on June 18, 2022.

Uzzi B., S. Mukherjee, M. Stringer, and B. Jones 2013. "Atypical combinations and scientific impact," *Science*, 342(6157): 468–472.

World DataBank, The World Bank Group, accessed on May 31, 2022.

YourStory Media. 2022. "The State of Women Entrepreneurship and Funding– 2018–2021," https://yourstory.com/herstory/2022/03/herstorys-funding-report-the-state-of-womens-entrepreneurs-india-startup, accessed on April 27, 2022.

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Comments and Discussion*

Chair: **Nirvikar Singh**
University of California, Santa Cruz

V. Ramgopal Rao
IIT Delhi

A lot of issues that have been raised in the paper need to be addressed for optimizing deep-tech research and fostering partnerships between industry and academia for carrying out such research in India. In the past six years, 23 alumni of the Indian Institute of Technology (IIT) Delhi have created unicorns, with the similarity among them being that all of them had BTech degrees and families that had some sort of small businesses; they came to IIT Delhi to get a degree and just created businesses, which came very naturally to them. Almost every second student at IIT had an interest in entrepreneurship rather than striving to indulge in deep learning or planning to go for PhDs.

In contrast, IIT Bombay produces about 400 PhDs every year and not even one per cent of them are interested in entrepreneurship, as all of them want to pursue post-docs and faculty positions. What is missing is, therefore, the relevance of the research that is conducted in these institutions. The students at IIT Bombay usually analyze the literature pertaining to the existing problems, get the required funds, execute the project, and write a few papers without exploring how the outcome of that research might help in answering a new question, and also how it may add to the knowledge frontier, specifically for India.

In order to ensure the relevance of the research at such institutions, there is a need to connect with other stakeholders, with industry, society, and strategic agencies, which is done aggressively at IIT Delhi. For instance, at IIT Delhi, there were at least 100 faculty members who worked on research problems funded by the Defence Research and Development Organisation (DRDO), and many of these subsequently became technologies. Hence, initiatives were launched to create more immersion programs in the institution, in order to connect with people and the society, flag the problems, and provide their solutions. In this context, the Grip Grassroot innovation program is

* To preserve the sense of the discussions at the India Policy Forum, these discussants' comments reflect the views expressed at the IPF and do not necessarily take into account revisions to the conference version of the paper in response to these and other comments in preparing the final, revised version published in this volume. The original conference version of the paper is available on NCAER's website at the links provided at the end of this section.

an important initiative wherein the faculty and students can identify a local problem and work towards its resolution, with the institute's support. Taking this idea forward for encouraging faculty to become entrepreneurs, a scheme called Faculty Innovation and Research-driven Entrepreneurship (FIRE) was also started, wherein any faculty member wanting to become an entrepreneur was offered a funding of Rs 50 lakh as a grant, and given a sabbatical to start a company (prior to this, a sabbatical was given only for taking up a teaching assignment abroad), with all the resources being provided by IIT. The success of these initiatives was reflected in the fact that at IIT Delhi, every second faculty member started a startup. A national-level process, including the setting up of a PhD incubator, was also launched.

These initiatives would, however, be more effective if they are managed directly by the faculty rather than bureaucrats. The biggest challenge is to procure sub-critical funding, which is increasingly becoming a bureaucratic issue. The ability of an institution to fund innovation is also rapidly diminishing. For example, an analysis was done at IIT Delhi, wherein all the data pertaining to the previous five years of research funding was examined. The average overhead that institutes received towards five years of research funding amounted to about Rs 1500 crores, the average overheads that the institute received was 5 percent, and the institute was spending about 12 percent on these projects. Thus, the more research the institutions carry out, the poorer (worse) they become. Consequently, our ability to invest in any research is actually diminishing, and the biggest challenge faced by these institutions is to become multi-disciplinary, start new programs, admit more students, and recruit more faculty. Since IIT funding is not linked to the number of students, if sometimes some director becomes more enthusiastic and starts multiple programs simultaneously, the institute again turns poor because the Ministry of Education does not assess the number of students being offered funding. One major policy challenge in India is thus to put in place a proper financial model for running higher educational institutions like the IITs.

Patenting is another critical issue, as the patent-to-publication ratio can also link research to innovation. An analysis of global data in the sphere of nanotechnology, especially in the USA, which is a hub for innovation, reveals that a patent is filed there for every five papers written by scholars on subjects related to nanotechnology. In, India, on the other hand, a patent was traditionally being filed for every 300 papers written. This number has since been brought down to one patent for every 18 publications.

Another challenge is to promote multi-disciplinary research. Until now, there was no scheme whereby two faculty members from two diverse departments or from two different institutes could come together to conduct a research study. Hence, we undertook an experiment at IIT Delhi, wherein if two faculty from two different departments or from two different institutes in the country would come together to write a coherent proposal addressing a social problem, the institute would offer each of the faculty members a seed grant of Rs 5 lakhs per year for two years. Thus, a total amount of about Rs 20 lakhs was spent on such multi-disciplinary projects with the condition that after two years, the researchers would have to seek extra support funding from other agencies. About Rs 12 crores have been spent on supporting such multi-disciplinary research at IIT Delhi over the last four years, with returns of about Rs 180 crores accruing from this experiment in the form of additional funding brought in by the faculty members engaged in this research.

It is imperative to devise and implement more such schemes in the country. This could be done by providing funding for such research to universities across the country, and also by encouraging faculty from Tier-1 institutes to interact with and write joint proposals with their counterparts from Tier-2 and Tier-3 institutes. These schemes can create widespread motivation among people from different institutions. A lot of good research is taking place in academia, which could meet the requirements of industries. However, such cross-cutting collaborations are hampered by the lack of interaction across both institutions and ministries.

This situation could change with the new National Education Policy 2020 envisaging the setting up of a National Research Foundation (NRF) to strengthen the research ecosystem in India by improving linkages between Research & Development, academia, and industry. Many agencies are now also providing funds to startups, including deep-tech startups and a large number of faculty of academic institutions are considering launching their enterprises. However, they need to be provided training and support in the areas of quality control, manufacturing, and marketing. It is thus important to create an entity which not only funds but also provides advice and technical assistance to such budding entrepreneurs. Such agencies already exist in other countries, which can be analyzed for their best practices. For example, the Industrial Technology Research Institute (ITRI) in Taiwan acts as a bridge between academia and industry, and can be seen as a role model for creating such entities in India too.

Thus, what is needed is a little reorientation in the research ecosystem to enable India to enter the deep-tech space. The focus needs to shift towards funding national programs to promote research activity by the faculty, entrepreneurs, and universities for harnessing the vast academic talent available in the country. India can do as well in the arena of deep-tech entrepreneurship as it has done in the e-commerce and other spaces.

Chintan Vaishnav

NITI Aayog

This paper identifies several critical gaps in the innovation ecosystem, specifically relating to science-based entrepreneurship. It paves the way for promoting science-based entrepreneurship by taking forward the perspective on the different dimensions it talks about, and the insights it generates. Our innovation ecosystem today broadly caters to those who are proficient in English, accounting for only about 11 percent of our population. Comparing that, say with Israel, which ostensibly has one startup for every 2000 citizens, we have 70,000 startups today, which for a population of 1.3 billion people, equates to one startup for every 20,000 citizens.

While a lot more work needs to be done in this area, we at NITI Aayog have launched a number of initiatives to boost science-based entrepreneurship across the country. A significant example of this, also mentioned in the paper, are the Atal Tinkering Labs established under the Atal Innovation Mission to foster curiosity, creativity, and imagination in young minds; and to inculcate in them skills such as design mindset, computational thinking, adaptive learning, and physical computing. We have built 10,000 such labs, but considering that there are 260,000 secondary and higher secondary schools in the country, clearly 10,000 is a very small fraction of that, and we need to do much more work infrastructure-wise.

The next layer that we need to work on is that of the human resources which utilize these labs. Thereafter, as regards the third layer where specialization begins to occur with a sector-wise innovation ecosystem, we built something called iDex, also flagged in the the paper. This initiative is aimed at fostering innovation and technological development in the Defence and Aerospace ministries by encouraging innovators and entrepreneurs to deliver technologically advanced solutions for modernizing the Indian military. iDEX will engage industries, startups, R&D institutes, and academia, and provide them financial and technological support to undertake R&D for fulfilling India's defense and aerospace needs.

We are also in conversation with several other ministries for establishing a similar platform for their respective sectors. This third layer of the entrepreneurship pyramid is in the early adopter stage with ongoing discussions with the ministries.

The paper really gives us the ammunition to tell these ministries that there are real returns for investing in research. One major challenge in writing such a piece as well as reading it is that most of the advanced ecosystems in the USA, such as in the Bay area, or Boston, are over 40 years old. The question that needs to be addressed is as to what were they like when they were ten years old, and whether they faced a similar skew in terms of excessive favoring of some sectors as compared to the others, and the types of deep science challenges they encountered in the early years of their inception.

The paper offers some dynamic insights. First, it makes a solid argument about the funding ecosystem, the availability of funding, and the low throughput of the ecosystem in terms of the incubators. The funding availability is a capacity of the ecosystem, while the throughput needs to be evolved by the stakeholders in collaboration with each other, not independent of each other. If the funding suddenly increases and it is not utilized efficiently, there is a loss of investor confidence.

On the other hand, if infrastructure increases independent of funding, then too there would be a loss in terms of the young innovators feeling that though they came up with a bright idea, it could not be fructified due to lack of funds. This could compel the young talents to give up the original projects and seek funding elsewhere. This co-evolution idea is thus a major contribution of the paper.

The other important argument made in the paper pertains to the public-private research funding and the very low quantum of funds we are currently investing as a nation on research. This dovetails into the idea of early stage grants and investments for deep science entrepreneurship, which has a deep and wide value. Thus, the idea of greater research funding, on one hand, and fostering more risk-loving early-stage grants, on the other hand, must coalesce to enable us to overcome scientific uncertainty at an early stage, which again is an idea promoted by the paper.

The third thing concerns the multiplier over how we have invested so far and the returns from early innovation incubation centres. This is the first time that such a back-of-the-envelope calculation has been made, and it has a direct impact on how we write our next Cabinet note, as it turns the idea of returns into a formula, assimilating the returns from a value created by startups, by incubators, and by tinkering labs, among others, in the entrepreneurial space. If we look at this formula from the perspective that technology is only a non-linear variable, then the returns of the first five years cannot be the same as those of the second five years, and there has to be a multiplier greater than the one for the second five years. One thing that would lead to that multiplier effect is the extensive utilization of the available infrastructure. iDex, however, achieved a return of 50 times because there was no need to build the infrastructure. The paper also offers the argument that this process has to be carried out for industry after industry, accompanied by the information that the infrastructure already exists but needs to be utilized for integrating innovation into the industry sector. This thought presented in the paper will also translate into our cabinet note.

The idea that the foundation for deep science entrepreneurship cannot come without academic strengthening is not adequately discussed. The paper talks about the AIM-Prime program, which envisages promoting science-based, deep-technology ideas to market through training and guidance provided over a period of nine months. The main intent of such a program is to take ideas from the lab to the land, and demystify that process to the extent that the program could. The booklet that it produced called the AIM-Prime playbook has all these frameworks, which guide readers in their choice of science-based entrepreneurs. A deep-science ecosystem is also missing for innovation. Further, highlighting the significance of the manufacturing capability, creating a prototype and small trials is easy but designing for manufacturing is a very different area altogether, and poses a major bottleneck for many start-ups. Second, the absorption capacity or the market creation for a particular startup is a difficult proposition, and this is where the government ought to step in. Finally, with reference to human resources and skill development, we are scaling the infrastructure but we also need to scout for human resources or managers who would consider these different deep-science and technology creation and innovation areas as long-term career choices.

General Discussion

Michael Kremer commenced the discussion by asking for details about the sale value of a company in Bengaluru mentioned by the author in his presentation. He assumed that there was some reason why the legal transaction for changing ownership of the company could not be undertaken. Presumably, this was because the location of the company had been changed through some internal purchase to Boston from India. He asked if the company wanted more employees based in Boston or if the ownership change could not be effected through a legal transaction.

Tarun Khanna responded that there are frictions in the form of taxation, as the country where the enterprise originated is understandably reluctant to accept them. Further, redistribution also takes place due to lack of synchronization of the tax scores. Besides, the buyers have the bargaining power due to lack of a vibrant market in the original location. Arvind Panagariya asserted that the bargaining power of the buyer should not be dependent on the location of the company. Karthik Muralidharan reiterated that the issue could have to do with the labelling of customer needs and the dynamics of the local markets.

Govinda Rao wondered why the private sector in India is not forthcoming in making investments in the specified areas. Was this because they still enjoy a lot of protectionism or because they want to sell off the existing companies? This is a matter of concern because the private sector leads many science-based entrepreneurships elsewhere.

Deepak Mishra wanted to know what market failures and government failures was the New Lab trying to solve, especially in terms of critical issues that are being addressed by this particular lab vis-à-vis a global innovation hub like the US. He also questioned as to whether the sub-title of the paper, "A Policy Glass Quarter Full", pertains to the perception that only a quarter of India's potential is actually being achieved, and how far this can be contextualised in the current economic environment prevailing in India.

Anup Malani asked the author about the importance of innovations in terms of the scientific, legal and financial infrastructure relative to science. If only the scientific issue were resolved while the other issues were left unaddressed, it would become a limiting factor for the proposed innovations. He also asked Ramgopal Rao why it was difficult outside of the IITs to generate a start-up infrastructure or a start-up atmosphere. It is imperative to identify the difficulties with university administration in India versus places like the United States, where the start-up culture has been embraced across a broader range of universities, and not just in the technical universities.

Tarun Khanna replied that the private sector issue relates to the new lab infrastructure issue. Even in the US context, where the market infrastructure for science-based entrepreneurship is much better than in other countries, it is important to consider experience and the need to deal with people of different mindsets, such as a researcher in a lab versus an executive who has to answer to clients and shareholders on issues like quarterly earnings and reports. As regards the legal infrastructure, he suggested that such an ecosystem is well established in India, reflected in the existence of intellectual property lawyers, who are cognizant of systems and processes and the functioning of global companies operating out of India currently, which trains them to deal with different types of IP regimes and patenting regulations.

Ramgopal Rao averred that in order to overcome the lack of confidence exhibited by corporates in funding new startups helmed by academia, there is a need to deal with the challenge of collating coherent data, and convincing the government to provide substantial funding for startups. The issue of extensive homogeneity and lack of cultural diversity in Indian academic institutions also ought to be addressed. For this, it is essential to engender multi-disciplinary institutions of higher learning and to foster structural changes in the existing academic institutions. Chintan Vaishnav flagged the question of lack of private sector interest in providing funds for startups, and noted that enterprises need to see improvements in both their top and bottom line outcomes as a result of engaging with the startups, resulting in higher market shares and improved profits, respectively.

Bornali Bhandari cited a specific NCAER project on improving farm mechanization in India and ways of making India a production hub for farm machinery. One of the big challenges in this sector is the insufficient R&D in this particular industry, for which the solution again lies in enhancing collaborations between academia and industry. Discussions with private entrepreneurs and the Indian Council of Agricultural Research institutes run by the government revealed that while the private players are largely driven by the aim of augmenting profits, the public institutes have access to research expertise and interest but are unable to forge sustained partnerships with private parties, essentially because they would not be producing a public good. Thus, though both the private sector and public sector enterprises are keen to partner with each other, this interest does not fructify into results on the ground.

One of the solutions could be the implementation of legislation like the Bayh-Dole Act, or an Act enabling public universities to partner with private parties, to produce goods, and create a productive R&D environment. Secondly, while the USA is undoubtedly a global innovation hub, one of the countries that has done quite well in terms of the academia-industry collaboration is Turkey, which offers rich examples of creating techno parks, and Science, Mathematics and Technology (SMT) clusters through an exchange between the public and private parties. Simultaneously, it is also imperative to generate patents to facilitate commercialization of the innovations.

Ruchir Agarwal alluded to the creation of a Bio Valley in Malaysia, in the book, *The Boulevard of Broken Dreams* by Josh Lerner, which ends up becoming a valley of bio-ghosts. In this context, public efforts need to be encouraged to scale up entrepreneurship in Indian cities to prevent them from suffering the same fate as the Malaysian Valley.

Karthik Muralidharan argued that if government funding for startups is bureaucratic and private funding depends on high returns on investment in a finite time horizon, the startup ecosystem is probably a fertile space for philanthropic funding, which is currently confined to the building of schools and hospitals in India. Taking the issue of philanthropy further, Sonalde Desai said the concept of industry CSR funding could also be considered. The Indian Government has actually mandated a certain percentage of CSR spending by the industries. So, in certain big growth areas like biometrics, auto parts, and pharmaceuticals, innovation could be encouraged by allowing these industries to initiate some deep-science funding in their respective areas.

Manish Sabharwal pointed out that as regards location-based valuation, 25 percent of the public markets are owned by foreigners, and 50 percent of the non-founder ownership of public markets rests with foreigners. But software, pharmaceuticals, consumer and services companies trade at higher multiples in India than they do in the US. Therefore, location-based valuation is advisable and for companies like Dr Reddy's or Tata Consultancy Services (TCS), it is more beneficial to be listed in India.

Ramgopal Rao highlighted the significance of a composite financial model, comprising CSR funding and creation of endowment funds for academic institutions on the lines of similar funding undertaken for universities in the USA. Perhaps the Indian government can mandate that 1 percent of the CSR must go to educational institutions. He revealed that IIT Delhi was the first institute in 2019 to launch a billion-dollar endowment fund. Another source of finance for American universities is that of overheads from research projects, which is conspicuously absent in India. Chintan Vaishnav stated that he had initiated discussions with a variety of stakeholders to create a hub like the New Lab, which would be distinct from the concept of clusters. What is also needed is a viable system of intermediation and a deep-tech climate to generate sufficient interest in science-based entrepreneurship in the country by fostering handshake mechanisms between entrepreneurs and scientists.

Concluding the discussion, the Chair, Nirvikar Singh remarked that the new National Education Policy offers some hope of fresh thinking and flexibility in encouraging innovations, especially in specific areas where things can be improved without difficult institutional interventions. There is thus some supremely low-hanging fruit that India can and should take advantage of, without further delay.

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