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6. From Development to Innovation

Policy for Science and Technology in India

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India, in 1939, was among the eight most industrial countries in the world and hosted one of the largest scientific communities outside Europe and North America.[1] It is no surprise then that a National Planning Committee (NPC) was established in 1938 by the leadership of the Indian National Congress Party (INC) following the elections under the Government of India Act (1935) to form government in provinces under British India.[2] The NPC took charge of the first concerted efforts to shape the regulation of science and engineering research and education in relation to public life in India. Earlier, at the start of the decade, Chandrashekhara Venkata Raman was awarded the Nobel Prize in Physics in 1930, and he remains, to date, the only Indian citizen to earn a Nobel Prize in the sciences. It made perfect sense for the first elected provincial government to establish a National Planning Committee because, by Independence, science had come "to assume a public importance, a social impact and a cultural resonance inconceivable at the start of the colonial era."[3]

The National Planning Committee, in its journey via the Planning Commission of India, established in 1950, was modeled on the success of the Soviet five-year plans to transform a largely agrarian economy into a modern industrial economy for economic growth and development.[4] It is the precursor to today's National Institution for Transforming India, or Niti Aayog, established in 2014 to signal the changed perception of the Indian economy both at home and, to some extent, abroad. The two institutions firmly establish the intent behind policy for science and technology (S&T) in the country: the development, industrialization, and economic growth of India. These objectives did not go uncontested, and in the early years of independence, an interesting debate ensued between those interested in the ideas of Mohandas Gandhi and, broadly speaking, those interested in ideas fronted by the country's first prime minister, Jawaharlal Nehru.[5]

At Independence, a "Nehruvian model" began to take shape. Science- and engineering-led industrialization became central to the nation's planned economic development.[6] Nehru himself played a significant role in supporting the establishment of a number of scientific institutions and organizations. Starting already in the 1940s, independent India's first government worked closely with scientists to create state-funded research and educational institutions such as the Council of Scientific and Industrial Research (CSIR), the Tata Institute of Fundamental Research (TIFR), and the Saha Institute of Nuclear Physics (SINP), laying the groundwork for the autonomy of scientific research in India, many a times at a distance also from the universities. The 1950s saw the expansion of scientific agencies like the Department of Atomic Energy (DAE) and the Indian Council of Medical Research (ICMR).

A SCIENCE POLICY RESOLUTION: 1958

Nehru's regime held fast that a welfare state could succeed only through investment in science and technology. Creating jobs, alleviating poverty, and industrializing India were deeply connected to rapid expansion of education, skills, and human capital, particularly through higher education institutions. This vision culminated in the first document in science policy for India: the Scientific Policy Resolution (SPR) of 1958. The SPR, a concise two-page document, laid the foundation for integrating science into national development. Increasingly aligned with India's Five-Year Plans over time, the SPR was foundational to future science policies. It stated:

> The Government of India have decided to pursue and accomplish these aims by offering good conditions of service to scientists and according them an honored position, by associating scientists with the formulation of policies, and by taking such other measures as may be deemed necessary from time to time.[7]

In 1960, during his inaugural address to the Indian Science Congress, Nehru stated how his own interest in science had arisen from "the social consequences of science rather than the science itself."[8] The SPR highlighted the position of scientists as key advisors toward the making of public policy. Commissions and other centralized regulatory agencies of the state headed by scientists—and not by bureaucrats—were created in the early years of independence. The Atomic Energy Commission (AEC), first headed by the physicist Homi Jehangir Bhabha, became the model for how to organize government for science and continues to do so today. The SPR could be seen as a document of aspiration that called for the cultivation of a "culture and mechanism where creative talents of citizens are recognized and opportunities are found in scientific activity, acquisition, dissemination, and discovery of new knowledge," setting the stage for the next two decades.[9] The resolution invited global attention for demonstrating the country's commitment to "science and technology in the service of development"; one might say it became foundational for the discourse on both scientific temper and scientific enterprise.

The two decades between the 1950s and the 1970s can be considered the era of "policy for science" in India.[10] This included determined efforts at gathering robust data by the Research Survey and Planning Organisation led by Abdur Rahman, an information scientist and science policy analyst, for the Council of Scientific and Industrial Research. The focus was on consolidating existing strengths and prioritizing policy implementation, which could establish basic infrastructure and human resources for the growth of science and industry in the country. New and specialized state agencies emerged in India, like elsewhere, such as the Department of Atomic Energy (DAE), Indian Council of Medical Research (ICMR), Council of Scientific and Industrial Research (CSIR), the Defence Research and Development Organisation (DRDO), and Indian Space Research Organisation (ISRO) all of which expanded significantly and increasingly shaped science policy away from the universities.

Itty Abraham, a political scientist, has argued that Homi Bhabha's successful creation of the AEC, which led to the formation of similar specialized and dedicated state agencies, was largely because of

> close personal ties between Nehru and Bhabha, with the former seeing in the latter

> the one person who could translate his vision for the technological transformation of the country into reality. Bhabha also had intimate ties to the largest private Indian business conglomerate, the Tata group, which not only was funding his Bombay-based research institute but also was connected to him through kin networks. Tata support for Bhabha reinforced his standing by adding financial backing and a professional managerial element to his acknowledged scientific abilities.[11]

The structures governing science and engineering education and research that emerged in the first two decades of independence are attributed to the close relationships between scientists and political leadership at the time, including personal relationships that Nehru shared with many of the institution builders of the time. Homi Jehangir Bhabha (of the Tata Institute of Fundamental Research and the Atomic Energy Establishment, Trombay), Shanti Swarup Bhatnagar (of the CSIR), Prasanta Chandra Mahalanobis (of the Indian Statistical Institute, the National Sample Survey Organisation, and the Planning Commission of India), and Daulat Singh Kothari (of the DRDO) led the establishment of structures and the mechanisms of both governance and institution building, which remain prevalent today. As a result of prioritizing "reasons of state," it is worth noting that rural technologies, agriculture, medical research, and, most critically, research and education in Indian universities have only seen marginal growth.[12]

Aspirations articulated in the Scientific Policy Resolution of 1958 under Nehru's leadership continued to inform the governance of science and the kinds of projects that the Indian state invested in between 1970 and 1980 under Prime Minister Indira Gandhi. In the middle decades of the twentieth century, comprehensive planning for science and technology adapting both the American New Deal and the Soviet models were abundant across the globe, especially in the newly independent countries, including China and India. The Chinese twelve-year science and technology plan (1956–67) and the first dedicated Indian five-year plan for science and technology (1974–79) were remarkable.[13]

Cold War geopolitics of technical assistance and development aid characterized the global oversight on science and technology policy. Organizations like UNESCO took the lead in documenting policies across countries and, in the process, also shaped the vocabulary for science policy studies, especially in the developing world. The Cold War indelibly embedded science and technology policy for defense and development in India: warfare and diplomacy determined the projects that would get invested in. If nuclear research, followed closely by aerospace research, was already on the tray at the end of World War II, the Green Revolution was added to it at the height of the Cold War to address the precarity of food aid. At home, India participated in three wars in the neighborhood between 1962 and 1971: the Sino-Indian War of 1962, the Indo-Pakistani War of 1965, and the Bangladesh Liberation War of 1971. Wanting to fortify defense capabilities and not wanting to be left behind in the global nuclear and space race, the country saw more than a fourfold increase in its budget for defense and nuclear research. This was a wartime economy that expected science for warfare.

In 1974, India conducted a Peaceful Nuclear Explosion declaring in no uncertain terms its aspiration to nuclear capability; a year later, in 1975, the Indian Space Research Organisation launched its first satellite, *Aryabhata*, followed by the launch of its second satellite five years later, in 1980. Key departments dedicated to dual-use technologies such as the Department of Electronics, the Electronics Commission, and the National Centre for Software Development and Computing Techniques (NCSDCT) were also established in this decade. The Indian Patent Act of 1971, which limited patent protection to seven years, brought support for the pharmaceutical industry and paved the way for India's global trade in generics. This was the policy that enabled CSIR laboratories to develop processes that allowed Indian pharmaceutical companies to commercialize essential drugs by exploiting existing patents. Indian pharma firms, in collaboration with CSIR's five drug research labs, attained high technological capabilities in reverse engineering, facilitating the introduction of generic drugs into the market.[14]

India's science and engineering capability was on the ascent in the 1970s and 1980s, which contributed to a return of the Gandhian argument on the secondary place of rural India in processes of industrialization. Scholars across the human, social, and natural sciences as well as bureaucrats noticed the disparity between the urban rich and the rural poor following the implementation of large engineering projects.[15] Could science and engineering deliver equitable development and alleviation from poverty to the taxpayer? A strong critique of science and technology–led development policy emerged in civil society with the People's Science Movement and the Alternative Science Movement, and in academically eminent institutions like, among others, Application of Science and Technology to Rural Areas (ASTRA) led by Amulya Reddy at the Indian Institute of Science, Bangalore.[16]

An aspirational resolution on science policy was inadequate by the early 1980s, and the strength of the critique of large engineering projects called for a more directly articulated policy on technology. In 1983, only a year before her assassination, Indira Gandhi's government introduced a Technology Policy Statement, one that her son and the next prime minister Rajiv Gandhi would implement infused with his own vision and that of his advisors, prominent among them being Sam Pitroda. As we begin to trace the next turn in science policy, it is perhaps helpful here to pin the argument that science and technology policy well into the early 1980s was essentially development policy that assumed a linear model of science-backed industrialization, at times folded into innovation.[17]

A TECHNOLOGY POLICY STATEMENT: 1983

The Technology Policy Statement (TPS) was introduced in 1983.[18] The statement was a declaration of confidence in what preceded: "Our science has shown its capacity to solve problems." Therefore, the statement was a guiding document to achieve one goal: self-reliance. India was not alone to firmly establish the need for self-reliance in the context of international conflict, competition, and capacity for collaboration.[19]

> We have regarded science and technology as the basis of economic progress. As a result of three decades of planning, and the Scientific Policy Resolution of 1958, we now have a strong agricultural and industrial base and a scientific manpower impressive in quality, numbers and range of skills. Given clear-cut objectives and the necessary support, *our science has shown its capacity to solve problems. . . . In a country of India's size and endowments, self-reliance is inescapable and must be at the very heart of technological development*. We must aim at major technological break-throughs in the shortest possible time for the development of indigenous technology appropriate to national priorities and resources. For this, the role of different agencies will be identified, responsibilities assigned and the necessary linkages established.[20]

Key technologies of the 1980s—biotechnology, information technology, and microelectronics—posed a new concern for India: the challenges of absorption and diffusion. But even before that, the most significant challenge came from export controls and technology denial implemented by the United States, particularly in the areas of supercomputing, space technologies, and critical high-tech components.[21] A primary motivation, therefore, for the TPS was to institutionalize processes to "reduce dependence on foreign technologies, support for infant industry protections for indigenously developed products and recommendation to back-engineer imported capital goods."[22] This was back-ended by an explicit policy directive for technology assessment studies. The CSIR agencies producing robust data on India's science and engineering capacity in the first two decades after Independence had been reconstituted, and systematic policy-relevant insights through comprehensive surveys were tenuous at best.

An important objective for the TPS was the consolidation of an Indian technology base in the up-and-coming sectors of the time—information, electronics, and biotechnology—by identifying obsolete technologies and replacing them with technologies that would improve "productivity, efficiency, quality and reliability of products using minimum capital and energy utilization."[23]

TPS eventually managed to address, at least in directives, some of the concerns that were brought up by civil society and scholars demonstrating, first and foremost, awareness of notable environmental concerns.[24] The previous decade had already seen two oil crises. The first occurred in 1973, with a total oil embargo by the Organization of Arab Petroleum Exporting Countries (OAPEC) of countries that had supported Israel during the Yom Kippur War. Barely six years later, in 1979, following the Islamic Revolution in Iran and the overthrow of the Pahlavi dynasty, a drop in oil production led to a second global energy crisis. In India, this prompted policy directives for reduced energy consumption. The TPS acknowledged an uneven development of the Indian economy and identified key sectors for investment in science and technology, specifically in health, food, housing, energy, and industry. Indira Gandhi's regime may be equally remembered for conservation policies that gave impetus to scientific research in ecology, which remains a patchily studied field.[25]

Only a year after the TPS was introduced, Indira Gandhi was assassinated and her son, Rajiv Gandhi, became the new prime minister. His regime inherited the vision embodied in the Technology Policy Statement to which he soon added his own. In 1987, Rajiv Gandhi appointed Sam Pitroda, an Indian telecommunications engineer and entrepreneur, as an advisor on National Technology Missions. Pitroda and Gandhi began with five critical missions: drinking water, immunization, literacy, oil seeds, and telecommunications, to which they soon added a sixth: dairy production. To achieve these objectives, a Department of Biotechnology (DBT) and a Technology Information Forecasting and Assessment Council (TIFAC) were established in 1986 and 1988, respectively.

INTERLUDE

In many ways the National Technology Missions, most critically the one on telecommunications, prepared the country to meet the sweeping global transformation taking place at the end of the Cold War. The New Industrial Policy of 1991 aimed at providing facilities and infrastructure, including a workforce, this time not primarily aimed at state-led development but at efficiencies connected with globally open or liberalized market forces.

Economic policy in India wrestled with the idea of import substitution especially in the first few decades after Independence given its success in East Asian economies like South Korea and Taiwan. However, given the skepticism of senior economic advisors on import substitution, it was not adopted as an overarching policy; economist Amiya Bagchi as late as 1990 argued that "the distinction between import-substitution and export-led growth strategies is too mechanical to serve as a policy guide in any real economy."[26] This thinking, in the context of low foreign exchange holdings of the Indian government, had interesting consequences on the acquisition of research and training apparatus from outside India that played out differently for dual-use science and engineering like nuclear research, space research, and electronics when compared with many other areas.

Economic reforms were introduced in India in the early 1990s. Industrial and political leadership in India that was aligned with the changing global geopolitical landscape came to the fore in shaping a private sector to lead economic growth and expect the free operation of markets.[27] With globalization (and liberalization and privatization, vocabulary articulated in the policy), increasing market competition, and the country opening up its economy, the principles of TPS 1983—technological self-reliance and the adoption of home-grown technologies—had to nest within a new paradigm. The inflow of external capital but more so of shifting priorities in market-driven technology projects sometimes conflicted with the TPS's goals. Some socioeconomic sectors became reliant on foreign technology and investment in the domains of information technology, entertainment, and aviation, among others, challenging the earlier vision of self-reliance. Science and engineering research and education as well as their real and imagined contributions to the economy became increasingly imbricated in foreign equipment, grants, and investments.

The global landscape of science and engineering saw extraordinarily rapid and substantial transformation during the 1990s and early 2000s. This period marked a transition toward a more multidisciplinary approach, fostering international collaboration that has shifted scientific practices even as they have become ever more deeply implicated in industry, the financialization of the economy, and technologically enabled governance. If earlier policies treated science and technology as not entirely but somewhat separate strands for regulation, it is evident that this approach is no longer possible in a knowledge economy.

A SCIENCE AND TECHNOLOGY POLICY: 2003

The Science and Technology Policy (STP) of 2003 came two decades after TPS (1983) to address the globally shifting language of knowledge, commerce, and fierce international competition. The principles of TPS paved the way for a new liberal approach that was consolidated in the STP. The state took on the role of encouraging and supporting all kinds of private enterprise but especially knowledge-based private enterprise through public-private partnerships. This shift marked a departure from the federal and nationalistic ideals of the past, when the state was the main patron of research and development (R&D), to align with a so-called universalizing impulse that looked for a global power status for India and one within which the discourse on science and engineering was well placed to nestle into.[28]

Perhaps the most significant aspect of this policy was the official recognition of a need for a substantial increase in R&D investments: the policy recommended the goal to increase investment to 2 percent of GDP.[29] Although this target was not met, the policy did bring about an increase in both public and private R&D investments, reaching a globally recognized figure of 0.7 percent of GDP by the end of the decade.[30]

Another significant aspect of STP 2003 was the perceived need for developing mechanisms within ministries and state agencies to solicit ideas from scientists and technologists for planning and policymaking. Toward this end, STP 2003 articulated the necessity to modernize infrastructures within academic institutions and introduced, to some extent, new funding mechanisms for basic research. In keeping with the global collaborative efforts of the early 2000s, the policy called for incentive systems to bring scientists and engineers, particularly those of Indian origin from abroad, to contribute to India's science, technology, and innovation (STI) ecosystem. STP 2003 also placed heavy importance on the protection of intellectual property by establishing an intellectual property rights regime to protect and further incentivize scientists and researchers. With international collaboration taking center stage, STP 2003 encouraged science diplomacy, especially among countries in the Global South.[31]

STP 2003 was an expression of the changed topography of education, research, and manufacturing and of international relations, including scientific collaborations and trade. The language that was developing around this change was one of "knowledge economy" and the word "innovation" was causing forest fires across the landscape. A National Knowledge Commission was created in 2005 with a tenure of three years during which it was to advise the prime minister on policy and reforms in education, science and technology, e-governance, and so on. Technology and engineering-led thinking was getting deeply embedded in the mechanisms of governance. In five years, a National Innovation Council was established (2010) with Sam Pitroda as its chairperson; its mandate was to draw up a Roadmap for Innovation in India for the next decade.

A SCIENCE, TECHNOLOGY, AND INNOVATION POLICY: 2013

As the country caught its breath following the rapid and sweeping changes in the organization of markets and social life around consumption that rolled off decisively in the early 1990s, the newest policy document identified the decade between 2010 and 2020 as a "Decade of Innovation."[32] Increased globalization accompanied by an exponential growth of engineering and information technology in everyday life made it imperative for India to find its own version of a knowledge-based economy. A decade after STP 2003, the Science, Technology, and Innovation Policy (STIP 2013) normalized the intention to support "innovation" through government with a continued older emphasis on finding pathways to show how "innovation converts knowledge into wealth and/or value."[33]

Among the first initiatives facilitated under STIP 2013 was India's increased involvement in (expensive) global mega-science projects, including the Laser Interferometer Gravitational-Wave Observatory (LIGO), the Large Hadron Collider (LHC) at CERN (Conseil Européen pour la Recherche Nucléaire/European Organization for Nuclear Research), the International Thermonuclear Experimental Reactor (ITER), and the Square Kilometer Array (SKA).[34] The policy embodied a faith in international scientific collaborations and diplomacy as new opportunities to harness global knowledge for domestic advancement. Innovation, the world agreed, was to be driven by skilled scientists and engineers and the knowledge they help produce.

This policy document speaks of ambition with a new language of confidence: the aim is to position India among the top five countries in research and innovation and to boost R&D personnel by a staggering 66 percent over five years. This would be achieved by stimulating innovation through the encouragement of private-sector investment in research and development. The policy also made a point of remembering other ambitions from bygone days: directing scientific discovering and technological advancements toward developmental priorities such as manufacturing, water, health, agriculture, infrastructure, and environment.

In 2014, only a year later, a new government led by the Bhartiya Janata Party came into power led by Prime Minister Narendra Modi. It continues to date through two subsequent general elections. Seen from changes perceived in the culture around science and technology policy, the new administration is seen to exert significant political-bureaucratic influence and control over the conduct of research and education, also in science and engineering.[35] The new government has shaped several national flagship programs and missions that involve science and technology, research and development, and technological inputs and resources, including financial and human expertise such as Make in India, Skill India, Digital India, and Startup India. The Technology Development Fund (TDF, 2023), a flagship program of the Ministry of Defence and executed by the DRDO under the Make in India initiative, has been established, offering financial assistance to industries.[36] Several policy reforms and regulatory changes like simplifying patent processes, providing tax incentives for R&D activities, and establishing clearer guidelines for intellectual property rights are also on the anvil. Following the implementation of STIP 2013, there has been a noticeable increase in private-sector participation in R&D activities and a great deal of energy in parts of the country toward innovation-driven start-ups.

STIP 2013 set fairly ambitious goals and there is a clear disparity, as has been the case over time, between the policy formulation and implementation. The period since has witnessed an increase in the publication rankings, a higher number of PhD graduates, increase in patent filings, and the birth of new start-ups. In 2020, 0.64 percent of the GDP was invested in R&D.[37] Scholars continue to observe that bureaucratic hurdles, lack of coordination among stakeholders, and inadequate infrastructure have hampered the effective execution of policy initiatives.

A DRAFT SCIENCE, TECHNOLOGY, AND INNOVATION POLICY: 2020

Only seven years after STIP 2013, a policy draft was introduced in 2020 with the aim to bring "profound changes through short-term, medium-term, and long-term mission mode projects by building a nurtured ecosystem that promotes research and innovation on the part of both individuals and organizations."[38] Given the spacing between the earlier policy documents, this one has been introduced early, marking, perhaps, not only the unprecedented rapid changes in science and engineering and geopolitics, but also the first full articulation of the ambitions for a science and technology of a new regime.

The draft STIP 2020 was floated to establish a more comprehensive framework for the growth and development of science, technology, and innovation in the country than seen earlier. The policy introduced an open science framework, addressing the importance of open access to scientific knowledge, data, and infrastructure. This framework of openness aims to create wider dissemination of existing knowledge that would lead researchers to benefit from scientific advancements and perhaps, as a consequence, to contribute to them. More so, the policy also focuses on enhancing the R&D ecosystem, placing importance on translational research and innovation-driven enterprises. STIP 2020 wants to address issues of gender disparity in the path to developing a strong workforce.

STIP 2020 outlines a framework of decentralization by delegating more responsibilities to state-level and local bodies. It also calls for the establishment of a National Science Technology and Innovation (STI) Observatory that would function as a central platform for continuous monitoring and evaluation of the STI landscape. Perhaps this might bring back, to some extent, data and evaluation of outputs and impact.

In a move away from hitherto predominantly state-funded research in India, STIP 2020 introduces funding mechanisms, such as public-private partnerships, venture capital, and other financial instruments, to support research and innovation. The last two decades have already seen a gradual increase in funding for scientific research, from both the government and the private sector. This thinking is embodied in the suggestion to establish a National Research Foundation (NRF), modeled on a combination of the National Science Foundation (United States) and the research councils of Europe, to fund and support high-impact research projects.[39] The need for an arm's-length funding body for cutting-edge research in science and engineering has been argued for by scientists in India for many decades starting with the Archibald Vivian Hill report of 1944. Intended to take stock of Indian research capability to meet the flaring Eastern Frontier during World War II, the report eventually became a guiding document for the organization of science in postwar India.[40]

The NRF is proposed as a replacement for the Science and Engineering Research Board of India (SERB). It aims to radically transform the R&D ecosystem in India by substantially increasing investment from the government, private sector, and international collaborations. This research funding is expected to flow into Indian universities, colleges, institutes, and national laboratories. The Anusandhan National Research Foundation Bill 2023 (which led to the establishment of the NRF) wants to push 500 billion Indian rupees (US$6 billion) into the STI ecosystem over the next five years (2023–28). About 70 percent of this funding is expected to come from industry and philanthropists.[41]

At least one reason behind establishing the NRF stems from the understanding that high-quality knowledge creation materializes in well-funded higher education institutions (HEIs) around the world. The Economic Survey of India (2016–17) notes that the number of researchers in India is a rather dismal 25 for every 100,000 citizens when compared with the 111 in China, 423 in the United States, and 825 in Israel.[42] In India's own assessment of its achievements, despite substantial progress in fields like pharmacology, molecular biology, chemistry, computer science, and telecommunications, India's science ecosystem, by and large, lags behind what many Indians consider "the great and the good." Indian researchers produce the world's third-highest number of journal articles in science and engineering (6.2 percent in 2022), but Indian political, industrial, and academic leadership compare this number with those of the United States (13.7 percent) and China (26.9 percent).[43] In the current international rankings of universities based in India, which the Government of India would like to see improve, the top three that appear in the *US News and World Report* of Best Global Universities are the Indian Institute of Science ranked at 612 and the Indian Institute of Technology, Bombay, and the Indian Institute of Technology, Madras, both ranked at 635.[44]

The NRF is offered as a panacea for the many concerns that plague the science and engineering ecosystem, including translational research that is seen to be critical to a knowledge-driven economy. The foundation is registered as a not-for-profit society before it will be converted to an autonomous body of the Government of India, through parliamentary legislation. The founding members of this society include the Prime Minister's Science, Technology and Innovation Advisory Council. Overseen by the Prime Minister's Office, the NRF will host ten major directorates dedicated to specific domains including science, arts, humanities, innovation, and entrepreneurship. An eighteen-member board comprising eminent Indian and international scientists, senior government officials, and industry leaders will advise the work of the NRF.

To begin with, the NRF was envisioned as an arm's-length funding body offering a path away from the bureaucratization of the conduct of research as a streamlined funding mechanism. The NRF was also to be run by a governing board of leading researchers and philanthropists.[45] As it stands now, the NRF is to be led by government officials, with the prime minister as the president of the foundation, and union minister of the Department of Science and Technology and the union minister of the Department of Education as its ex officio vice presidents.[46] In this deviation from the initial plan, the proposed structure of governance brings back the concerns around bureaucratic protocol and renders the organization at less than an arm's-length funding body for independent research. How this will eventually unfold, of course, remains to be seen.

In the meanwhile, there is an increase, when compared with the previous six and a half decades after Independence, in the attention to Indian Knowledge Systems, something that became highlighted in the National Education Policy (2020). Dedicated centers, including those for the study of Indian languages, have been established at universities and institutes across the country.[47] The vision statement backing state funding for such centers is to "rejuvenate and mainstream Indian Knowledge Systems for the contemporary world." While these efforts are focused on epistemic legitimacy for knowledge systems historically developed on the Indian subcontinent, the offer appears to be one of supplementing the world of science. There is no direct and explicit effort to discredit the conduct of modern science in Indian laboratories. A few scholars find this effort discomfited with the practice of modern science.[48] Historians of science such as Mark Walker have made sense of the "science and ideology" question historically to show that the freedom to conduct science on questions considered important by practitioners or "scientific freedom" under any regime, including science during and for the Cold War in the United States and the Soviet Union, is not necessarily affected in the same manner as political freedoms.[49] Again, how this will eventually unfold remains to be seen.

CODA

In the journey from science and technology policy for development to now science and technology for accelerated economic growth and wealth generation, three weak links are apparent: research, education, and translational research [R&D] spending is inadequate; data for robustly informed policy is insufficient and, when available, not reliable; and most of India's universities are not ready to meet the moment—they do not have the funds for research, the structures to institute contracts, or the standing to recruit the most motivated students globally, or for that matter from India, Africa, or West Asia, which have been historically the major sources for student enrollment.

It is difficult to imagine an effective policy that can address problems at scale with inadequate funding allocation. Science in India is still predominantly state funded, and yet only 0.65 percent of India's GDP goes toward research and development; it is the lowest among major scientific powers in the world.[50] The bulk of government spending on science moves to atomic energy, defense, and the space program—about 55 percent of gross domestic expenditure on R&D (GERD).[51] Venni Venkata Krishna, a policy studies scholar, argues that the "two decades of relative stagnation in the national R&D and S&T investments, particularly in universities, have drastically aborted their ability to compete at the international level in the World Class University rankings."[52] The private sector's contribution to GERD has, in the meanwhile, marginally increased from 25 percent (2004) to approximately 36 percent (2020).[53] It also appears to be the case that firms claim tax benefits for R&D but engage in activities like quality control or calibrations that are not about research or development. Furthermore, a significant portion of the R&D conducted—especially by or for multinational firms in India—is not meant for India nor does it get used in India.

Given the state of the majority of Indian universities (and the astonishingly low number of institutions for advanced research otherwise), the private sector appears to be hesitant to pump funding into the system. Many in the private sector chose to establish their own educational institutions instead, and in the bargain, research capacity, which takes time to develop, suffers in places where it could grow, although it may well grow in time in the new institutions. The inadequate funding for universities also leads to another problem: poor quality of higher education. Teaching faculty at most universities cannot do their own research or attend conferences that would keep them informed about the frontiers of their fields or disciplines. Perhaps it is time for some borderline radical measures: India's education policy could purposefully meet India's science and technology policy. In 2023, India became the largest source of overseas graduate students in America, surpassing China.[54] India is a young country. In the absence of an adequate number of institutions to train and retain its talent, those who can will continue to leave, but those who cannot will remain underserved and unable to develop their best capacities.

A second set of concerns arises from the bureaucratization of scientific practice in India. Itty Abraham analyzed five strategic technological sectors in postcolonial India: atomic energy, space, electronics, biotechnology, and telecommunications. In his findings, there is no single factor that explains the successes and failures of these technological initiatives; however, there is one common factor that poses a significant challenge to all:

> The common feature of both the Commission and the Mission models is a discourse that proposed the need for organizational autonomy from established state institutions and norms in order to let allegedly exemplary techno-scientists "get on with the job." From this standpoint, regulatory bodies are only seen as hindrances to the achievement of strategically vital technology projects.[55]

On the one hand, agencies responsible for the government of science are headed by scientists drawn from the community of practitioners. On the other hand, their staff—while recruited for their basic training in science—function as bureaucrats to run the state machinery. Given that most science in India is funded by the state, this group is quite large and holds considerable power over the scientific community because of their ability to decide and eventually conduct research. Science is run by protocol where officers are held accountable for compliance with procedures but not for the outcomes of those procedures.[56] Astonishingly, this exact concern was diagnosed already in the late 1960s by a visiting American scholar, Ward Morehouse.[57] Bureaucratized mechanisms of control lead to an excess of procedure that is not inherent to the matter at hand—research or education—thus delaying if not stifling science and engineering initiatives.

One manifestation of "science by protocol" is the significantly delayed release of funds for scholarships and research, which halts ongoing projects and discourages other planned projects.[58] Protocol also encourages risk-averse interpretations of policy directives—as a result, investment in new areas of research at the frontier, which may well sink funds, is rendered excruciatingly difficult. All of this is legible to policymakers and to the community: in 2017, around twelve thousand researchers in around forty cities in India participated in a "march for science" and in 2019 more than a hundred economists wrote to the prime minister asking for a better-defined policy on data collection for official statistics.[59]

From the foundational efforts of the Nehruvian regime and the leading scientists of the time to more recent attempts aimed at strengthening innovation and addressing contemporary problems, India's STI policy landscape is a mixed bag. If we line up key science policy documents and leave aside education and industrial policies, which are also closely linked into the ecosystem, we find that from SPR 1958 to STIP 2020 all reflect, in time, the aspirations of India's scientific and political leadership to respond to the changing global politics, furthering self-reliance and ensuring that science and engineering play a key role in organizing social life.

All policy statements and resolutions are interesting exercises in visioning and the sociopolitical imaginaries they propose: what is missing in India, at least from the public domain, is any insight into the strategic thinking behind these policies and thinking toward any action plan that can operationalize these vision statements. In 1968, Abdur Rahman, the policy analyst mentioned earlier in this chapter, hooked science policy to seven other elements his colleagues and he considered necessary to close the loop on policymaking and implementation. We are missing that kind of insight today from policymakers and policy studies scholars on how policy moves from vision to strategy to, finally, an action plan:

> Seven elements of science policy: (1) surveys and studies for evolving science policy, (2) the planning of science and technology, (3) national science policy, (4) national budgeting of science, (5) implementing agencies, (6) co-ordination and evaluation of research, and (7) international collaboration.[60]

Early policies like SPR 1958 and TPS 1983 outlined the requirements for a well-equipped science and engineering infrastructure that could deliver technological self-reliance and help grow the science in India. State-formation and science policy usually go hand in hand, and in a new country, this was especially true in the early years. Resource scarcity meant that priorities of a new state took precedence and atomic energy, space, and defense grew relatively strong when compared with other areas like technologies for rural areas and medical research. Early policies played a pivotal role in the establishment and growth of scientific institutions such as the Council of Scientific and Industrial Research, the Department of Atomic Energy, and the Indian Space Research Organisation.

Subsequent decades saw a different approach, policies that could rely on gradually stabilizing institutions and on experts trained both in India and abroad through aid and technical assistance programs who were now leaders of the new institutions. Like in the rest of the world, India's science policy began to be driven by a strong commitment to a somewhat fuzzy idea called innovation; science policy also, at least marginally, responded to concerns of the environment and ecology. STP 2003 and STIP 2013 called for an integration of innovation with the broader sociopolitical context, increasing international collaboration, private-sector participation, and the protection of intellectual property.

The draft STIP 2020 is the latest chapter in India's STI policies with the expansive ambition to introduce a comprehensive framework for the growth of science and technology, laying specific stress on open access to scientific knowledge, enhancing R&D capacity, and—a first for science policy in India—explicitly addressing gender disparity in the scientific community. Nesting within this dream is the long-drawn establishment of the NRF to "revolutionize India's research landscape" by increasing philanthropic and industry support for research, establishing a space for interdisciplinary research, and promoting international collaboration.

When we look back at India's science policy journey, whether it's through examining the earlier commission model or today's mission model, we see that success, when apparent and judged so by peers in India and abroad, has hinged on three key factors: first, intellectual autonomy of the institution that has allowed scientists and researchers to operate independently and efficiently as seen in the success especially of institutions considered to be of "national importance" like the Indian Institutes of Technology and those dedicated to research enveloped within the Department of Atomic Energy budget; second, a well-trained talented pool of researchers and scientists collaborating with peers in India and abroad; and, third, adequate funding, again, as seen in the success of institutions of national importance and also, today, in the mushrooming start-up world where state and private funding has allowed a new set of smaller initiatives to thrive.

Much more may be accomplished with effective policymaking in India, as elsewhere, and this is a rather critical juncture. Science policy studies in India, which is finally beginning to take off, may want to systematically explain learnings from the past for decision makers and the taxpayers both. We need to know more about successful as well as failed initiatives in order to understand where India stands today and at what cost.[61] What have we learned from previous policy articulations and their implementation? What are India's best preferred techno-social imaginaries?[62]

Equally, this might be a good moment to examine the assumptions that propel science and technology policy in India. When and how does research meet economic growth and wealth generation? Can that process be orchestrated under circumstances where there is no immediate existential pressure, like war or a pandemic? What are the relationships to foster between the human, social, and natural sciences as they interface with engineering, art, and design? Why and how might we consider continuing funding for fundamental research? What is our collective relationship to fundamental research?

A public debate, even as a demonstration, might be useful to generate a discussion on what the newest science policy may be expected to accomplish. What is the place and the role for an informed and invested citizen in shaping science and technology policy? We are dealing with rapidly shifting frontiers in artificial intelligence, new genetic technologies, climate change, and pandemics, to name but a few. What are the policy frameworks and appropriately corresponding institutional structures required to regulate and govern research and technology at these and other emerging frontiers?

Science and engineering have been at the core of India's identity after Independence. A range of policies have converged to shape how science and engineering have come to be organized in India across education, research, and industry. In a world where new technology is ubiquitous, extractive, and all encompassing, science and technology policy in India and elsewhere may benefit from keeping planetary interests at the center of decision making. India stands at yet another critical juncture: there is more wealth and potential in India today than there has been in the last decades. The temptation, therefore, to mobilize science and engineering along the known path to wealth and growth is strong. Is it, however, in India's own best interests to accelerate or might it be worthwhile to take stock and share global responsibility in an inequitably organized world?

Is it time, perhaps, to get cautiously comfortable with the idea that, apart from key areas of excellence and of strategic importance, India is largely an R&D recipient rather than producer? Is transfer, adaptation, economizing, and distribution the more rewarding policy objective over the ambition to achieve an end-to-end chain across areas?[63] Nehruvian science, as the historian of science David Arnold has argued, "presented science as a program of delivery, committed to redressing such basic social problems as ill health and poverty, an endeavor answerable to the state and the public it aspired to represent."[64] Early on, then, a distinction was drawn between "science as authority" on the one hand—as articulated in the first SPR and informed by ideas like "scientific temper"—and "science as delivery" on the other. Has the Indian state delivered on the promise of science and technology for development? Are science and society coproduced in India?

There is precedent in India for thoughtful engagement: scientists, bureaucrats, and industry leaders *collectively* took several years in the 1940s to take stock and draw up the National Planning Committee Reports; and yet again, they took eighteen full months in the early 1970s to draw up the first Science and Technology Plan for India.[65] Might this be the moment for the political, administrative, and scientific leadership to consider a more determined pause before finalizing a new science policy document?

NOTES

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