Rethinking innovation policy in India: amplifying spillovers through contracting-out

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Abstract

At independence, India committed itself fully to foster, promote and sustain the creation of science and scientific research in all aspects. In this paper, we present first principles reasoning on the case for state action, and the optimal mechanisms for using taxpayer resources, to fulfill this commitment. We argue in favour of a reorientation of public spending on innovation: away from building vertical government organisations, and in favour of a *contracting-out* strategy. Such a strategy would induce knowledge and capabilities in the society, and through this, induce greater gains for the people of India. We present a preliminary sketch of the path to implementation.

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1 Introduction

At independence, the Indian state was precocious in placing a considerable emphasis upon building up science and technology (S&T) capabilities in India, even at a time when India was poor. In some respects, these ideas have persisted into the present. Even though the Indian per capita GDP in 2023 was one-ninth of that of the U.S., the spending of the Indian Department of Space (at 0.05% of GDP) is only half of the comparable value in the U.S. (0.1% of GDP).

The foundations of knowledge about economics and public administration have been greatly clarified in the following decades. In this paper, we engage in systematic thinking on *why* state action is required; *what* areas require focus; *how much* spending is optimal; and *how* taxpayer money should be spent. Within this overall intellectual framework, we dive into details on the *how* question.

At the outset, innovation spending by the Indian state was grounded in an inchoate desire to match the achievements of science abroad. Now, we are able to articulate the logic that motivates innovation spending. The case for a government that raises tax money and spends it on innovation lies in the *market failure* of *positive externality*, which is associated with knowledge. Private persons tend to under-invest in innovation to the extent that they only perceive gains to themselves, without reckoning for the spillovers of the same knowledge to others in society. This creates the possibility that government can add by investing in innovation activities, paying for these by raising tax revenues.

But solving for this market failure directly involves organise public spending in ways which creates spillovers of high end knowledge *into the society.* As an example, about 80% of the NASA budget is contracted-out to private persons. Through this, US taxpayer money is primarily spent to push the knowledge capabilities *of the society* and not of the employees of a government organisation. This is in contrast with ISRO which largely spends taxpayer money on growing capabilities within itself. The overall gains to society from the NASA approach are higher: it represents a direct response to the market failure which motivated public spending in the first place.

Alongside this gain, there is also the possibility where contracting-out mechanisms yield a better translation of expenditure into scientific objectives, by harnessing private energy, and by improving the ability to take risk.

In the paper, we deep dive into three examples of innovation activities of governments: NASA and the NIH in the US, and innovation policy in French defence procurement. We also study the important experience, of the 'New Millennium Indian Technology Leadership Initiative' (NMITLI) program at 'Council of Scientific and Industrial Research' (CSIR), which was the pioneer in building such a mechanism in India.

Once there is an agreement that this is a desired path, there is the question of implementation. In a 'great man theory', a modified policy strategy is about hiring the right people to lead the relevant organisations. But in thinking institutionally, every action of state organisations is shaped by formal processes, that are coded into legal documents. The implementation puzzle lies in understanding how these documents must change, in order to induce the desired legal effects. We propose an implementation path, which involves changes to the General Financial Rules (GFR), the founding documents of innovation organisations such as Defence Research and Development Organisation (DRDO), changes that require the creation of new rules, and the changes to internal manuals for procurement.

India stands at a time where there is a willingness to invest considerable magnitudes of public money into innovation policy, and there is a highly capable society – outside of the state – that is able to build complex organisations and capabilities. The gains from changing course to a higher engagement with private parties, compared with the present configuration of innovation policy, would be considerable.

2 Foundations of innovation policy

In this section, we view the questions of innovation policy through the general methods of public economics. As with state intervention in all fields, we require clarity on the *why* (what motivates state intervention in innovation?). This understanding helps shape the three downstream questions – the *what* (in what areas should government intervention take place in India?), the *how* (what mechanisms should be used when spending public money) and the *how much* (at what point do the incremental gains to society equal the incremental costs).

Why: what motivates state intervention in innovation?

What is the purpose of innovation policy? The standard script of public economics requires starting at a zero-state, which is a society without state intervention, and identifying the 'market failures' in this state.[1] In the area of innovation policy, the market failure is the problem of 'positive externality'.

We are more familiar with the idea of negative externality, where the action of one person indirectly causes harm to others. A well known example of negative externality is pollution. Positive externalities, on the other hand, arise when actions by one person benefit others, in ways that are not negotiated. The individual or private firm spends resources on innovation, and obtain private benefits from these activities. But the ideas and capabilities from this expenditure tend to spread, to deliver beneficial spillovers to other persons in society. The spillovers are not contracted – the beneficiaries do not pay for them. This causes a gap between the private gains to the private innovator, and the total gain to society from a given innovative activity.

When private persons make decisions to spend resources on innovation, they are guided by their private benefits alone. They do not take into consideration these positive spillovers, which they cannot observe and do not value. As a result, private decisions on innovation expenditures add up to an underspend at the level of the society as a whole.

This is the rationale for innovation policy, the actions by the state that seek to address this identified market failure. The intervention runs in three steps: (a) The state raises resources through taxation, (b) The state spends this money on innovative activities, and (c) It is hoped that these activities result in spillovers that diffuse into the society.

What: where adoption is feasible vs. where invention is essential.

One part of the policy question is, what should receive public spending for innovation? There is an interesting distinction between the areas where work done elsewhere in the world creates 'free rider' possibilities, compared with the areas where such possibilities do not arise. Table 1 shows some examples of problems where there are global investments in innovation, from which India can gain greatly through *adoption*. The table also presents examples of problems where the world will not adequately fund the knowledge that India requires.

[1] Market failures come in four kinds: public goods, information asymmetry, monopolies and externalities.

Table 1 Areas that require adoption vs. areas where invention is essential

The universe of knowledge can be classified into problems where persons in India are able to free ride on global developments in knowledge, and those where research expenditures outside India are unlikely to arise. A few examples are offered in this table.
The left column shows opportunities for adoption, where persons in India can benefit from knowledge produced elsewhere. The right column shows areas where invention is essential, where adoption of knowledge obtained elsewhere in the world is unlikely, or outright infeasible.

Adoption	Invention
Covid vaccine	Malaria vaccine
Military drones ≈ those used in Ukraine	Military drones for Himalayan conditions
Natural language processing for English	Natural language processing for hundreds of Indian languages
Climate science	Monsoon science
The bulk of STEM knowledge	The bulk of humanities and social science knowledge

In the journey to decarbonisation, innovation expenditures undertaken in advanced economies made solar or wind energy practical, and persons in India benefited from the resulting knowledge without needing to fund the underlying research. The IT revolution involved positive externalities for India, owing to innovation expenditures that were undertaken in the advanced economies, starting from the transistor onward. At the same time, there are many areas in Table 1 where only Indian expenditures will achieve the desired outcomes for India — such as the solution for the extermination of malaria or solutions for heat wave related deaths and disruptions in society — because innovation expenditures elsewhere in the world will not adequately solve for these. This reasoning helps shape research priorities for scarce innovation funding in India.

How much: the socially optimal level of government spending on innovation

How much should a government spend on innovation? This question will be answered by identifying the point at which the incremental costs to society outweigh the incremental gains.

All state expenditures involve the hurdle of the 'marginal cost of public funds' (MCPF). It is estimated that the total social cost of Rs.1 spent by the government might be about Rs.3 (Kelkar and Shah, 2022). Public spending of Rs.1 is then only justified when the gains to society are over Rs.3. Hence, public expenditure for innovation should be raised to the point where a marginal gain to society of about Rs.3 is obtained from the last Rs.1 of public expenditure.

There is a connection between the 'what' and 'how' questions, and the 'how much' question. When better mechanisms are adopted in the 'what' and 'how' questions, the marginal gains to society from public expenditure is greater, and then bigger state expenditures are justified.

How: the most efficient methods for government expenditure

How can public money be spent so as to best create the gains to society – to obtain the spillovers that are lacking owing to the inadequate level of private innovative expenditures?

Consider the problem of sending a craft to the moon. There are two path through which this can be done. We refer to these as the "make" vs. "buy" paths.

The 'make' path involves:

1. Raising money from taxpayers (which imposes a cost upon society of about 3×),
2. Recruiting scientists and engineers as civil servants,
3. Building the craft, and
4. Sending it up to the moon.

The 'buy' path uses the same public money differently:

1. Raising money from taxpayers (which imposes a cost upon society of about 3×),
2. Identify a skeletal design with high-level parameters,
3. Contract with multiple parties to get competing designs,
4. For successful designs, contract with vendors through a multi-stage process of unfolding risk, from proof of concept till a final craft that can be fabricated, and
5. Sending it up to the moon.

In both cases, one measure of success is the same – a craft is sent to the moon. However, the more important measure of success is the benefit to society from the use of taxpayer resources. While work can be done within government organisations ("make"), this misses out on the high spillovers to society that come when work is contracted out ("buy") to parties outside of government. Such parties include universities and profit-motivated firms, both of which can be private or public. When universities are contracted to create knowledge, the spillover comes in the form of knowledge which is diffused through society, while the spillover through profit making firms takes place through commercial applications in the market place. While both pathways (make and buy) have strengths and weaknesses, the buy strategy has the following strengths:

1. Harness multiple competing teams
2. Explore multiple design pathways
3. Greater bang for the buck through private energy and management
4. The knowledge created *in the society*, and not held within the state.

and the following weaknesses:

1. The complexities of contracting with universities (public and private), private research organisations, and private firms.
2. Inherent in research is the possibility of failure. Many research projects fail. The commensurate institutional capability is required, to demand effort but not necessarily a successful outcome.
3. Creating an incentive environment that avoids and proscribes recipients of research funding who do not put in the effort.
4. There will be accusations and there is the threat of the investigative agencies of the state.

It is not of interest to consider either extremes – a pure "make" approach or a pure "buy" approach. In the real world setting, the choices are perhaps between 80% make vs. about 80% buy. For example, our review finds that the NASA in the US is roughly at 80% "buy" while the Indian ISRO is mostly "make".

The overall field of innovation policy is about the concepts and mechanisms for the *why*, the *what*, the *how much*, and the *how*. In this section, we have a summary of strategic sense about the four questions. We next undertake a dive into the question of the ways in which greater gains for society can be obtained as compared with present mechanisms. The solutions to the *how* question are orthogonal to the answers chosen for the other three questions, and this journey starts with a deep dive into four fascinating case studies of innovation policy.

Table 2 The four cases studied of innovation policy

We summarise the domains and the key learnings from the four case studies here.

Space:		
NASA, US	DOS, India	Contract planning based on a Technology Readiness Level (TRL); multiple contracts for the same deliverable; risk management; tolerance of failure
Health:		
Research grants at NIH	No Indian counterpart identified	Grants need not be competitive; resolving research malfeasance
Defence:		
Ministry of Armed Forces, France	Ministry of Defence, India	Flexibility in contract management during price escalations; system of tax credits
Science & Technology:		
No foreign counterpart identified	NMITLI	How to do "buy" within the context of India's invisible infrastructure

3 Four case studies

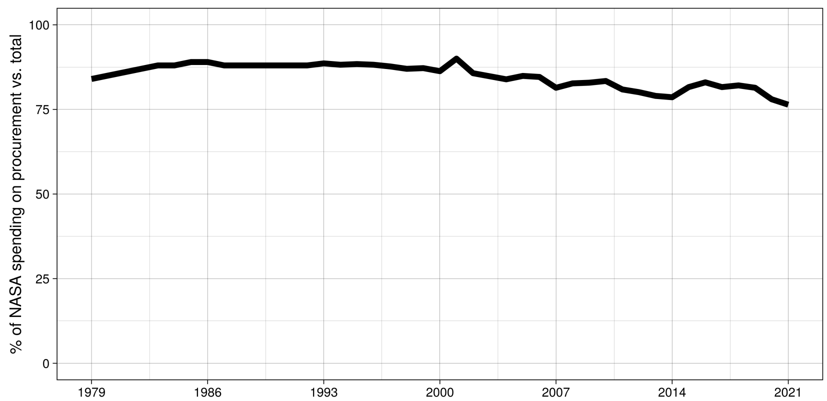
Table 2 presents a summary of the four case studies of innovation policy that we study. In each case, we attempt to juxtapose a global story and an Indian story. We do not always find a natural comparator in all these cases. Nevertheless, there are rich learnings from each case.

3.1 The US NASA

The National Aeronautics and Space Administration (NASA) draw on a long tradition in the US of avoiding building organisations under control of the government. The clarity on "make vs. buy" was present at the very outset, in the founding documents of NASA. §102(c)(8) of the National Aeronautics and Space Act of 1958 directs NASA to pursue "the most effective utilization of the scientific and engineering resources of the United States" towards aeronautical and space activities. Those who conceptualised and created NASA were clear that the most "effective utilization" comes from contracting. In response, NASA was built as an organisation that primarily contracts out

Figure 1 Contracting emphasis in the budget at NASA

The bulk of the money that comes into NASA flows out of it through contracts. The intensity of contracting has been above 75%.



Source: NASA Annual Procurement Reports (1979–2021).

research projects and processes.

> "It is natural that our scientists and engineers want to keep to themselves all of the interesting and creative problems, while farming out to industry only the repetitive and straight production items. This does not make sense to me ... *even preliminary design contracts could be awarded to industry to round out industry's capabilities*. Unless industrial contractors are encouraged to round out their capabilities, NASA will find it necessary to expand its in-house capabilities" — (emphasis added, T. Keith Glennan, 1993).

This mandate has helped ensure a high ratio of "buy" vs. "make". Figure 1 shows that over 75 per cent of the public resources coming into NASA go out of NASA into the external world, which is a mix of private firms, universities and other research organisations. As an example, 'Jet Propulsion Laboratory' (JPL) was created by a private university (Caltech) in 1936. From 1954 onward, JPL has been the recipient of contracts and resources from NASA, and has played a critical role in all of NASA's work in exploring the solar system.

Obtaining the political commitment to long-term R&D spending is always

Figure 2 Contract mapping with TRLs: example of Magellan probe

TRL	Period	Action taken (US Government Accountability Office, 1988)
1 – Conception	1966–1978	1 – NASA conducted studies on the feasibility of mapping the topography of Venus. Contracts to Illinois Inst. of Tech, Hughes Aviation and Martin Marietta
2 – Basic principles reported	1978–1979	2 – Success of Mariner probe prompts go-ahead for conceptualisation of mission to orbit Venus.
3 – Potential applications validated	1979–1980	3 – Joint study with USSR. JPL, Ames, Marietta, and Hughes contracted to supply alternative mission designs.
4 – Proof of concept	1980–1984	4 – Full scale development. Launch date planned. Contracts with Mariette for spacecraft, Hughes for radar equipment.
5 – Laboratory validation	1984–1987	5 – Radar tests done
6 – Simulation/real space validation	1987–1989	6 – Spacecraft tests done
7 – System adequacy in simulation	1989–	
8 – System adequacy in space		8 – Successful launch

hard, especially when it generates no headlines or propaganda. Spending for NASA has been better supported by lawmakers who understand that the bulk of resourcing for NASA turns around and becomes spending into the society.

NASA engages in a diverse array of contracts from inception to implementation. There is a well structured classification scheme about the level of knowledge available on a given question. At each level of maturity of knowledge, different *kinds* of contracts are given out. Complex projects are initiated by contracting out the development of high level designs. Once a first design document is in hand, subsequent contracts are given out to work out the details. This runs all the way to contracting out of specific engineering designs of spacecraft. NASA does not build spacecraft: private vendors do.

Formal process manuals that vary based on the level of maturity, on a given problem, was a management innovation of NASA. In the 1970s, NASA scientists developed the concept of 'Technology Readiness Level' (TRL) for the better planning of future missions (Sadin, Povinelli, and Rosen, 1989). An example for the Magellan mission is given in Figure 2. In this figure, we see a journey that began with concept level contracts, at TRL 1, which ran from 1966 to 1978. The journey went through a series of contracts at escalating levels of detail, all the way to launch in 1989.

This contracting approach is conducive to risk taking across multiple rival pathways. At every point in a research journey, the scientists and the engineers know that there are multiple alternative possibilities of the route to an answer. As an example, the Manhattan Project faced the choice between a nuclear bomb made using Uranium vs. one made using Plutonium. In a government bureaucracy, under a 'make' approach, there is a risk of one pathway being prematurely chosen, of a lack of competition between teams pursuing different pathways, and of hesitation in accepting that a chosen pathway was not the optimal one. All these problems are well addressed through the contracting approach:

1. At NASA, multiple studies are commissioned in order to explore multiple pathways.
2. These external parties know that there is competition, and try hard to do well in that competitive environment. The persons who succeed at TRL n are more likely to succeed in the procurement of the larger contracts at TRL $n + 1$.
3. The unfolding of knowledge and risk-taking, through a sequence of external contracts, helps NASA choose the most plausible pathway, without suffering from sunk cost fallacy, from the established positions of powerful internal persons, or just the lack of adequate exploration of alternative pathways.

The legal basis for contracting at NASA comes from the Federal Acquisition Regulation (FAR), which is analogous to the GFR in India. There are some interesting features in the FAR that allow for risk management through contracting. For example, §1834.003 of the FAR allows the procuring agency to award contracts to multiple organisations to meet the requirements of a single solicitation.

§1834.003 of the FAR requires the procuring official to conduct market research to ascertain if private sector firms can reasonably be expected to generate outputs. At NASA, this is mapped to specific TRL levels, which in turn informs contract planning and management.

In the Indian setting, the GFR is primarily designed around a fixed-price contract where a private person promises delivery of certain outputs for a certain price. In the US, the FAR allows the procurement official to choose between four kinds of contracts:

Fixed price contracts are governed by §16.2 of the FAR. They are typically entered into when the goods/services are of a routine nature since they are easier to monitor and enforce (Baron and Besanko, 1987). Upon *delivery* of the goods/services, NASA commits to paying the specified price even if actual costs are higher.

Example: The contract awarded by NASA to SpaceX in February 2023 to supply commercial payload processing services (NASA, 2023a) was a fixed-price contract.

Cost reimbursement contracts are governed by §16.3 of the FAR. They are typically entered into when the procurement official needs more material information on the production possibilities (Baron and Besanko, 1987). NASA pays for allowable costs incurred and they sometimes stipulate a cost ceiling. These contracts need closer monitoring, but they incentivize the supplier to take greater risks since their costs will be reimbursed. The test of completion is whether the supplier made *"good faith efforts to meet government needs"*. Completion of the task is not necessary.

Example: A contract awarded to Bechtel in July 2019 to supply mobile launchers for the Kennedy Space Center (NASA, 2019b). NASA's storied engagement with the JPL at Caltech (a private university) involves a succession of five-year cost-plus contracts that have been renewed since 1958 (NASA, 2018).

Grants are governed by 31 US Code §6304. Certain provisions of the FAR do not apply to them. Grants are used when NASA is not "substantially involved" in the direction of the research. Risk to, and oversight by, NASA is low (Walker, 1997). Information sharing between researchers and NASA is annual, biannual or quarterly.

Example: A 2019 award to Georgia Tech to research on sustainable supersonic commercial flight (Georgia Tech, 2022).

Cooperative agreements are governed by 31 US Code §6305. Certain provisions of the FAR do not apply to them. NASA is "substantially involved" in the direction of research. Risk to, and oversight by NASA is substantial — which is why information sharing between researchers and NASA is frequent, sometimes even daily.

Example: A 2018 award to University of Maryland to study comets (University of Maryland, 2021).

Organisations like NASA and the Department of Defense have special provisions to customise their contracts (Gunasekara, 2011). For example, under the Space Act of 1958, NASA can enter into 'Other transaction agreements' (OTA). These agreements are not considered to be "procurement": i.e. the FAR does not apply to them.

In 1981, 70% of contracts at NASA by value were cost-plus-award contracts. In 2021, cost-plus-award contracts constituted 32% of the total value. Meanwhile, firm fixed price contracts have risen from 14% in value of all contracts in 1979 to 32% in 2021 (NASA, 1999; NASA, 2022) reflecting the growing maturity of space travel as a field with the emergence of private firms which substantial capabilities in building satellites or putting a cargo into orbit. Grants and cooperative agreements constitute an average of 5% of total NASA procurement spending.

The strategy of emphasising "buy" at NASA is grounded in the first principles understanding of the public economics of innovation policy: the role for the state is to fuel spillovers. "Buy" allowed NASA to adopt evaluation processes that involve a true meritocracy regardless of the applicant's profile, size or status. Under the system of dual anonymised peer review, a proposal cannot carry any identification details whatsoever about its proposer, whether they are individuals or organisations. As a consequence, there is no bias in NASA against contracting with private firms, private universities, young organisations or small organisations. As with other federal agencies, NASA adopted the Small Business Innovation Research Act of 1982 which improved the rates of commercial success (e.g. better market linkages) for small businesses (Archibald and Finifter, 2003).[2]

The strategy of emphasising "buy" requires commensurate capabilities in contracting. Procurement officers at NASA are well-trained to manage downstream issues. The US Federal Acquisition Certification in Contracting (FAC-

[2]Under this law, NASA and other federal agencies have to offer certain favourable contract terms for small businesses engaging in innovation.

C) is a compulsory qualification for all procurement officers. It takes a year to acquire the certification. After obtaining the certification, the officials are expected to spend 80 hours every two years, to complete continuous learning requirements, in order to maintain their certification.

These conscious choices generated remarkable spillovers and have thus generated consistent legislative and taxpayer support for NASA budgets. For example, between 1970 and 1990, NASA-funded research directly led to 0.2% of total US patent grants. These patents were unusually influential: they were cited as prior art for 2% of all US patents during this period (Jaffe, Fogarty, and Banks, 1998). Entirely new sectors like semiconductors, aerospace, weather and disaster forecasting were born thanks to NASA-funded research (Ginzburg et al., 1976).

Inherent in contracting is the possibility of failure and of fraud. An emphasis on contracting requires commensurate sophisticated legal frameworks that think about these things. The term "failure" at NASA as well as other US federal agencies can only be applied in the aftermath of a fixed-price contract. Failure to deliver the goods/ services within the given milestone time amounts to non-performance under contract law.

When it comes to grants, cooperative agreements, cost-reimbursement contracts and OTA agreements, making "good faith efforts" is sufficient for contract performance. There is no "failure" other than the failure to make good faith efforts. In the terminology of Kelkar and Shah (2022), the 'invisible infrastructure' (judiciary, legal systems etc.) present in the US helps address allegations, delivers cases settled out of court, etc.

"Good faith efforts" are, in turn, judged on the basis of the TRL of the project (NASA, 2007):

1. Research-based TRLs (TRLs 1–3): Dual Anonymous Peer Review is used to judge whether good faith efforts took place. Complete anonymity is maintained in proposals and research works to carry out blind review.

2. Prototype-based TRLs (TRLs 4–7): "Support and simulation" testing in controlled conditions is used to determine whether good faith effort took place.

3. Flight-based TRLs (TRLs 8 and 9): Performance in flight tests is used to determine whether good faith effort took place.

Most government contracts are susceptible to some kind of principal-agent problems. There are two risks in an innovation procurement contract: failure and research malfeasance. It is difficult to make a fine distinction between the two (Bruce, Figueiredo, and Silverman, 2018). There are four methods to mitigate these risks:

1. Reassign intellectual property rights (IPR) (Aghion and Tirole, 1994),
2. Use a system of fixed fees and royalty payments,
3. Making equity investments,[3] or
4. Direct supervision (Bruce, Figueiredo, and Silverman, 2018).

When a research contract goes to a private firm which stands to obtain commercial benefits from spillovers, the problem of research malfeasance (i.e. taking the money and not actually doing the research) is diminished. The firm stands to gain from actually doing the research and obtaining spillovers into the knowledge within the firm.

At NASA, observed cases of fraud are typically about concealment of facts, or concealment/ malfeasance in supply of products e.g. supplying a lower grade of steel, or supplying Chinese-made transistors instead of US-made ones despite the contract specifically imposing a domestic purchase requirement (NASA, 2019a). On average, five fraud cases arise out of the 20,000 to 25,000 contract actions each year. They result in imprisonment, or, in some cases, out-of-court settlement (NASA, 2023b). In addition, §42.151 of the FAR requires "prior contract performance" as a factor to be considered while evaluating a firm during market research. This dissuades opportunistic breaches by contractors.

Matters concerning fraud and whistle blowing are investigated by the Office of Inspector General (OIG) who has statutory powers to do so under the Inspectors General Act, 1978. The Inspector-General is directly appointed by the President. In case of bid/contract award challenges, the US Government Accountability Office (GAO) conducts the investigation. However, the GAO desists from overturning NASA's bidding decisions unless anti-competitive behaviour is apparent (Gunasekara, 2011). As an example, in 2022, there

[3] Equity investments by the government into private firms are not permissible in the US and is hence ruled out there.

Table 3 What does the DOS "make"?

Description	Make or buy
Mission conception and validation	Fully "make"
Manufacture and supply of spacecraft and components	Mix of "make" and "buy".
Proportion of "make" versus "buy"	Not known.
Final assembly and launch	Fully "make"

were 11 bid protest applications that went to the GAO, all of which were denied, dismissed or withdrawn.

For a comparison, we examine procurement at the Indian Department of Space (DOS). The DOS has an institutional preference for "make". Table 3 shows the break-up of process-based procurement preferences. The DOS does some limited "buy" for the supply of certain components. Critical products like engines, radars and crew recovery modules are being increasingly manufactured by Indian private sector firms, like Tata Elxsi and Larsen and Toubro (Larsen & Toubro, 2023; Tata Elxsi Ltd., 2023). At the same time, the approach remains primarily one of "make".

Table 4 compares the contracting processes of the DOS and NASA, which summarises the distance between the make-intensive DOS and the buy-intensive NASA.

A 'what-if' calculation is shown in Table 5. We obtain an estimate of the procurement expenditure that would arise if DOS organised itself on the lines of NASA, and put 84.94% of its present level of expenditure into procurement. We find this would create high-innovation procurement of Rs.106 billion a year, going out into universities and firms, including private organisations. This would constitute an important gain for the Indian innovation ecosystem. If India stepped up public expenditure on space research as a share of GDP up to the level seen in the U.S., this would involve one doubling, and in this case, a NASA-style contracting-out strategy would create procurement expenses of about Rs.106 billion a year.

3.2 The US NIH

The National Institutes of Health (NIH) in the US was born out of the need to develop health research during the Second World War. At the time, there was

Table 4 Comparing processes in NASA and DOS

Issue	NASA	DOS
Contracting profile	Legal basis from FAR. 24,989 contract actions in 2021.	Legal basis from GFR. Number of contract actions not known.
Kinds of contracts	Fixed-price, cost-reimbursement, grants/CAs, OTAs etc.	Goods, services and works. Cost plus contracts allowed but scope is limited (Rule 225).
Is bidding necessary?	No	Yes (Rule 158)
How is failure defined?	Delivery for FP, "good faith efforts" for others	Delivery of goods/services (Chapter 8).
Contract planning	Should be mapped to TRLs	Based on budget and departmental considerations (Chapter 3).
How are principal-agent problems solved?	Direct supervision. In addition to this, peer review, support and simulation, testing done for agreements that are not fixed-price.	Direct supervision. No scope for other monitoring since "delivery" is the test of discharge from contract.

Table 5 What if DOS spent its budget like NASA did? (2022)

Share of NASA budget in U.S. GDP (per cent)	0.1
Share of DOS budget in India GDP (per cent)	0.05
Share of NASA budget spent on procurement (per cent)	84.94
Share of DOS budget spent on procurement (per cent)	NA
DOS total budget (INR billion)	124.94
What if DOS spent on procurement like NASA? (INR billion)	106.12

a keen awareness about the gains from medical advancements like penicillin and safe procedures for blood transfusions. The Public Health Services Act of 1944 sought to consolidate various research institutes and create the NIH system.

What shaped the NIH on its buy vs. make question? A key person in that period of US innovation policy was Vannevar Bush, who was an engineer, researcher, policy maker and public intellectual (Vannevar Bush, 1945). Prior to his work in public policy, he was a co-founder of the firm Raytheon in 1922. He is regarded as the principal designer of the NIH system. In his seminal report in 1945, he laid down its design principles:

1. There should be stability of funds over a period of years so that long-range programs may be undertaken.

2. Administration of funds should be done by an agency whose staff are selected only on the basis of their interest in and capacity to promote the work of the agency. They should be persons of broad interest in and understanding of the peculiarities of scientific research and education.

3. The agency should promote research through contracts or grants to organizations outside the Federal Government. It should not operate any laboratories of its own.

4. The agency should support basic research in public and private colleges, universities, and research institutes but it must leave the internal control of policy, personnel, method, and scope of the research to the institutions themselves.

5. The agency should be free of the obligation to place its contracts for research through advertising for bids. This is because the measure of a successful research contract lies not in the dollar cost but in the qualitative and quantitative contribution to our knowledge.

6. Research should be conducted on an actual cost basis without profit to the institution receiving the research contract or grant.

7. NIH should be able to make, modify, or amend contracts of all kinds with or without legal consideration, and without performance bonds. Similarly, advance payments should be allowed and voucher requirements should be relaxed.

These were remarkable ideas at the time. No other major nation had an innovation framework like this.[4] At the time, in most European countries, researchers were employees of a university or a government research institute. They would receive bureaucratically allocated funding for their work, and they did not have to compete for grants.

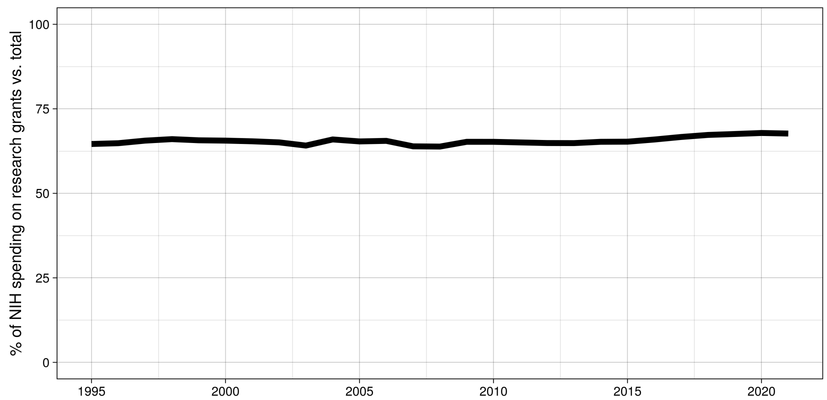
The innovation system of the US is defined by the absence of central control, even when a university is owned by the government. This decentralisation applies at two levels: (1) There is little government control of universities, and (2) Universities exercise low control over their academic staff. The individual researcher, in their university, is "their own boss" (Kornberg, 1997). This promotes a culture of competition among *individual researchers* who seek grants for career progression and generate cutting edge research judged by peers. The early design of the NIH was located within these values, and sought to achieve high bang-for-the-buck based on the optimising response of individual researchers in this ecosystem.

The design of the NIH built on the then-prevailing frameworks of health research financing in the US. The biggest funders of medical research at the time were philanthropic organisations like the Ford Foundation, who had evolved beyond simple humanitarian notions (assistance to certain chosen individuals) to bigger concepts of impact, of improving the world in a sustained fashion. Organisational concepts from the private philanthropy of that age – high levels of risk taking in funding and in implementing grants, tolerance of failure, rewards for long-term success – were adopted by the NIH in their grants system (Azoulay, Graff-Zivin, and Manso, 2009).

One criticism of the grants system was that scientists face high costs of switching from an area in which they are established to a new area thought important by the NIH. Several elements of the design of the NIH help address this problem; they help strong teams to switch fields and come into the great questions of the age. The decision process at the NIH respects grant applications by persons who have low track record in a field, and the size and time horizons of NIH grants help overcome the cost of learning a new field (Myers, 2020).

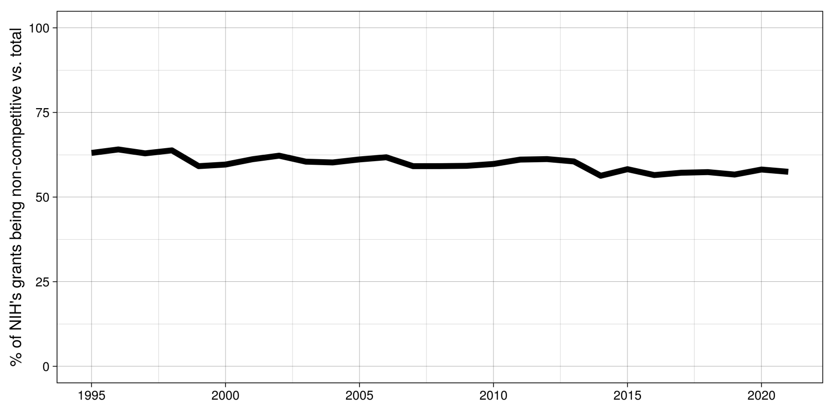
[4] An interesting analogy is found in the checks and balances for agencies external to the government. The US got to the 'Administrative Procedures Act' (APA) in 1946, which governs the working of all US federal agencies. This 1946 law is ahead of the intellectual frontiers in the working of union government agencies in India as of 2024.

Figure 3 Contracting-out in the NIH budget



Source: NIH Data Book, 1995-2021.

Figure 4 Competitive bidding in NIH grants



Source: NIH Data Book, 1995-2021.

Like NASA, the NIH also spends most of its budget on contracted-out research. Figure 3 shows the consistently high levels of contracting-out. The employees of NIH often choose one proposal without competing bids: Figure 4 shows that most grants are awarded without a competitive process.

The award process is based on a process of peer review. The NIH may solicit proposals or a researcher can submit an unsolicited proposal for review. A process of double-blind peer review, with different review criteria based on the research area and task, is followed and a numerical score is assigned to each criterion. The peer review process is carried out by a "study section" whose panelists are chosen for a term of four or six years. These panelists are top researchers who have an excellent understanding of their field as well as the grants process. The working of the study section is dominated by scientists and not officials. Generally, federal officials can attend peer review meetings only when they have "need-to-know or pertinent related responsibilities" (National Institutes of Health, 2021a).

There are two rounds of review. The criteria for the first round of review are (National Institutes of Health, 2021b):

1. Significance
2. Profile of the investigator
3. Innovation
4. Approach adopted
5. Environment

The second round of review is done by "examining applications and consider the overall scores and summary statements in light of the institute/center's priorities" (National Institutes of Health, 2021a).

Similar to the processes at NASA which are covered by the FAR, the test of completion and discharge of research work that is funded by a grant is the demonstration of "good faith efforts". This is proven by peer review. Part 52h of the Code of Federal Regulations require a two-level process of peer review:

1. Scientific excellence review — this is done by the NIH Scientific Review group. This group is chosen on the basis of a roster of scientists who are *not* federal employees.

2. Public health relevance review — this is done by the NIH Advisory Council/ Board.

The system of peer review has worked well for the NIH. It is a proven and efficient predictor of high-quality research (Ginther and Heggeness, 2020).

Research misconduct is rare — these were 36 cases among more than 500,000 grants which were awarded between 2008 and 2022 (NIH Office of Research Integrity, 2023). These involved plagiarism, falsification of data, etc. In 20 of these cases, the individuals were debarred from government procurement. In the remaining 16 cases, the individual's research project was put on a supervision plan where an oversight committee constituted by the NIH study group monitors the progress of the work. The terms for these supervision plans could range from 3 to 12 years.

Unlike NASA, the NIH has not reported any instance of the following types of misconduct between 2008 and 2022: (i) breach of peer review confidentiality, (ii) inappropriate foreign influences, and (iii) harassment and discrimination.

The NIH has emerged as a major source of health research in the US, and funds a substantial fraction of health research on a global scale. As an example, NIH funding was vital in the development of the COVID vaccines that benefited the entire world. Some measures of the impact of the NIH are as follows. An increase of 1% in NIH research funding is associated with a 1.8% increase in the number of new molecular entity applications from private industry. The return to public investment in basic biomedical research is 43% (Toole, 2012). A funding increase of USD 10 million leads to a net increase of 2.3 patents (Azoulay, Graff-Zivin, Li, et al., 2015).

In the case of NASA, we were able to compare against the Indian DOS. In the case of the U.S. NIH, there is no comparable organisation in India. While India is able to free ride on a lot of NIH-funded research[5] There is a case

[5]As an example, from 2000 and 2019, the NIH funded over $17.2 billion in published research on vaccine technologies, providing the foundation for COVID-19 vaccines including the Oxford / Astra Zeneca vaccine that accounted for the bulk of Covid vaccination in India under the trade name 'Covishield' (Cross et al., 2021).

Table 6 What if India spent on health research like the NIH does?

Share of U.S. GDP spent on NIH (per cent)	0.22
Share of Indian GDP spent on health research (per cent)	0.01
Share of NIH budget spent on procuring research (per cent)	67.26
If India had an organisation like the NIH, what would its budget be? (INR billion)	606.17
How much of this amount would go out as research grants? (INR billion)	407.71

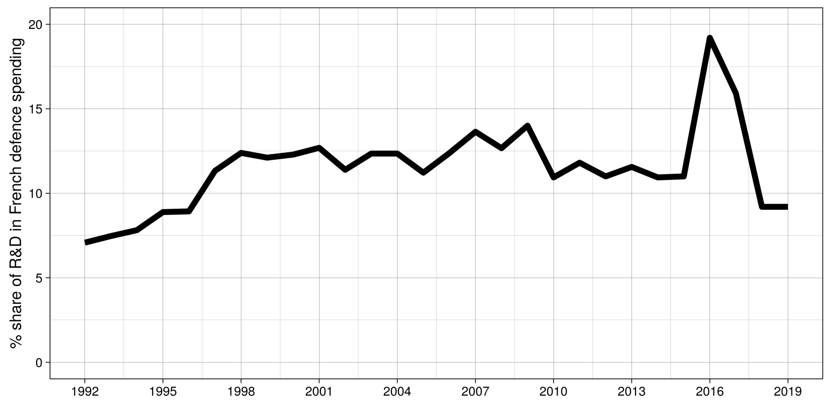
for building such an organisation in India, as there are many health research questions which weigh on India to a great extent, where the incentives for overseas research is limited.[6] At Table 6, we have prepared a simple what-if scenario which uses the (admittedly high number of) the size of NIH spending relative to the US GDP. Simple extrapolation suggests that such an organisation might have an overall spend of Rs.606 billion of which Rs.407 billion would go out into the Indian society to a diverse array of innovative organisations.

3.3 Innovation policy in French defence procurement

France has influenced the imagination of Indian strategic thinkers. India and France aspire to concepts of "strategic autonomy": both seek close ties with like-minded nations but stop short of aligning themselves with one group of nations or the other (Droin et al., 2023). India historically preferred the Soviet Union and then Russia as its primary defence partner. In 2021, for the first time since 1961, France overtook Russia as the primary supplier of armaments (Stockholm International Peace Research Institute, 2023). India also seeks to diversify and deepen its own domestic industrial base. After the war in Ukraine, India's defence minister has called for increased production and procurement from domestic private sector sources to prevent shortfalls in supplies of imports (Associated Press, 2022; The Economist, 2022). In this context, it is particularly interesting to understand the 'buy' mechanisms for defence R&D that are used in France.

[6] As an example, Section 3.5 in Shah (2020) sketches India-specific questions about Covid, which were not in the fore when the NIH kicked off a great wave of funding for Covid research in early 2020. These India-specific questions should be the prime focus of an Indian health research funding organisation.

Figure 5 French spending on defence R&D



Source: French Ministry of Higher Education, Research and Innovation (1992–2019).

France partially withdrew from NATO in 1966 to preserve its "strategic autonomy". As a consequence it developed its own mix of public and private sector defence industries with an emphasis on the positive feedback loops of R&D, exports and economies of scale (Office of Technology Assessment, US Congress, 1992). While the French military budget decreased from 2.69% of GDP in 1992 to 1.84% in 2019, the budget for defence R&D remained constant.

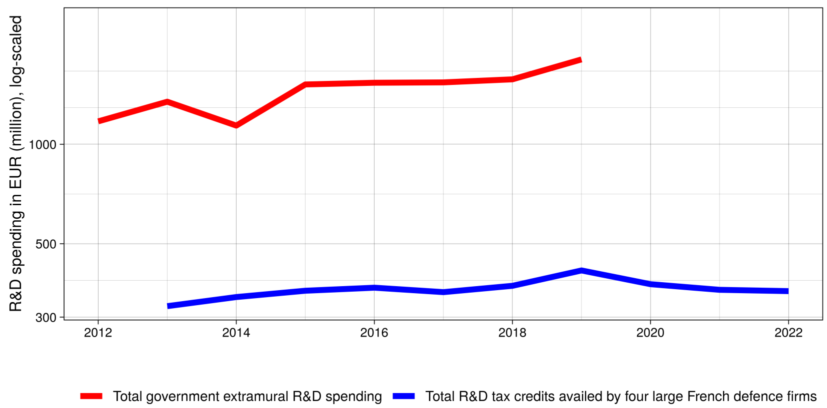
The bulk of this defence R&D is done in the private sector. This is funded by the French government through two pathways. They directly purchase research outputs from firms as part of their military development program. And, they offer generous R&D tax credits to the firms. On average, direct spending is EUR 1.76 billion per year (82% of total) and tax credits (for our sample of four large firms) is EUR 0.364 billion per year (18%).

Figure 5 shows that French spending on defence R&D has remained consistently above 10% of its defence budget.[7]

Figure 6 shows the split between direct spending by the government on "buying" defence R&D and the sum of tax credits granted to four large French

[7] These estimates are biased on the lower side, as they do not include the tax credits through which private firms are incentivised to do defence R&D.

Figure 6 Two ways of spending on R&D: direct funding and tax credits



defence firms.[8] The split between the share of direct spending vs. tax credits when it comes to "buying" defence R&D is about 4:1.

Defence R&D is done by the government also, alongside the firms. This is done by Direction général de l'armement (DGA). DGA procurement officers are almost always recruited from the Grande Écoles. Their jobs are highly sought after which attracts the most qualified candidates (Kapstein, 2009). The government also encourages DGA staffers to do secondments in industry roles. It is common for DGA staff to be deputed to companies like Dassault, Airbus and MBDA.

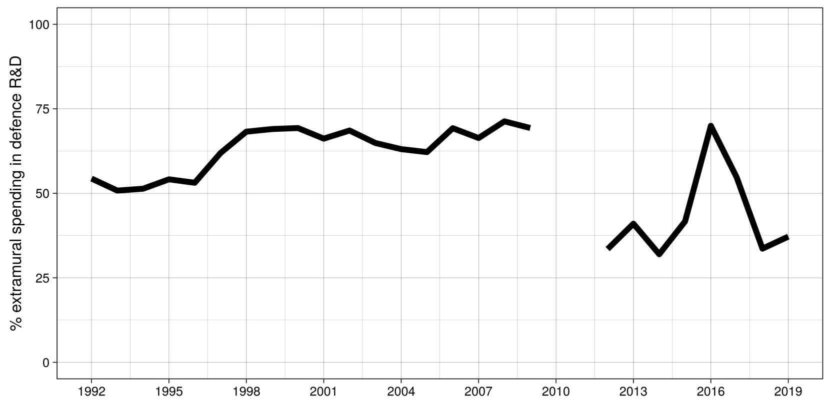
In 2018, a new agency, Agence de l'innovation de défense (AID), was created to coordinate spending for innovation in the defence space. It signals a policy re-orientation towards a US DARPA-style model of contracting out. AID's budget was increased to 1 billion euros (16% of total government spending on defence R&D) for FY2022 (European Defence Agency, 2021).[9]

Private sector R&D in defence is done by the large defence companies (such

[8] Government spending covers "buy" only. Sources: French Ministry of Higher Education, Research and Innovation (2012-19). We were able to obtain the R&D tax credits awarded for only four French defence firms: Dassault Aviation, Thales, Naval Group and Safran (2013-22).

[9] Defense Advanced Research Projects Agency (DARPA) is the main military research agency of the U.S. It has a staff of 220 who manage a budget of USD 4 billion (2022), 85% of which was spent on R&D contracts and grants. It has a long history of risk-taking and engaging in the most cutting edge research.

Figure 7 How much R&D does the French government "buy"?



as Dassault, Airbus, Thales, MBDA). Figure 7 shows the share of "buy" vs. "make" — on average in the last thirty years, 55% of R&D spending in defence was done by the private sector.[10]

When it comes to directly "buying" R&D, the French government prefers fixed-price contracts. However, in France, fixed-price contracts are "highly flexible" with "frequent renegotiation and price adjustments" (Kapstein and Oudot, 2009). The frequency of renegotiations and adjustments allows contractors to account for unforeseen events and uncertainties associated with research and development.

The DGA includes a "responsibility" clause in the contracts. This means that the bearer of costs in case of escalations is the party responsible for the escalation. Kapstein and Oudot (2009) studied 48 contracts which had 133 situations of cost overruns. Of these, the government took full cost overrun responsibility in 52 cases, the contractor did so in 26 cases, 32 were cost overruns stemming from "exogenous factors" (e.g. cancellation of import license from source country for a customised part, etc.) and 23 were cases where the cost overruns were "indeterminate". In all, 35 out of 48 contracts were renegotiated.

In case of exogenous factors, a French administrative court ruling requires that the government reimburses 90% of the contractor's actual losses which could not have been "reasonably predictable" (Vecchiatto et al., 2022). In

[10]Source: French Ministry of Higher Education, Research and Innovation (1992–2019).

case of indeterminate losses, the costs are equally shared between the contractor and the government.

Frequent cost overruns and a liberal legal interpretation for contractors when it comes to compensation might lead contractors to misuse the provision by placing the lowest possible bid in the face of high levels of competition. But in case of cost overruns, competitors can protest the award decision when an impossibly low bid is made (Kapstein and Oudot, 2009).

There is a generous R&D tax credit policy (Belin et al., 2019). Under Article 244 of the French Tax Code, the following expenditures qualify for a tax credit as long as the activity is conducted in the EEA:

1. Depreciation for research-related property.
2. Staff salaries and costs (deduction of 200% for doctorate holders for the first two years of the employment contract, 43% for all other researchers).
3. Certain operating expenditures.
4. Patent fees.
5. Expenditure on "technological intelligence" e.g. journals, periodicals etc. up to EUR 60,000.

The rate of credit allowed is 30% if the research cost is more than EUR 100 million and 5% if less than that. This policy strategy encourages large organisations, where network effects of numerous thinkers interacting with each other can arise.

The French defence R&D model has shown success. French defence exports enjoyed a compounded annual growth rate of 2.5% per year between 1992 and 2022 (Stockholm International Peace Research Institute, 2023). French defence R&D also promotes R&D in other industries — a 10% increase in government spending on defence R&D in France was correlated with a 5-6% increase in the R&D spending of other industries (Moretti, Steinwender, and Van Reenen, 2019). Defence R&D has spillover effects not just within the country but to other allies and friendly nations also. Increases in French defence R&D correlate to significant increases in R&D across some OECD member states (Moretti, Steinwender, and Van Reenen, 2019).

Table 7 What if Indian defence R&D was organised like France

Share of French GDP spent on defence R&D (per cent)	0.24
Share of French defence R&D contracted out (per cent)	56.81
Share of India's GDP spent on defence R&D (per cent)	0.06
DRDO spending (INR billion)	186.79
What if DRDO's spend was at the French defence R&D share? (INR billion)	677.44
How much of this would be contracted out under French-style 'buy' ? (INR billion)	384.85

When it comes to failure, we have already observed some mechanisms for mitigation such as flexibility in renegotiation and compensations for cost escalations, etc. Other mechanisms include:

1. To avoid concentration of bargaining power at the hands of the contractor, the DGA conducts systems integration contracting and sub-contracting separately.

2. Direct supervision is done by mandatory government audits.

3. IPR generally rests with contractor (Jenayah et al., 2022). This incentivizes them to develop dual-use and commercial-use technologies.

4. Disputes are handled by the National Committee for Amicable Settlement of Disputes in Public Procurement (CCNRA). This is a conciliation mechanism which gives non-binding decisions according to Article R-2197-1 of the French Public Procurement Code. The CCNRA is headed by an administrative judge. If either party is unsatisfied, they approach the French Administrative Court whose decisions are binding.

In India, the equivalent of the French DGA in India is the Defence Research and Development Organisation (DRDO). Unlike the DGA, the DRDO tends to "make" and not "buy" research.[11] Table 7 presents a 'what-if' scenario for what if the Indian government spent like the French government on defence R&D.

[11] The DRDO fund external research under the 'Technology Development Fund' (TDF) scheme, which began in 2016. The TDF scheme has an outlay of INR 500 million per year which is 0.21% of the DRDO budget for 2022-23.

3.4 The CSIR NMITLI

The NMITLI is an important milestone in Indian innovation policy. It was the first situation where the government of India embarked on contracting-out of R&D activities in a grand challenge-driven 'public-private-partnership' (PPP) mode. It began as a pilot scheme in 2001. The Cabinet Committee on Economic Affairs gave its approval in 2003 and it became a full-fledged central sector scheme the following year. The CSIR is the implementing agency. NMITLI directly "buys" research from private players, with an explicit recognition that grand challenge research has high risks, but also reaps high rewards.

NMITLI covers two types of projects: 'Nationally Evolved Project's (NEP) which are evolved through national consultations and 'Industry Oriented Project's (IOP) which are based on concepts received from the industry in response to annual calls for proposals. CSIR catalyses the project development and team building, selecting the recipients of the grants (in case of NEP) or loans (in case of IOP). After the early award, there is a monitoring and review process.

Selection for institution-initiated projects is done by CSIR in two stages. A screening committee makes a short list of research topics, around which Indian private firms[12] are invited by a high powered committee to partner with a government research organisation. For industry-originated projects, CSIR invites proposals through advertisements published in newspapers, as well as through invitation to specific firms to participate. A committee of experts evaluates the proposals from the firms, and shortlists projects and funding recipients.

The mechanism design for institution-initiated projects is:

Instrument of funding Once the institutions are selected, CSIR signs an MOU and executes an agreement for grants-in-aid with them.

Monitoring Each project has an internal Steering Committee consisting of the lead PIs which is required to meet once every three months. A Monitoring

[12] The ownership or shareholding of the industry partner must be of Indian citizens. If the majority shareholding is foreign, it must have an R&D center in India that is recognised by the Department of Scientific and Industrial Research (DSIR).

Committee consisting of three reviewers chosen by CSIR meets once every six months.

Payment conditions Grant amounts are paid on the basis of the payment schedule specified in the grant agreement.

What if the research fails? The institute can abandon a project. The external committee can also advise CSIR to abandon a project if it is found to be technically or economically unviable. Further payments from the date of abandonment are stopped. However the amount paid thus far need not be returned.

Questions of malpractice Since only government institutions are given grants-in-aid, malpractice is dealt with under service rules or industrial standing orders.

The mechanism design for industry-initiated projects is:

Instrument of funding Once the industry partners are selected, CSIR signs an MOU and executes a loan agreement with them. The loan is a "soft" loan (3% simple interest). Generally, there are publicly-funded R&D institutions in the project as partners and they are provided grants-in-aid.

Monitoring Each project has an internal Steering Committee consisting of the lead PIs which is required to meet once every three months. A Monitoring Committee consisting of three reviewers chosen by CSIR (usually CSIR scientists) meets once every six months.

Payment conditions The loan is to be repaid in ten equal instalments after completion of the project. The loan amount is fixed and will not cover budget overruns.

What if the research fails? The firm can abandon the project upon repayment of the amount outstanding at the time of exit. The external committee can also advise CSIR to abandon a project if it is found to be unviable.

Questions of malpractice The only malpractice covered is diversion of funds. If this happens, the firm has to repay entire outstanding amount with 12% monthly compounded interest.

Dispute resolution In case of disputes, as per the loan agreement, the external committee mentioned above acts as an arbitral tribunal.

Table 8 NMITLI size and achievements

Amount granted (INR billion)	7.41
Industry-initiated projects (number)	30
Institution-initiated projects (number)	55
Projects where only PSUs/government institutes were involved	4
Novel technologies that emerged	31
Technologies that were commercialised	12

Traditionally, researchers in India have focused on import substitution and incremental research, i.e. late stage TRLs. The essential feature of early stage research is the need for risk capital, that is able to withstand the high probability of failure.

Stevens and Burley (1997) list out the significant odds that an innovator would face by analysing data from new product development, potential activity and venture capital experience. They show that there is a universal curve which illustrates the number of substantial product ideas that survive between each state of the product development process. Out of 3000 raw ideas, 300 are submitted, 125 lead to small projects, 9 significant developments, 4 major developments, 1.7 launches and 1 success. By this reasoning, to get to one successful product launch, the innovation system needs to support hundreds or thousands of ideas at TRL 1.

NMITLI was novel in bring government and private firms to play for early stage ideas, at TRL 1–4. NMITLI was also novel in the idea of "buy" when it comes to government spending on R&D in India. Table 8 lays out some summary statistics. With a relatively small budget, NMITLI led to development and commercialising of many new technologies.

The NMITLI's performance would have been even better if there was a public procurement policy with the government itself as an initial buyer. This would have helped in market seeding and feedback to create refined market-ready products and accelerated the process of commercialisation. Mashelkar (2018) has elaborated on the possible models of innovative public procurement policies, some of which have been successful in other parts of the world.

There are two official reports evaluating NMITLI in the public domain. The first is the audit report by the Comptroller and Auditor General of India (CAG), which focused mainly on compliance. The second is a report that arose as a result of the Ministry of Finance (Department of Expenditure) directives on Appraisal and Approval of Public Funded Schemes and Projects.

CAG compliance audit the CAG had performed a compliance audit with 30 randomly selected NMITLI projects (Comptroller and Auditor General of India, 2015). This recorded instances of procedural lapses (such as mandated, quarterly meetings of the steering committee, biannual meeting of the monitoring committee not being conducted regularly). Also, there were records of time and cost overruns in the projects, and defaults in repayment of loans by private firms.

A problem in this document lies in the CAG assuming that NMITLI operated at TRL 9, while actually it operated at TRL 1–4.

VK Saraswat committee set up by DoE, MoF The Department of Expenditure (DOE) set up a committee chaired by Dr. V. K. Saraswat, Member (Science and Technology), NITI Aayog to review the outcomes of CSIR schemes, including NMITLI (Ministry of Finance, Government of India, 2016). Its review of the NMITLI scheme was, overall, a positive one, ending with a recommendation to extend the scheme for another five year period. It observed:

- *Rigour of selection*: Out of 1131 IOP proposals, 243 were shortlisted by the CSIR standing committee, 87 were short listed by area experts and 46 projects were developed. The selection rate was around 5% (Council of Scientific and Industrial Research, 2017).
- *State of progress*: Since its inception, NMITLI had undertaken 79 projects for implementation, out of which 68 projects were completed and 11 were ongoing. These projects included about 418 partners (318 public sector and 100 private sector). An amount of INR 6.96 billion had been released, of which INR 3.98 billion (57%) was grant-in-aid to academic and R&D institutions while INR 2.98 billion (43%) was loans to private firms. NMITLI directly induced 202 patent filings, 659 paper publications and 31 technologies or products.
- *Towards a National Innovation System* (NIS): The committee appreciated "the efforts and achievements of NMITLI, in particular for leveraging synergy of NIS through creation of desired networks of industry, national laboratories / R&D institutions and academia, for developing

well positioned technology and products, through focussed and well positioned projects."

- *Expansion to all* TRLs: The committee recommended that NMITLI should expand its mandate across all stages of the innovation process.
- *Cumbersome screening and selection process*: The committee recommended that the screening and selection process should be made simpler and shorter.

Some major achievements that the Saraswat Committee highlighted related to products/technologies like MicroPCR, Proton Exchange Membrane Fuel Cell, JD Vaccine, novel molecular diagnostics for eye diseases, cleaner leather processing technology, Fibre Supercontinuum Light Source System, solutions for security and operations based on UV sensor technologies, a complete Intelligent Video Surveillance System (IVSS), non clonable ID technology for medical product-authentication, novel DPP IV Inhibitors for the treatment of Diabetes, novel biotech therapeutic molecule (Lysostaphin), Novel Therapy for Management of Sepsis, Functional Genomics in Mentha, process for synthesis of Dimethyl carbonate (DMC) from methanol and urea, etc.

Our assessment of NMITLI locates this innovation in institutional design within the limitations of invisible infrastructure in India, which includes accounts, audit and dispute resolution. Looking forward, systems and processes need to be designed which help resolve disputes and frictions when they arise in the journey from ideas to impact, which inevitably take place over horizons that are longer than the tenure of most who serve in these organisations.

We close our treatment of NMITLI with one success story. The Proton Exchange Membrane Fuel Cell project started in 2005 as an 'institutional' project, with a consortium of government laboratories. This consortium developed single cells in Phase 1, and progressed to short stacks in Phase 2. By Phase 3, it had progressed to a industry-oriented program which sought to scale up the power of the stacks. However, despite successfully developing the technology to TRL 4 ('proof of concept'), the commercialisation of the project did not progress further because the fuel economics at the time made the technology economically unviable.

As of 2016, the project was at TRL 4, and would be deemed unsuccessful if NMITLI was judged for delivering TRL 9 outcomes. But after 2016, the project continued towards commercialisation, with another industry partner which developed higher wattage stacks (from 3kW to two 20kW cells in 2021) using mostly indigenous components, at a price of $400/kW against the prevailing competition at $1000/kW to $1200/kW.

On 28 February 2024, the Prime Minister launched India's first 50 kW PEM hydrogen fuel cell which has been built by NMITLI's technology partners, led by KPIT Technologies. This fuel cell will power a ferry that has been built by Cochin Shipyard Ltd., and will be deployed for service at Varanasi.[13]

In this success story, we also see cost advantages of doing R&D in India, when compared with operating in the advanced economies. The overall expenditure on the PEMFC project (2005–2019) was INR 450 million (approximately USD 7 million over the full period). The U.S. Department of Energy conducted a similar project on fuel cell systems for transportation and stationary applications at an annual (FY2009) cost of USD 77 million.

4 Charting a course to higher innovation

So far, we have made three main arguments:

1. The policy motivation for public expenditure on R&D is to trigger greater knowledge in the society. This happens best when this public expenditure involves contracting-out to high spillover sites in the society: universities (public and private) and private firms. The knowledge must not be in isolated groups of civil servants, but inside the society. This calls for a reorientation away from that 'make' path to the 'buy' path. Such an approach yields a higher bang-for-the-buck of gains to society per unit public expenditure, and helps overcome the hurdle rate of the high value for the marginal cost of public funds in Indian public finance.

2. Many success stories of innovation policy, in advanced economies, are grounded in this kind of connection between public expenditure for innovation and spillovers into the society that are obtained through the 'buy' approach.

3. Care is required in institutional design, when going from concept to action, so as to design how these funding mechanisms will work, and to respect the weaknesses of invisible infrastructure in India.

[13]This is a part of the 'Harit Nauka' initiative of the Ministry of Ports, Shipping and Waterways for green transition of inland vessels and is proposed to be replicated in other parts of India (Philip, 2024).

Going from thought to action, how might such a change in strategy be achieved by policy makers in India? A precise analysis of the root causes of difficulty is required, which lends itself to identifying the list of modifications of legal documents through which the desired change is achieved.

At first blush, strategic thinking in reorienting Indian innovation policy faces the challenges posted by skepticism that arises from a risk-averse mindset. However, the choices of officials and organisations are shaped by legal texts. Legal clarity is one path to addressing the fears of officials who may be "intimidated through overmonitoring" and are "accountable through accounting" due to the investigator's reliance on the "paper trail" when discretionary procurement decisions are made (Sneha et al., 2021).

The challenges seen here are, of course, not unique to innovation policy. All across the Indian policy landscape, the question of buy vs. make is a fundamental one which shapes strategic thinking in public policy. In many areas, it is possible to make progress through learning by doing on the 'buy' path (Chitgupi and Thomas, 2023). At the same time, there are important difficulties faced when the Indian state enters into contracts. Government contracting is a difficult challenge and a specialised skill in its own right. In recent years, a research literature has started emerging on this field.[14] This paper draws on this knowledge, and represents one component of this literature.

4.1 Changes in legal texts

The creation of an enabling environment for innovation requires a change in the mesh of legal instruments that govern the actions and choices of research institutions and officers. Four groups of legal texts require changes: (a) Changes to the GFR, which is the basis on which officials make contracting decisions, (b) Changes to the founding documents of innovation organisations such as ISRO or DRDO, (c) New rules that govern the internal working of these implementing organisations, and (d) The establishment of internal manuals that guide processes in these organisations. At a high level:

The four areas of change are summarised in Table 9 and we now examine them in more detail.

[14] Many elements of this research literature are visible at https://xkdr.org/field/public-finance .

Table 9 Summary of recommendations

Changes to the GFR: Researchers, not officials, should monitor scientific projects. Procurement of research should be free of the usual requirements of bidding and tendering — it should be possible for a innovation institution to award a non-competitive grant to an individual researcher, a university or a private sector firm. All types of entities should be eligible to receive grants. A more flexible approach should be adopted by changing the scope and definition of cost-plus contracts. None of the Indian institutions have rules on peer review: a chapter on the process of peer review as the method of evaluating research should be placed into the GFR.

Changes to the founding documents / cabinet resolutions: The parent legislation and/or other founding documents of innovation institutions should be amended to reflect the institutional preference for "buy". The separation of roles between scientists and procurement officers should be clearly laid down. Innovation institutions generally place their annual report in the public domain. This report should mandatorily disclose "make" vs. "buy" ratios.

Changes to procurement rules and internal process manuals: Alongside changes in the GFR, manuals and guidance documents at each innovation institution need to be modified. The institution should be required to prepare and follow annual research plans. Procurement officers should be trained and certified in conducting procurement for R&D, drafting contracts and managing contracts with a combination of law knowledge and domain knowledge. While government contracts now come with arbitration clauses, there is a need for a good-faith, non-binding mediation framework as well.

Such expertise should be developed within the implementing organisation itself, rather than at the level of the relevant ministry in charge of legal matters. All contracting comes with an element of risk, hence a suitable risk evaluation framework should be designed to act as an input in contract planning. New rules need to be made to address research malfeasance such as plagiarism and falsification of data. Detailed process manuals should be created to implement all the rules mentioned above. These processes should be mapped to the specific TRL.

4.1.1 Changes to the GFR

The General Financial Rules (GFR) is the fundamental document that shapes government contracting in India. We believe it requires a certain set of changes in order to enable contracting-out for innovation policy:

Researchers, not officials, should monitor scientific projects : Researchers are better suited to monitor scientific projects. The "competent authority" under Rule 2(vi) should remain scientists.

Remove bidding requirements for procurement of research : Bidding and tender requirements are unsuitable for research contracts. Efficiency of research will be impaired and costs of contracting will increase through tendering. Rule 144 (for goods) and Rule 201 (for services) should be modified to exclude research contracts.

Allow all types of entities to receive grants Grants are a flexible instrument to fund research. Under Rule 230, only educational institutions, co-operative societies and government organisations are allowed to receive grants from the Union government. This should be amended to include all forms of organisations including private for-profit firms.

Change the scope and definition of cost-plus contracts : As per Rule 225 cost-plus contracts, while allowed, are to be "ordinarily avoided". This should change. Research contracts benefit greatly from the cost-plus structure. The language of the Rule should be changed to incentivize the use of cost-plus contracts. The Rule should also allow for "good faith efforts", and not "delivery" of the goods or services, to be the test for discharge from the contract.

Add a chapter on peer review The persons best placed to judge "good faith efforts" in research are the researcher's peers. A chapter should be added to the GFR which covers the principles of how innovation organisations should do peer review.

4.1.2 Changes to the founding documents

In organisations like NASA or NIH, the founding documents have text that establishes the 'buy' orientation of the organisation. This helps steer the senior managers of the organisation, and answers future questions about why a certain element was contracted out. An examination of the corresponding founding documents with innovation institiutions in India shows that such direction and clarity is lacking. In order to close this gap, we propose the following:

Amend parent legislation/ founding documents The foundation of the scientific organisation should be that of contracting out. As an example, in India, the NHAI was expressly created to "*unify ... the varying levels of competence and diligence ... project preparation ... quality control and development of contracting industry*" of highway construction (Lok Sabha, 1988). Such role clarity is required in each organisation that spends public money as part of innovation policy.

Clarity on the roles of scientists and procurement officers The founding documents should specify that the organisation should lay down clear and separate processes for how scientific staff monitor research progress and how procurement staff monitor the progress of the contract.

Disclose "make" and "buy" ratios In the annual reports which should be laid before the Houses of Parliament, the innovation organisations should disclose the total amounts spent on "make" and "buy" respectively. Returning large amounts of resourcing into the society, and kicking off spillovers into the society, is something that should be monitored and is something that will help achieve legitimacy for enhanced resourcing.

4.1.3 Changes to procurement rules and internal process manuals

Innovation policy is ultimately implemented by the officers within innovation institutions. The ability of these individuals to "buy" innovation is shaped by the procurement policies and rules of their organisations, and these legal texts need changes:

Prepare and follow annual research plans Each organisation should lay on the floor of the Houses of Parliament their annual research plan. The research plan should contain details of the big ideas and projects that the organisation seeks to work on, and achieve, in the next one, five and ten years. Procurement should guided by the research plan.

Training and certification programs for procurement officers Procurement officials (who manage contracting and contract progress) require certified skills and the commensurate training. As an example, the US certification system in this field is called FAC-C.

Develop in-house legal expertise Each organisation should have a legal division that advises on contract design, customisation and management. As an example, NASA employs 170 legal officers in-house.

Devise risk evaluation frameworks Each organisation should develop a risk evaluation and mitigation strategy that should be updated every five years.

Adopt mediation before arbitration Arbitration is the default method of settling disputes (Department of Expenditure, Ministry of Finance, Government of India, 2021). However, similar to the CCNRA, there is a role for good-faith mediation and negotiation before the arbitration clause is invoked. This forum can be a common one across many innovation institutions. It should be staffed by scientists and legal experts.

Punish research malfeasance Persons who engage in research malfeasance should, after a fair hearing and right to appeal, be debarred from receiving government funds for research for a period of three years. If malfeasance is repeated, they should be permanently debarred.

Prepare detailed process manuals All innovation organisations should incorporate the principles of contracting-out in their internal processes. Changes to contracting processes that permit greater flexibility will induce cautious but far-reaching changes in the behaviour of optimising employees.[15] A new manual containing step-by-step instructions on how to procure should be prepared in each innovation organisation.

Adopt TRL-based processes Research design and funding should follow the TRL model. Projects should be classified into discrete categories from "TRL 1" for basic conceptual research to "TRL 10" for technologies that are fully operational and capable of being commercialised. Contracting processes should be sensitive to the TRL of the question at hand. Research should be judged on the basis of the TRL it seeks to achieve. Each organisation should also have detailed descriptions of how they perceive each TRL, and use this as an organising principle in the annual research plan.

4.2 New or existing organisations?

Should the reorientation from 'make' to 'buy' take place in new or existing innovation organisations?

[15] One example is the change in the rule that now allows processing of single-bid tenders. Based on the samples taken by Mehta and Uday (2022), the number of single bids that are getting accepted and processed across states have increased.

Our analysis of the Indian innovation policy landscape in 2019 suggests that six organisations make up nearly 90% of the union government's research spending: DRDO 32%, DOS 19%, ICAR (Indian Council of Agricultural Research) 11%, DOAE (Department of Atomic Energy) 11%, CSIR 10%, and DOST (Department of Science and Technology) 7%[16] Structural changes to these six organisations could thus materially change the Indian innovation system. Feasible reforms could then take three alternate pathways:

Path 1 : All five organisations undertake the transformation to a "buy" orientation.

Path 2 : New organisations are started which are buy-oriented from the start. Components of the US innovation system which are at present lacking in India include the Defense Advanced Research Projects Agency (DARPA) of the US Department of Defense, the NIH, and the National Science Foundation (NSF). These new organisations would be analogous to the early establishment of the NHAI, which was 'buy' oriented at inception.

Path 3 : A combination of change management at one or two old organisations alongside one or two new organisations.

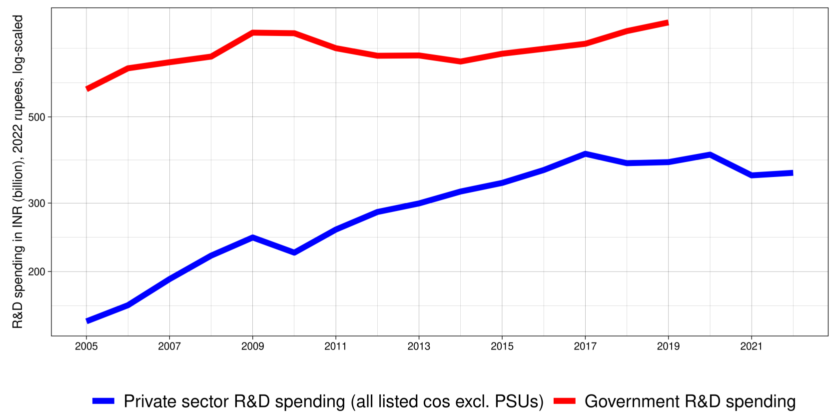
The third path appears to have advantages: To get going on completely new organisational design with DARPA, NIH and NSF style organisations, and to undertake change management in three old organisations (e.g. DRDO, DOS and CSIR, which add up to 62% of the existing spending).

Implementing this program of change will require a strong and sustained community of public intellectuals, thinkers, researchers and doers that will bring passion, imagination and entrepreneurship to build/transform six organisations over roughly a decade. The early moves are visible in the present policy discourse. Innovation policy in India is in a time of great ferment. Many important initiatives are presently underway:

1. In the Union Interim Budget of 2024-25, an announcement has been made to "encourage the private sector to scale research and innovation significantly in sunrise domains" (Ministry of Finance, Government of India, 2024). The provision has been announced for a corpus of Rs.1 trillion to facilitate interest free loan to private sector.

[16] These values are from Ministry of Science and Technology, Government of India (2020).

Figure 8 R&D expenditure, 2005–2019.



Source: CMIE Prowess for firms, and Ministry of Science and Technology, Government of India (2020) for government.

2. The 'National Research Foundation' has been set up under the Anusandhan National Research Foundation Act, 2023. The law came into force on 5 February 2024.

3. In 2024, the K. Vijay Raghavan Commitee has submitted its report in early January 2024 on reforming the DRDO. An early sense of the ideas of this report are visible in press reports.[17]

There is a harmony between the philosophy of these three moves, and the ideas of this paper. Conversely, the detailed work of this paper can be useful when translating these initiatives from concept to implementation.

4.3 Resource allocation in a gentle reform trajectory

We now turn to a public finance and expenditure strategy view of these questions. Figure 8 presents the graph of the magnitude of R&D expenditure in India, separately presenting public and private funds allocated.

Figure 8 shows that the government is the major source of R&D spending. At the same time, growth of R&D spending by the government is relatively weak. Private sector (which is measured only partially, for listed companies only)

[17] See *Do or die for the* DRDO, Pradip R. Sagar, *India Today*, 16 February 2024.

has shown a compound real growth rate of 6.49% per year from 2005 to 2019: a pace that corresponds to a rough doubling every 11 years. It is now likely that the most important private R&D organisations in India are the research centres built by global companies: these would be completely invisible in the Indian listed companies data. Over this period, the comparable growth rate for government R&D spending was 2.87% (which corresponds to a doubling every 24.5 years). We treat this historical compound growth rate – of about 3% real per annum – as a fact that will prevail in coming years, for the purpose of long-term fiscal planning.

What is a most-conservative scenario through which the required change can be achieved? The least difficult reform is a passive scenario where the scientific staff in government organisations declines by 3% a year through natural attrition. Alongside this, we assume a proportional decline of 3% per year (in real terms) on associated operational expenditures. Thus, overall, we assume that the expenditure on the 'make' strategy declines by 3% per year in real terms.

The least difficult reform, then, involves a 3% annual decline in the spending through 'make' and a 6% annual increase in the contracted-out expenditures. A growth rate of 6% real is a doubling every 11 years. Such a time horizon gives adequate time for the institution development that is listed in the previous section, which is critical to achieve high capability in contracting out. As an example, under Indian conditions, NHAI achieved considerable capability in contracting out over its important 11 years, from 1999 to 2010.

Table 10 shows how such a proposal would pan out if it were to be operationalized in the DOS. This transition path envisions that it spends Rs.133 billion in contracting out by 2036.

This relatively conservative scenario, of a combination of gaining from the 3% per year attrition of scientific staff, is not the only possible path. Even with this least-disruptive strategy, there are material numerical values at the end which would exert a major influence on better spillover into the society by 2036. This scenario gets to a 70% expenditure through contracting-out by 2036, and in a few years more would match the NASA value of 80 to 85 per cent. More ambitious reform trajectories can, of course, be constructed, but this least-difficult fiscal pathway constitutes a floor.

Table 10 The least-difficult trajectory for the Department of Space to evolve from 'make' to 'buy'

We show a least complex trajectory for the Department of Space, where the emphasis gradually shifts to 'buy', to contracted-out research. All values are in billion 2022 rupees. In this simulation, it is assumed that total spending grows at 3% per year in real terms and the number of internal scientific employees declines at a natural attrition of 3% per year with no new recruitment of scientific staff. Thus the projection envisions an annual 6% (real) increase in the procurement budget.

Year	Budget	Scientific employees	Procurement spend	
	Bln. Rs.		Bln. Rs.	Share (per cent)
2023	130.21	12398	7.81	6.00
2024	134.12	12026	15.86	11.83
2025	138.14	11665	24.15	17.48
2026	142.29	11315	32.69	22.97
2027	146.56	10975	41.48	28.30
2028	150.95	10646	50.54	33.48
2029	155.48	10327	59.87	38.50
2030	160.15	10017	69.47	43.38
2031	164.95	9717	79.37	48.12
2032	169.9	9425	89.57	52.72
2033	174.99	9142	100.06	57.18
2034	180.24	8868	110.88	61.52
2035	185.65	8602	122.02	65.72
2036	191.22	8344	133.49	69.81

4.4 Project planning for the desired reform

Once there is a decision to move in these directions, the required steps include:

1. Arrive at a decision on the question of new or existing organisations (Section 4.2).
2. Choose the time horizons of the transformation, with some variant of the calculations for the gentle glide path shown in Section 4.3.
3. Establish a technical team that would translate the drafting instructions in three areas (in Section 4.1) into the required legal documents.
4. Enact these documents.
5. Release a white paper which announces the new strategy.

5 Conclusion

Independent India has valued science and rationalism at an early stage of social and economic development. This is reflected in paragraph 7 from the *Science Policy Resolution* of 4 March 1958, which establishes the objectives of science and technology policy as :

> 1. *to foster, promote, and sustain, by all appropriate means, the cultivation of science, and scientific research in all its aspects - pure, applied, and educational;*
> 2. *to ensure an adequate supply, within the country, of research scientists of the highest quality, and to recognize their work as an important component of the strength of the nation;*
> 3. *to encourage, and initiate, with all possible speed, programmes for the training of scientific and technical personnel, on a scale adequate to fulfil the country's needs in science and education, agriculture and industry, and defence;*
> 4. *to ensure that the creative talent of men and women is encouraged and finds full scope in scientific activity;*
> 5. *to encourage individual initiative for the acquisition and dissemination of knowledge, and for the discovery of new knowledge, in an atmosphere of academic freedom;*

6. *and, in general, to secure for the people of the country all the benefits that can accrue from the acquisition and application of scientific knowledge.*

These words drafted 66 years ago ring true today. What has changed over these 66 years is our understanding of the means through which these goals can best be pursued. In this paper, we have undertaken a first principles examination of innovation policy, drawing on modern knowledge from economics and public administration. The case for innovation policy is grounded in the problem of spillovers. Private persons undertake inadequate innovation expenditures as they do not capture the full gains to society that flow from their private expenditures. State intervention – taxing the people and then spending this money – is intended to address this market failure.

What has changed today, compared with 1958, is the level of capability in the society – outside the state – that can now be harnessed. The market failure is most directly addressed when public expenditures are delivered *into* the society: into the high-spillover sites of universities (public and private) and private firms.

While there has been a recognition of these issues in India for some time, there has been a gap in knowledge about the mechanisms of policy reform. Many thinkers and policy makers have been daunted by the problems of mindset, fear of allegations and controversies, and the deficiencies of the invisible infrastructure in the Indian institutional environment. All too often, policy thinking in India engages in a 'great man theory' where the solution to a stated problem lies in recruitment of the right people. In this paper, we have undertaken a root cause analysis and have identified the legal texts that require changes. In this paper, we have proposed the 'drafting instructions' which can then be turned into precise drafts of legal texts through specialised legal drafting projects.[18]

A change in course is feasible, and over a decade it can induce considerable gains for innovation policy in India. Our calculations involving expenditure have been conservative in assuming that the values from the past (3% real growth in government R&D expenses) will play out into the future: no acceleration in the growth rate of government expenses on innovation are called

[18] In separating drafting instructions from legal text, we draw on the work mechanisms of the Financial Sector Legislative Reforms Commission, led by Justice B. N. Srikrishna, which organised itself over 2011-2015 through this two-step process.

for.

There are three dimensions in which the outcomes may surprise on the positive side:

1. As has been observed elsewhere in the world, when budgets for innovation policy largely turn around and go back into the society, the political support for these expenditures goes up. When the bang-for-the-buck from public spending on innovation policy goes up, through the ideas of this paper, the political support for these expenditures may go up. Thus, the budget process in the future might choose a higher growth rate for this public expenditure in coming years.

2. When government resourcing amplifies the capabilities of R&D departments in universities (public or private) and private firms, it is likely that private R&D spending will also go up as the gains for private firms per rupee of expenditure would then be higher.

3. It is now likely that the most important private R&D organisations in India are the research centres built by global companies. The strategy of this paper, where innovation expenditures are delivered into the society, harnesses the superior capabilities in the society that are being engendered by the presence of these overseas firms doing R&D in India, and enhances the attraction for global firms to place a bigger share out of their global R&D expenses into India.

The ideas of this paper are connected with policy thinking in higher education also. Universities induce positive externalities upon society and therein lies the case for public funding for universities (both public and private). A meritocratic mechanism for doing this at a significant scale has yet to be devised. The ideas of this paper hold the key in solving this problem. If about 80% of the public expenditure on innovation policy across all fields (nuclear, defence, space, health, agriculture) is contracted out, this creates the mechanism through which more ambitious universities can rise to compete for these grants and contracts, and thus obtain public funding and in a meritocratic fashion. The ideas of this paper thus solve both questions: *How to get large levels of resources into universities (public and private)*, and *How to avoid doing this through bureaucratic budget allocations.*

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