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**Higher Education, Scientific Research and
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by

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Higher Education and Scientific Research for Industry: Reflections on Priorities for India

Naushad Forbes²

“The applications of science are inevitable and unavoidable for all countries and peoples today. But something more than its application is necessary. It is the scientific approach, the adventurous and yet critical temper of science, the search for truth and new knowledge, the refusal to accept anything without testing and trial, the capacity to change conclusions in the face of new evidence, the reliance on observed fact and not on preconceived theory, the hard discipline of the mind -- all this is necessary, not merely for the application of science but for life itself and the solution of its many problems... The scientific approach and temper are, or should be, a way of life, a process of thinking, a method of acting and associating with our fellow men.”³

“Politics led me to economics, and this led me inevitably to science and the scientific approach to all our problems and to life itself. It was science alone that could solve these problems of hunger and poverty, of insanitation and illiteracy, of superstition and deadening custom, of vast resources running to waste, of a rich country inhabited by starving people”.⁴

Both quotes from *Jawaharlal Nehru*

Investing in Higher Education and Scientific Research have long been viewed as essential to the development process, though attempts to quantify their contribution to the actual growth experience across countries have been unsuccessful.⁵ India invested early and strongly in both Higher Education and Scientific Research, with the explicit objective of economic development. Among developing country world leaders, Jawaharlal Nehru was perhaps the most articulate and passionate about science and research. Nehru often

¹ The comments of the participants at the fourth annual Conference on India's Economic Reforms at Stanford University, 5 – 7th June, 2003, are gratefully acknowledged, especially those of Ken Arrow and Kirit Parikh. The comments and input of Gerhard Casper, Harry Rowen, Armaity Desai, Arun Nigvekar, Ram Natarajan, Ashok Kolaskar, and H.K. Abhyankar have been invaluable. I am particularly indebted to the many detailed critical comments of T N Srinivasan and Ashok Desai. As always, my greatest debt is to Alex Inkeles, for many critical comments on this and other papers on like topics over several drafts. The usual disclaimers apply.

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³ Quoted in Nayar, Vol 2.

⁴ Nehru inaugurating the Indian Science Congress in 1937. Nehru always did inaugurate the Science Congress, setting a precedent every Indian Prime Minister has had to follow.

⁵ See Wolff, E.N. (2001), ‘The role of education in the postwar productivity convergence among OECD countries’ *Industrial and Corporate Change*, Volume 10: 735-759

referred to himself as a "devotee" who had "worshipped at the shrine of science".⁶ The path Nehru laid was followed by successive Indian leaders: as is often repeated, India today has the third largest pool of S&T people, and its higher technical education (HTE) system is correctly credited with its successful software industry and growing strength in IT-enabled services.

Higher Technical Education (HTE) in India today faces at least three challenges. First, the last twenty years have seen very rapid growth in private HTE with the number of engineering colleges and engineering enrollment growing at 20% a year. These have contributed directly to India's abundance of engineers in general and software professionals in particular, but raising their standard of quality is a pressing concern.

Second, select HTEs such as the IITs have provided a world-class technical education at the undergraduate level. As Indian industry seeks to move up the value-chain in technical competence, they increasingly need better graduate engineers. The best Indian HTEs are today wrestling with the problem of improving graduate education, where they have a poor track record, and which means doing research. That brings us to the third challenge.

Although India was an early investor in scientific research, this investment went overwhelmingly into autonomous Scientific Research Institutions. Although much of this investment was explicitly justified based on potential benefits to Indian industry, studies have repeatedly showed little contribution.⁷ This is hardly surprising, as the role of scientific research in industrial technology for a newly-industrialising country such as India is very limited. Within Indian firms, the role of R&D covers a range of activities from indigenising imported components to catching up with more advanced forms to improving existing products to providing low cost R&D contract research. The role of research itself is very limited in industry everywhere, and in an industrialising country like India especially. As such, India should seek to create the capacity for being an effective "free" rider on global science, and India's real need for scientific research is as a means of producing better graduate technical people. The end result of doing scientific research in autonomous institutions has been for research to bypass the university system, which is where countless studies from countless countries say research should be done.⁸ Any attempt to reform the Indian scientific research system which does not address this core issue of combining public research with teaching and not doing it in autonomous research institutions will be fruitless, and the paper suggests how the Indian research system can be reformed.

⁶ Nayar, Vol. 1, p. 551.

⁷ See in particular Hussain (1986).

⁸ See in particular the work of Nathan Rosenberg, Richard Nelson, Keith Pavitt, and Paul David and in particular Rosenberg and Nelson (1994), Nelson (1993), Pavitt (1998), David (1998) and OECD (1992 and 1998).

Combining research and teaching will benefit both. The huge growth in HTE in India has all been at the undergraduate level; graduate technical education has stagnated. As the better HTEs, and in particular the IITs, attempt to grow their graduate and especially their PhD programmes, a shortage of qualified faculty is becoming increasingly acute. World-class graduate education requires that teachers do research, and unless there is dramatic growth in research at HTEs, we cannot hope to have world-class graduate education. But the benefits from combining research and teaching would not flow one-way to teaching. Research would benefit too. Thanks to India's early investment in scientific research, it achieved the levels of a medium-sized developed country in the primary measure of science output, publications in scientific journals. But this lead in publications did not show up in patents, often used as a measure of the output of technology research, where Korea and Taiwan have been the big new entrants. And in the last fifteen years, India has also fallen back in its share in publications as Korea and Taiwan have invested more in public research (largely in their university systems) based on their lead in industrial technology. Learning from Korea and Taiwan, the flow runs sequentially from industrial development to industrial in-house R&D to public scientific research. An industrial sector competing with the best firms in the world in increasingly sophisticated industrial sectors is a requirement for sustaining investment in in-house R&D, and strong in-house R&D is a requirement for sustaining investment in public scientific research of value to industry. It is only since 1991 that Indian industry has increasingly had to compete with the world's leading firms. This has in turn driven some limited investment in in-house R&D by specific Indian firms and industries such as pharmaceuticals. The more advanced technological sectors in Indian industry are probably only now capable of utilising, and therefore sustaining, investment in public scientific research. By combining this research with teaching, the Indian economy will get the primary benefit of doing research: the availability of trained researchers.

I. Higher Education

Higher Education and Industrial Competitiveness

Education matters to industrial competitiveness at three distinct levels: schools, higher education, and 'mover and shaker' higher education. Schools matter in providing basic literacy and numeracy for the general work-force, and have the vital side-effect of spreading attributes of efficacy, efficiency and planning which give factories a head start

with their employees.⁹ Widespread numeracy and analytical abilities played a key role in Japan's success - ideas to improve the operation of imported technology more often than not originated on the shop-floor.¹⁰ The East Asian Miracle countries were particularly successful in providing widespread numeracy and literacy. It was not that these countries spent more on public education than comparable countries; instead they gave a greater share of public spending to primary education.

General higher technical education is also important, to provide all those engineers who can seek out the best technology, unpackage it effectively, fill in the gaps in the package through local effort, and then adapt and improve the technology further. Finally, the 'mover and shaker' category is necessarily a small number of people, the people who make things happen.

Higher Education in India

India, too, invested in education in general and higher education in particular in the first decades of independence. While the focus of Indian government spending on education has been primary education, especially in recent years, investment in higher education has also been significant.

Higher education in India, as in most countries, was generally provided by the state. Since independence, the numbers show significant investment in higher education: the number of universities increased from fifteen at independence to 250 in 2001 (14,000 colleges growing at over 10% a year).

Table 1: Growth in universities and university enrollment by state.

Table 1: Number of UGC Recognized Universities and Institutions			
State	1947	2001	Enrolment 2000-2001
Uttar Pradesh	5	21	1,141,364
West Bengal	1	11	449,908
Delhi	1	5	159,437
Tamilnadu	1	15	616,388
Orissa	1	8	286,927
Maharashtra	1	18	1,159,031
Kerala	1	7	223,476
Karnataka	1	13	552,290
Bihar	1	11	642,333
Andhra Pradesh	2	16	590,532
Madhya Pradesh	1	14	472,429
Others	0	54	1,706,120
TOTAL	16	193	8,000,235

⁹See Alex Chikies, *Becoming Modern*, for the definitive statement on Modernity. See also his *Education and Individual Modernity* for the role of the school as a moderniser.

¹⁰Japan *did* have an economic miracle, but from 1868 to 1905. Japan's post-WW II economic record is indeed outstanding, but hardly miraculous given the human capital built up in the population before the war. For example, Japan achieved a primary school attendance rate of 96% by 1905, ahead of the UK and USA.

Source: UGC (2002) Appendix I and IV¹¹

Indeed, higher education expanded in India well ahead of the demand for qualified people, leading to chronic educated unemployment. Writing in 1976 on the progressive qualification-inflation that he called the Diploma Disease, Ronald Dore referred to “India, the home of the BA bus conductor, famous for its 60,000 unemployed graduate engineers”.¹²

Today, about 8% of the relevant age-group is in college, if you go by University Grants Commission (UGC) figures. ¹³The UGC shows the following split in student enrollments by faculty:

Table 2: Student Enrolment by Faculty, 2000-2001

Faculty	Total Enrolment	Percentage to Total
Agriculture	61,855	1
Arts including Oriental Learning	3,421,912	43
Commerce including Management	1,654,617	21
Education	135,369	2
Engineering/Tech.	529,461	7
Law	273,319	3
Medicine	261,207	3
Science	1,573,966	20
Veterinary	17,139	0
Other (including Music/Fine Arts etc.)	72,090	1
Total	8,000,935	100

Source: Appendix VI of UGC 2000-1

Higher Technical Education in India

The widespread availability of technical skills in India has long been recognised. For as long as I can remember, certainly 25 years, we have been told ad nauseum that we have the third largest pool of scientific and

¹¹ An additional 47 private institutions are “deemed universities”.

¹²Dore (1997), *The Diploma Disease*, second edition, p 78.

¹³ This number would seem to be an underestimate. I would estimate the UGC figures for engineering students to be about 1 million lower than it really is, and for other technical subjects to be another 1 million. So just adding that makes it 10% of age group.

technical manpower.¹⁴ This assessment, though, was based through the early 1980s on counting bachelor of science graduates as a part of this pool. In India, a Bachelor of Science degree is a three year course, as it is for Commerce and Arts. An engineering degree takes four or five years, and the content is considered much more on par with an international undergraduate qualification. The best illustration of the distinction between a B Sc and B E in India that I can suggest is in the job market: a B Sc would generally be hired as a technician, a B E as a professional engineer, with widely different prospects of salary and career advance. As such, in talking of higher technical education in India I will restrict myself to talking of undergraduate engineering degrees alone and only graduate (Masters and PhD) degrees in Science.¹⁵

Through to the early eighties, almost all engineering colleges were either government or government-aided. The only exceptions were a few private educational institutions, such as VJTI in Bombay, which pre-dated independence and continued as private institutions post-independence, but were often still dependent on government funding. In 1983, in a major liberalisation, private unaided colleges were encouraged. Some states saw a large expansion in colleges offering engineering degrees in particular. (Education, including higher education, is a state subject in India's federal system. The central role – through the University Grants Commission - is limited to course approval, accreditation, recognition of universities, funding of special improvement programmes, and a few central universities and institutions). This led to a massive rise in the number of engineering colleges: Consider the case of one state, Maharashtra. In 1983, it had five state and four state-aided engineering colleges with an annual in-take of 2000 BE's per year. Twenty years later the system has expanded twenty-fold, and Maharashtra today has 150 engineering colleges offering Bachelors degrees, admitting 50,000 engineers a year. This growth in the private provision of engineering education has been concentrated in the central and southern states, as Table 3 shows. The top five states – Andhra Pradesh, Karnataka, Maharashtra, Tamil Nadu and Kerala – have 31% of India's population but 69% of the annual engineer-degree intake. Conversely, the five states, (UP, Bihar, West Bengal, Rajasthan, Gujarat) with 43% of India's population, account for 14% of the annual engineer intake.

¹⁴ The understanding is that it was Indira Gandhi who started saying this, on data given to her by her then Science Advisor. There was apparently no thorough analysis that led to this assertion, but in this case it actually became true –after Indira Gandhi's death – with the growth of the private engineering colleges.

Table 3: Undergraduate Engineering Colleges by State

State/Union Territory	No. of Engg Instts	Annual Student Intake	% of total	Population-Census 2001	% of total
Tamil Nadu	250	79122	22	62,110,839	6
Andhra Pradesh	215	64300	18	75,727,541	7
Maharashtra	151	47035	13	96,752,247	9
Karnataka	111	40385	11	52,733,958	5
Uttar Pradesh	83	22491	6	166,052,859	16
Kerala	73	17858	5	31,838,619	3
Madhya Pradesh	45	12970	4	60,385,118	6
West Bengal	45	10709	3	80,221,171	8
Gujarat	25	9559	3	50,596,992	5
Orissa	38	9505	3	36,706,920	4
Haryana	33	9385	3	21,082,989	2
Punjab	33	8875	2	24,289,296	2
Rajasthan	29	7807	2	56,473,122	6
Bihar	7	1575	0	82,878,796	8
Others	77	19720	5	212,043,576	13
Total	1215	361296	100	1,027,015,247	100

Source: AICTE

It is this expansion of engineering education that fueled India's software boom, and it is no accident that the states with massive private expansion of engineering education are precisely those where the software industry is located. (When the dot-com boom went bust in 2001, the talk in Silicon Valley was that B2B and B2C had new meanings: Back-to-Bangalore (capital of Karnataka) and Back-to-Chennai (capital of Tamil Nadu). Unfortunately, there was no B2H for Hyderabad!)

This dominance of central and southern states does not apply to the university system as a whole. Table 1 showed that while the northern states, and in particular UP, have lost the dominance of higher education they had at independence, their share of the university system is still reasonably proportionate to population. I interpret the contrast with engineering education two ways. First, growth of colleges in some states reflects the market: the supply of students from states with higher literacy and school enrollments, and the demand from job opportunities for graduates. Second,

¹⁵ To which should be added the 1006 institutes (Economic Survey, 2002-3) offering a Masters in Computer Applications, a qualification almost always taken by those with B Sc or B Com degrees to place themselves on

that this growth has been focussed on engineering, and technical and professional education, again reflecting improving employability in the job market.

How many engineering students are there?

The UGC split of Table 2 says there are 530,000 engineering students enrolled. However, if one uses the figures of the UGC's sister department for technical education, the All India Council for Technical Education, the number of undergraduate engineering students enrolled is 350,000 each year, or 1,400,000. This number would also be more consistent with the Economic Survey's statement that there are 1200 approved colleges leading to an engineering degree.

As of 2003, then, institutions for Higher Technical Education in India¹⁶ would consist of the following:

Bachelor of Engineering	1203
Master of Computer Applications	1006
Master in Business Administration	930
MSc in Pharmacy	116
Master, PhD in Engineering	314
MSc, PhD in Applied Sciences	51

Source: Economic Survey, 2002-3; AICTE

The IIT system: Quality in engineering education

Following Inkeles' Law that says that it is easier to set up a new institution than reform an existing one, Nehru set up the Indian Institutes of Technology as five (now seven, with the foundation of IIT Gauhati and the conversion of REC Roorkee into an IIT) world-class institutes for engineering education in the fifties. In their fifty years, the IITs have established themselves as an oasis of consistent quality. Demand for admissions to the undergraduate curriculum has only increased – around 3000 students are admitted from 150,000 students who take the entrance examination. The IIT system has long been heavily subsidised, though fees have been increased over the last ten years. In earlier years, an IIT Bachelor's degree was seen as a ticket of admission to graduate work in the best technical institutes world-wide. Many of these students never returned to India, and several IIT graduates spoke of having more class-mates in Silicon Valley than in Bombay. The one non-anecdotal study of IIT graduate location, done by Suhas Sukhatme, the previous Director

par with engineers in the IT job market.

¹⁶ Excludes MSc and PhD in Natural Sciences. The data comes under the UGC and is not readily available.

of IIT Bombay, found that the emigration rate was around 25%. It is higher for undergraduates¹⁷ and lower for graduates.

One could argue that the IIT system, with its one-in-fifty admissions proportion might operate as an expensive selection device, but every qualitative indicator says that the education students receive is on a par with the best undergraduate engineering education anywhere in the world. I would advance two qualitative facts to support this: The international job-market has long recognised the merit of an IIT education. McKinsey says it has more IIT graduates in its world-wide work-force than those of any other institution world-wide – including Stanford, MIT, and Harvard.¹⁸ Second, IIT graduates have great institutional loyalty – they are grateful for the education received as the graduates of even the better engineering colleges around the country would just not be. Recent years have seen a conscious attempt by the IITs to tap into their network of graduates for institutional development. To take the example of IIT Bombay, annual donations in the last five years have run at about Rs 200 million a year, about 20% of its annual budget. Donations have mainly been used to fund new buildings: a building for the new school of information technology (funded by Kanwal Rekhi), a new business school building (Shailesh Mehta), a thoroughly revamped Industrial Design Centre, a new dormitory complex adding a third more student housing at a stroke (Nandan Nilekani). The major source of donations have been IIT graduates resident in the US: Kanwal Rekhi, Shailesh Mehta, and Raj Mushroowala are all Silicon Valley entrepreneurs. This donating back to the system is very much a new phenomenon for Indian education in general, and provides opportunities for the IIT system to build new strengths in the years ahead. I would make the rash assessment (which I am sure will be hotly contested), that today the IITs face *no* significant financial resource constraint on anything they want to do. However, the governing ministry for the IITs, MHRD, has demonstrated a breath-taking capability of stopping a good thing in its tracks. MHRD decreed in April 2003 that all donations to the IITs must be channeled through a new general purpose foundation set up by the government in 2002 to fund education, the Bharat Shiksha Kosh. This is a very dangerous development that will dry up the donation stream if it is taken seriously, and needs to be fought.

Developing Graduate Education and Research in the IIT System

The strength of the IIT system has been fully-focussed on the undergraduate programme. All the IITs have run graduate programmes too (indeed, they have more graduate than undergraduate students), but their world-wide reputation rests

Some may find it odd to include MBA programmes as technical education. I include them here as the AICTE does too. Besides, the average MBA can at least add.

¹⁷ Professor Sukhatme estimates that the emigration rate for undergraduates has risen somewhat in the 90s to around 40%.

¹⁸ Personal communication from Rajat Gupta, Managing Partner of McKinsey. Rajat Gupta is himself an IIT Delhi graduate. McKinsey primarily recruits graduates from the world's leading business schools, and their IIT recruits primarily refers to the student's undergraduate degree.

very much on their undergraduate programme. In recent years, the IITs main focus is to develop graduate education and research. To take the IIT Bombay as an example, the target is to increase faculty strength by a quarter so as to create capacity for faculty to do research. The proportion of graduate students is expected to go from under half in 1990, to over 60% in 2003, to over 70% by 2010. The number of PhD students in particular are targeted to double between 2003 and 2010.¹⁹

Other Graduate Technical Education programmes

India was one of the few industrialising countries to produce its own graduates with Masters and Doctorate degrees in engineering and science from the fifties. The NSF reported that by 1990, India produced 4850 PhDs in Science and Engineering, about the same as the sum total produced by China, Japan, Singapore, Korea and Taiwan all put together.²⁰ But graduate education has stagnated since the 1990s, and in 2000 India produced 11,100 PhDs, 5300 of which were in the sciences and engineering.²¹ Contrast this growth of just 10% in graduate technical education in the ten years from 1990 to 2000, with the undergraduate system more than doubling and then more than doubling again in the same ten years, and continuing to grow at over 20% per year.

Many of these PhDs come out of research centres – the National Chemical Laboratory in Pune, the Inter-University Centres for Astronomy and Astrophysics in Pune, and Nuclear Science in Delhi, the Bhabha Atomic Research Centre in Bombay, the TIFR are examples. Some departments such as the University Department of Chemistry (UDCT) in Bombay, and Physics in Poona, have acquired world-class reputations and function as independent centres, with autonomy from their own university operating requirements.

I will return to the issue of graduate education and research later in the paper.

Improving the quality of Higher Technical Education

As we saw earlier, states like Maharashtra, Karnataka, Andhra Pradesh, and Tamil Nadu have seen their number of engineering colleges and student enrollments expand ten and twenty-fold in as many years. The growth continues at an estimated 20% a year. The latest AICTE newsletter reports that 245 proposals for starting new technical institutions for undergraduate engineering programmes were received for the current year, 2003 – 4. The growth is taking place in the same four states, with Madhya Pradesh and Rajasthan now joining in, as Table 5 shows. The growth in MBA

¹⁹ Numbers from IIT Bombay, personal communication. The number of PhDs are projected to increase from 992 in 2003 (21% of the student body) to 1967 in 2010 (31% of the student body).

²⁰ NSF (1993)

²¹ UGC (2002)

programmes is even more dramatic, with proposals for 587 new MBA institutes in just one year, on a base of 930 institutions, or growth of 60%!

Table 5: Growth in Engineering colleges

Under Graduate Engineering Programmes for the Year 2003-2004			
State/Union Territory	No. of Engineering Institutions as of 2002	No. of New Engineering Institutions Proposed for 2003-4	% Growth in one year
Tamil Nadu	250	14	6
Andhra Pradesh	215	88	41
Maharashtra	151	15	10
Karnataka	111	7	6
Uttar Pradesh	83	15	18
Others	77	30	39
Kerala	73	7	10
Madhya Pradesh	45	21	47
West Bengal	45	7	16
Gujarat	25	4	16
Orissa	38	7	18
Haryana	33	8	24
Punjab	33	10	30
Rajasthan	29	19	66
Bihar	7	1	14
Total	1215	253	21

Source: AICTE

These private engineering colleges vary hugely in quality: one cannot expand a college system ten and twenty fold in twenty years, and expect otherwise. Some private colleges are good, and compete effectively with their state counter-parts (which have also seen some fall in standards, as private colleges have recruited faculty from them). But most suffer from poor facilities and large staff vacancies. The Vice-Chancellor of Poona University estimates a 20% vacancy rate of engineering faculty for the system as a whole and that if one goes by the AICTE standards for qualified faculty, the vacancy rate would be above 60%.²² In other words, a majority of engineering faculty do not meet the official standard.

This quality problem is well recognised, and the response was to set up a National Board of Accreditation. Accreditation was initially voluntary, and very few institutions got themselves accredited: just eight in the first year, and

²² Interview with Ashok Kolaskar, Vice-Chancellor of the University of Poona, 14th May, 2003.

137 cumulatively as of March 2003, of which 102 are engineering colleges (so just 9% of engineering colleges have at least one of their programmes accredited). In November 2002, AICTE issued a notification saying that further increases in intake capacity are linked to accreditation, a very sound move. This has led to sudden growth in proposals for accreditation, and AICTE aims to have all institutions accredited by 2006. Anecdotal reports say the accreditation process is handled with objectivity and a high regard for maintaining standards, with each programme of each institute graded on a 1000-point scale. Every institution accredited has its “grade” published in a bi-annual directory. Programmes were graded A (> 750), B (650 to 750) or C (550 – 650), or Not Accredited (< 550). From 2003, probably in response to protests from B-grade institutions, programmes are simply being Accredited (> 650) or not (< 650). However, if the institution scores over 750 it gets accredited for five years, if between 650 and 750 then for three years, so it does not require much math to get back to A and B!

One of the key incentives for acquiring a reputation for quality that accreditation provides is the ability to attract foreign students (upto 15 percent are permitted) who pay about five times the annual tuition of an Indian student. The economics is roughly as follows: each engineering student costs around Rs 40,000 a year at a good private engineering college. They pay fees that are just about that – once you add in a few extras.²³ A foreign student pays Rs 200,000 a year (\$ 4000), and few institutes have been able to come anywhere near the 15% limit.

The Vice Chancellor of Poona University, Ashok Kolaskar, believes that while many private engineering colleges still suffer from large faculty vacancies, they have significantly improved their facilities in the last three years. Certainly, a drive around any city in Maharashtra, Andhra, Tamil Nadu or Karnataka provides ample evidence of college-building projects! The faculty vacancy is still chronic, though, and is only getting worse as growth in the number of institutions continues. A qualified faculty member is required to take three exams, two set by the state in which around 50 – 60% pass, and the third conducted by the centre using a national syllabus in which the current pass rate is 1.7%. As such, Dr Kolaskar estimates that 50,000 faculty have qualified in the last ten years when the annual demand is 50,000! The problem in certain fields is particularly chronic: in Computer Science, where the demand is the

²³ In October 2002, the Supreme Court ruled that private colleges could set their own fees provided they did not indulge in “profiteering”. The result has been that private engineering colleges across the four states where they are concentrated attempted to raise fees dramatically. The resulting public outcry, reported daily in the national press, against what was often a four-fold increase in fees has led to state governments attempting to set limits on what can be charged. The dust has still to settle, especially since many private colleges are run by trusts promoted by politicians who are themselves involved in establishing the rules for private colleges. The most likely outcome is that private colleges will be able to charge higher fees for what are called management seats (students who meet lower entrance criteria) while about half are reserved for “merit” seats. The change will make transparent what was earlier the case with parents until last year forced to pay as much as \$10,000 to 20,000 in cash without a receipt to get their child into a management seat in a desirable field in a good private college.

greatest, just one or two faculty pass each year – nationally! There is huge pressure on the UGC and Vice Chancellors to compromise on the pass criteria, and the system has demonstrated a remarkable ability to maintain standards.

The key priority for the great bulk of Indian Higher Technical Education, then, is faculty quality. Salaries for teaching at different levels are set by the state, and are not merit based. Private colleges so far as I can make out are free to pay more, but don't. Perhaps this is where industry can help – with topping up of teacher salaries on a merit basis. As institutes also (tentatively) start graduate programmes, the demand for more qualified faculty will only grow.

II. Scientific Research

Background on Scientific Research and Industrial Innovation²⁴

For many analysts, the normal mental construct of the relationship between scientific research and industrial innovation is simple: scientific research leads to discoveries that permit the development of new technology, and this new technology finds itself into production and the market. This mental model, referred to in the literature as the linear model of innovation²⁵, was conceptualised for many years as the primary way innovation happens. But over the last forty-five years, the work of Kenneth Arrow, Paul David, Steve Kline, Richard Nelson, Keith Pavitt, Nathan Rosenberg, and Derek de Solla Price has greatly enriched our understanding of the true role that scientific research plays in industrial innovation. I will provide only comments as background for a discussion of scientific research in India, and the reforms I suggest at the end of this paper.

It is almost forty years since da Solla Price showed that new scientific discoveries appear in industrial innovation with a typical lag of some 25 years. As such, an understanding of old scientific findings is adequate for most industrial innovation. This understanding of old research will usually be fully captured in course teaching, which leads one to the conclusion that science education matters much more to most industrial innovation than new scientific research.

Indeed, far from being the dominant source of industrial innovation, new scientific research matters to industrial innovation in just two exceptional cases. First, advance in certain fields, like biotechnology and semiconductors, has close connection with scientific research. Second, there is a broader role for scientific research as one of 'technology's wellsprings' - to reinvigorate technical progress in a particular field²⁶. This "reinvigoration" typically takes the form of

²⁴ This section draws on Forbes (2001)

²⁵ See, in particular, the late Steve Kline's many insightful attacks on the linear model (Kline ___)

²⁶ *ibid*

a new technological paradigm for industry – the compact disc taking over from cassette tape, or the jet engine from the propellor. As Nelson puts it:

“There is persuasive evidence that in many industries technological advance is what Winter and I have called cumulative, in the sense that today’s new technology not only provides enhanced operational capabilities but serves as a starting point for tomorrow’s efforts to further advance technology. Science may be involved as well, but in most industries science seems to be tapped as a body of general knowledge relevant to problem solving, with ‘new’ findings not playing a special role. Where new science is not particularly important, a steady flow of newly minted scientists and engineers suffices to keep the laboratory adequately up to date with the world of public science”³

The Mirage of Relevance in Public Research

The case for public subsidy for research

Forty years ago, seminal papers by Kenneth Arrow²⁷ and Richard Nelson²⁸ argued that society would under-invest in research because the benefits would not be *apparent* enough or *appropriable* enough to the investor. Their arguments were made at the mid-point of a secular increase in public sector funded research, from the 40s to the late 70s. The 80s and 90s have seen much debate world-wide on the proper role of the state in research. General funding of research in the US and UK has been under pressure²⁹, while attempts have been made everywhere to “make research more relevant”. A British scientist even wrote a notorious book, *The Economic Laws of Scientific Research*, which argued that state funding had actively harmed British research, and that the proper role of the state in research was, essentially, nil.³⁰ After a 30 page review of this “thoroughly bad book”, Paul David (1998) ends by saying that the Arrow/Nelson case for public subsidy of research is still to be answered. Keith Pavitt too says that “Distinctions between ‘blue-sky (i.e. probably useless) and ‘strategic’ (i.e. potentially useful) research should be made with great caution and treated with great scepticism.”³¹

Nathan Rosenberg has argued that technical change is inherently uncertain. As such attempts to select research on the basis of relevance are misplaced. Instead, “Government policy ought to be to open many windows and to provide the

³ Nelson, 1992, p. 175.

²⁷ Arrow (1962)

²⁸ Nelson (1959)

²⁹ In my first draft of this paper, I said “decreased” instead of “been under pressure”. Thinking about it some more, though, I would say that general funding is still the basis for most research funding in the US and Europe; there would appear to have been more talk about relevance than actual change in the funding basis.

³⁰ Kealey, (1996)

³¹ Pavitt (1998), p 803.

private sector with financial incentives to explore the technological landscape that can only be faintly discerned from those windows.” So it makes sense to “manage a deliberately diversified research portfolio”.³²

It would be too much to argue that a consensus has emerged on the appropriate role of public research, but Nelson, Rosenberg and David’s work would allow one to conclude that there is still a strong argument for the state subsidising public scientific research.³³ This investment should be as broadly targeted across alternatives as possible. Indeed, attempts to “make science relevant” and choose between specific projects could have a negative impact on welfare. The fact that the results of research are both uncertain and imperfectly appropriable continues to justify state funding.

But what about Newly-industrialising countries like India?

So research is critical to technical advance in science-based industries and to the innovation of new technological paradigms. The results of research can be appropriated by other firms and indeed by other countries. One can argue, therefore, that social welfare can only be maximised by state funding of scientific research, as the free-rider problem³⁴ would otherwise limit investment both by individual firms and by countries. There is thus a case not only for the state *broadly* subsidising scientific research, but that *all* states should do so to maximise human welfare. It is here, though, that we must draw a distinction for newly-industrialising countries such as India. Neither of the two areas where research will be critical to technical advance - science-based industries and new technological paradigms – will be the province of a country like India. As such, the role of scientific research in innovation will be even more limited. Far from seeing free-riding on scientific advance by other countries as a *problem*, a newly-industrialising country should see it as an *objective*.³⁵ Only when particular industries – such as semiconductors in Korea and Taiwan or cars in Korea – approach the technological frontier is there a case for scientific research itself, and hence for publicly subsidising it. Scientific research should be seen, then, as the follower, not the leader, of industrial activity. Keith Pavitt made just this point:

“...national technological activities are significant determinants of national economic performance as measured by productivity and economic growth. But what about the causal links between developments in national science and in national technology? Do they run from a national science base that creates the ideas and discoveries that the national technology system can exploit? Or do they run from the national technology system that creates both demands on – and resources for – the national science system? Our reading of the

³² Rosenberg, (1996) p. 352.

³³ I should add that while my argument essentially derives from those of Nelson, Rosenberg and David, they would themselves I suspect be loathe to draw as clear a policy prescription!

³⁴ The free-rider problem is that since one can benefit from someone else’s research, everyone waits for someone else to do the research. The Learning benefits from research, however, mitigate the free-rider problem. See Forbes and Wield (1999), Rosenberg (1990) and Cohen and Leventhal, 1989 and 1990 for discussion of this Learning benefit.

³⁵ There is free and there is free: published knowledge is “free” in that one does not need to pay anyone for it. But it is not “free” in that one will need to have first invested in a lot of ones own research to be able to access it. See the paragraph on Research as a Ticket of Admission in the next section.

(imperfect) evidence ... is that the causal links run from the national technology system to the national science system.”³⁶

This discussion raises fundamental questions about the utility of scientific research in national development.³⁷

What public R&D in NICs?

Given this understanding of scientific research in industrial innovation, what public scientific research should then be done?

First, there are areas where new knowledge is a much higher priority for a particular industrialising country than for the developed world. In these cases, research clearly should be done. Research on a seed suitable for local soil, or developing an algae-resistant paint for the tropics, or making cheese from buffalo milk are all examples where research that has greatly benefited industrialising countries would not otherwise have been done. The World Health Organisation has been increasingly critical of the tiny proportion of R&D spending that pharmaceutical MNCs spend on tropical disease; this is a vacuum public research in a country like India could fill.

Second, there may well be certain specific *sectors* or sub-sectors where newly-industrialising countries may be technology-leaders. In such cases, the same argument applies that justifies scientific research in richer countries. Examples would include the armour-plate industry in Brazil and the sponge-iron direct oxidation alternative to blast furnace smelting in Mexico. In both cases, local firms are world leaders and local research closely interacting with operational firms would be aimed at pushing forward knowledge frontiers. The local firms would be well-placed to

³⁶ Pavitt (1998), p 800.

³⁷ In a recent issue of *Research Policy*, Bernardes and Albuquerque argue that seeing science as follower is just as bad as seeing it as leader (as the old linear model argued).³⁷ They compare scientific papers (as a science-output indicator) and patents (as a technology output indicator) and make the argument that both have risen together in South Korea and Taiwan, while in Brazil papers have risen while patents have not. They then compare papers, patents and GNP per capita for 120 countries and tentatively conclude that scientific and technological production are correlated to income levels. Second, they say there seems to be a “threshold level in the scientific production (for 1998, in the neighbourhood of 150 scientific papers per million inhabitants), beyond which the efficiency of the use of scientific output by the technological sector increases.” Third, this threshold keeps increasing with time. Three quick responses: first, of course, showing that papers, patents and GNP per capita are correlated is to say that rich countries do more science *and* more technology than poor ones. The key comparison should be with GNP *growth*, not per capita GNP at the end of the scale, and one could adopt a longer time comparison – going back say fifty years, not thirty. Second, there would seem to be huge exceptions, including the same countries the authors use: South Korea and Taiwan indeed increased investments in science and technology post the mid seventies. But they experienced their most rapid economic progress in the 60s and 70s, before these investments were made. The same for China in the 80s and 90s: the world’s fastest growing economy over twenty years is not noted for either paper production except the stuff that comes from forests or patents. Third, indicating that science output is used more efficiently beyond a certain threshold per capita, may actually be saying that the more advanced and dynamic the technology system, the more it will draw on and need to draw on the science system. In other words, it is not that science and technology do go together, but that technology should come first, and science should follow technology and industrial development.

appropriate the benefits of the new knowledge, thus justifying the research.³⁸ In pharmaceuticals, Indian firms have emerged as leaders in the generic market and are also now multiplying in-house R&D investments, including for molecule discovery.³⁹ The idea, though, is that establishing the research programme would *follow* the emergence of industrial leadership, not attempt to precede it.

Third, there have periodically been highly-focussed efforts to build technological leadership in particular fields through a national research effort. The Japanese, Korean and Taiwanese experiences in semi-conductors are oft-quoted examples. In 2001, the Council of Scientific and Industrial Research in India following a nation-wide search which generated a thousand ideas launched nine “strategic technology projects” involving fifty-five research institutions and twenty-three industrial partners.⁴⁰ We should track these with interest, though the ability of the state to pick winners has not been suspect since Harold Wilson’s “white heat of the technological revolution” mainly generated a lot of cold red ink.

Fourth, Research would also be justified in areas where appropriability would be a major problem, or where the benefits of the new knowledge are required for wide diffusion. Examples would include the provision of potable water in remote villages or long-term reversible birth control devices. One of the few Indian government research institutes that is long regarded as having done work useful to Indian industry is the Central Leather Research Institute in Chennai that has researched curing methods for animal hides. The benefits have flowed to hundreds of small leather firms that have made leather a major export. No one firm of the small leather firms in the area would have had the incentive or resources to invest in such research.

Fifth, there is a clear distinction between the generation of new knowledge and its diffusion, or the use of that new knowledge. As such, a fundamental argument against doing scientific research is the whole issue of the appropriability of the findings. First of all, the product of such research is relatively often published knowledge.⁴¹ So one can appropriate private benefits from the new knowledge without the need to own it, and hence there is no need to do it. But *published* knowledge is not the same as *public* knowledge, in terms of equal public appropriability of the benefits of that knowledge. To appropriate benefits from a new discovery done anywhere requires a high degree of sophistication (and operation) to start with. (This explains why a current discovery at the National Chemical Laboratory

³⁸As a corollary, research in technology-leader countries would not really be justified where one has little chance of appropriating the benefits of the new knowledge. An example might be the UK doing research in mainstream DRAMs, where a local DRAM industry does not exist.

³⁹ See Forbes and Wield (2002), Chapter 6, for much more detail.

⁴⁰ DSIR, Annual Report 2001 – 2.

⁴¹Although the difference is decreasing, new scientific knowledge is still rewarded by “publish first”, while new technological knowledge, generally proprietary to firms, has to “leak out” over the years through the movement of people and social interaction. See Nelson’s various writings on the issue. Especially 1987.

in Pune, may well be more useful to firms in North America than to those 100 miles away in Bombay). Understanding a new scientific discovery, in other words, requires a mastery of old science. To have this mastery of old science one will often need to do research as a “ticket of admission” to understanding the new discovery.⁴²

Where should public research be done in NICs? University research as end in itself

Research in universities, indeed research universities, are an essential supplement to basic numeracy and wider higher education in technology-follower countries. They are an essential supplement, not so much because of the research they do, or would do, but because top-class graduate education (and it is good education, not research, that is the objective here) requires co-habitation of research and teaching. As we saw in the earlier discussion on higher education, leading technical educational institutions such as the Indian Institutes of Technology provide at least as fine an undergraduate *engineering*⁴³ education as Stanford or MIT or Caltech. The difference at the graduate level would seem to be driven by a difference in doing much less research.

An additional benefit of doing research in universities is that one can attract better teachers that way. Indeed, in some Brazilian universities there appeared to have been no attempt whatsoever to direct research. The approach seemed to have been one of getting the good teacher - what he or she researches is quite secondary.⁴⁴

Even more powerfully, the research-teaching combination is not a one-way benefit for teaching; research benefits too. The unique benefits of the research and teaching combination is not a new idea; it was precisely the objective of Wilhelm von Humboldt for the University of Berlin in the early 19th century, which became the model for that great success story, the American Research University. Stanford University’s Presidents have been among the most articulate advocates of this argument:

Donald Kennedy speaks of an apprentice-journeyman benefit.

“Most of the basic science in America today is done by mixed groups of journeymen and apprentices; the result is that the nation’s research trainees are being developed alongside the best scientists. That is the singular feature of our pattern of government support for basic science in the universities; to it, our most thoughtful European colleagues usually attribute our special success....”⁴⁵

Gerhard Casper has been even more eloquent. Speaking, instructively, in Beijing:

⁴²See Rosenberg (1990) for the same argument applied to firms. This is probably also a good place to acknowledge my debt to his many clear explanations on manifold technological issues.

⁴³ I emphasise *engineering* education, because American universities provide a much more liberal education – the technical content of an undergraduate course is almost surely substantially exceeded by technical institutions in other countries which have a much narrower ambit.

⁴⁴I owe this insight to a discussion many years ago with Aldo da Rosa, Professor Emeritus of Electrical Engineering at Stanford.

“... in countries in which research and teaching are fundamentally or even partially separated, much creative force lies fallow....My point is not what goes without saying – university teaching should be based on university research – but that university research benefits from teaching, not just from teaching graduate students but also from teaching first-year students.”

Indeed, this research-teaching combination results in an automatic close linkage between research and industry:

“The most successful method of knowledge and technology transfer on the part of the universities lies in educating first-rate students who themselves have been engaged in the search to know – men and women who will then be in a position to take on leadership roles in industry and business. Students who receive their training in university-based research arguably have a greater influence on the economy than the patentable inventions of university scientists.” (p 3)

“Outstandingly educated students are still the most meaningful contribution that university-level research has to make to technology-transfer....” (p 4)

“...technology transfer is a ‘bodily contact sport’” (p 5)

Note also that it is not sufficient that research be done at the university, but with researchers and teachers being separate individuals. Researchers must teach: “the link [between teaching and research] is also nullified when teaching at the university is primarily carried out by those who have no direct relationship to research”(p 3)⁴⁶.

Indeed, Pavitt calls trained researchers “perhaps the most important” social benefit of basic research, and he further argues that it is this output of basic research that is most capturable by home-countries: “Such person-embodied knowledge is nowhere near as footloose as information: numerous empirical studies have shown that the links between basic research and application are inversely related to distance and directly related to common nationality...As a consequence, many of the benefits of nationally funded basic research stay at home”.⁴⁷ But, I should add, only if you do research in universities and your researchers stay at home too.

Finally, recall Nelson’s argument earlier that for industries “a steady flow of newly minted scientists and engineers suffices to keep the [firm R&D] laboratory adequately up to date with the world of public science”(Nelson, 1992, p. 175). Since fresh graduates are the primary – and adequate – source of new scientific knowledge, it helps if this knowledge reflects the current state of the art of science. By doing Scientific Research in Universities, it will tend to be.

⁴⁵ Kennedy (1986)

⁴⁶ “The Advantage of the Research-Intensive University”, speech given in Beijing at the Peking University Centennial, May 3, 1998.

⁴⁷ Keith Pavitt (2001), “Public policies to support basic research: what can the rest of the world learn from US theory and practice? (and what they should not learn)”, *Industrial and Corporate Change*, September.

III. Scientific Research in India

In no other industrialising country was research accorded such high-level importance, and absorb so large a share of resources as early on. National Laboratories were established in key areas before independence, and the first non-Western Nobel prize in Science went to an Indian, C V Raman, in the thirties. India established the Council of Scientific and Industrial Research in 1943, modeled on the British DSIR (subsequently disbanded in Britain, but continuing in India as in several other Commonwealth countries such as South Africa). By the late 80s, India was spending just under 1% of GNP on R&D, relatively high for a poor country at India's per capita GNP level – as Table 6 shows, it was significantly higher than the share in Brazil, Mexico, or Thailand. Among NICs, only Korea had reached a significantly higher share of R&D in GNP.

Table 6: R&D spending in India and other NICs

Country	Year	R&D % GNP	R&D as % GNP in 2000
South Korea	1986	1.8	2.7
Taiwan	1986	0.9	2.01
Singapore	1984	0.5	1.9
Thailand	1985	0.3	0.3
India	1984	0.9	0.9
Brazil	1982	0.7	0.9
Mexico	1984	0.6	0.4

Source: Lall (1990) and IMD (2002). Indian data for 2000 from DST (2002)

1. Nehru and the political origins of the Scientific Research system

India was an early investor in public scientific research for three reasons: first, most policy saw the innovation process as the linear model of Scientific discovery followed by Technological innovation. Here is Nehru, my favourite source of quotations, on Scientific Research:

“I am convinced that of all the big problems that face India today nothing is more important than the development of scientific research, both pure and applied, and scientific method. This is indeed the basis and foundation of all other work. ... The extensive use of that method can only come through a properly directed education and a large number of research institutions which deal with pure science as well as the innumerable applications of it” (Nehru, Selected Works, Vol. 14, p. 558).

In other words to make the desired objective of technological progress happen, it is necessary to have a scientific base for it. Otherwise local technological progress will be permanently dependent on imported science.

Second, going with this linear view, many post-WWII Indian leaders and in particular Nehru himself, were influenced by the public benefits of organised Scientific Research demonstrated in the War. The potential of Science was

most pronounced in an 'invisible college' of British scientists, whose views influenced policy-makers in India in the 40s and 50s.⁴⁸

Third, Research is prestigious. Take the statement by an ex-Director of the Council of Scientific and Industrial Research (CSIR) that "no country which aspires to take its rightful and honored place in the comity of nations can afford to neglect its scientific and technical resources. A policy of self-reliance is the only one which a self-respecting country with a tradition, history and culture should have" (Nayar, 1983, p. 494). In other words a *self-respecting* country needs scientific and technological activity as an end in itself. Or discussing India, as Ron Dore says, "creating new technology is of course more exciting than scouting it out, copying it, learning it from elsewhere. And even if you do not feel confident about actually being able to create it, it is much better for your prestige if people *think* that is what you are doing"⁴⁹

These three drivers all added up to "Do Scientific Research", and that is exactly what India did. Nehru chose also to do the research in newly-founded autonomous public R&D institutes instead of the University system (Inkeles' Law at play again!). There has been widespread dissatisfaction with the contribution that these autonomous research labs have made to industry, and we will return to this point in the next section.

2. An Overview of Scientific Research in India today

In the 90s, R&D spending as a share of GNP dropped from 0.9% in 1987 to 0.7% in 1996, rising back slightly to just above 0.8% in 2000.⁵⁰ The state has long dominated R&D spending, and what is striking about Indian R&D spending after 12 years of Indian economic reform is how little has changed at the macro level:

⁴⁸Jawaharlal Nehru's views on the importance of Science, and indeed on Socialism, are certainly consistent with those of the invisible college. This view at its most rudimentary holds that what matters in a society is the proper organisation of Science. Once Science is produced it will automatically result in technological and social progress. Indeed Science needs to be properly organised and controlled for a true Socialist society to emerge. (The Invisible College is the name given to the social relations of science movement that developed in inter-war Britain. Their views were best articulated in J.D. Bernal's Social Function of Science. Many leading scientists - J.D.Bernal, Joseph Needham, P.M.S. Blackett, J.B.S. Haldane, Lancelot Hogben and Hyman Levy were subscribers to this school. See the Invisible College by Gary Werskey. Several of these scientists visited India at Nehru's invitation and one played a key role in establishing the CSIR).

⁴⁹ Dore, (1984).

⁵⁰Before one reads too much into these downs and ups, it would be more correct to see R&D spending rising at much the same rate, with the percent of GNP changing based on ups and downs in the GNP growth rate. So as Indian GNP growth improved from 1991 to 1996 (with three-years of a tiger-like 7% from 1994 to 1996), R&D as a share of GNP fell back from 0.9 to 0.7%. As GNP growth slackened off towards the New Hindu (RSS) Rate of Growth from 1997, it rose back to 0.8% by 2000 (and I would estimate it to be at 0.9% as of 2002).

The official source is the Department of Science and Technology's "R&D Statistics" and "R&D in Industry". These used to be annual publications, which appeared within a year, but reform seems to have hit them the wrong way. As of early May 2003, the most recent R&D Statistics is for 2000 – 1, published in 2002 and using only occasional "projected estimate" figures for the years ending March 2000 and 2001. As such, the

Table 7: R&D Spending in India (Rs. Million)				
	1990-91	%	2000-2001	%
Central Sector	30,583	77	118,358	67
State Sector	3,659	9	13,506	8
Private Sector	5,500	14	40,588	23
Higher Education Sector			4,151	3
TOTAL	39,742	100	176,602	100
Source: DST (2002), Table 1.				

The only significant change has been a decline in public-sector industrial R&D (included in central sector spending) as a % of the national total, from 10.5% in 1990 to 5% in 1998-9. Total industrial R&D has also risen somewhat from about 25% in 1991 to just over 30% (my estimate) by 2002.

In the US and most OECD countries, one needs to distinguish between funding and doing R&D: publicly funded R&D in the US is largely done in private industry, public and private research universities, the National Institutes of Health, and only last in public R&D institutes. Even including defence R&D in the picture does not change it - showing the dominance of the practice of the state funding, but not doing, R&D. In India, there is little difference between who funds and who does research. The lines between public and private R&D are sharp: Publicly-funded R&D is done in public R&D institutes. Privately funded R&D is done in private industry.

As we saw above, the Central Government dominates R&D spending, with its 67% share in 2000-1. This spending takes place mainly in the autonomous R&D laboratories that come under different agencies. The central government currently operates well over 200 major R&D labs in Defence, Space, Atomic Energy, Industrial Research, Agriculture and Medicine (each agency, such as Defence Research and Development Organisation or Council of Scientific and Industrial Research consists of several independent laboratories focussing on different subjects). As Table 8 shows, Defence, Space, and Atomic Energy accounts for over half of central government R&D spending. The next biggest are the Indian Council of Agricultural Research and CSIR.

official numbers are now four years out of date. R&D in Industry has suffered an even worse fate: the most recent year is for 1996-7. The data published on the official National Science and Technology Management Information System website (www.nstmis-dst.org) is even worse: they still show 1998-9 data as the most recent even though the site was last updated in February 2003.

Table 8: Expenditure on Research & Development by major scientific agencies under the Central Government			
Agency	Spending in 1998-9 in Rupees Million	As % of total central government spending	As % of national R&D spending
Defence Research & Development Organisation	23002	26	18
Department of Space	15156	17	12
Indian Council of Agricultural Research	8440	10	7
Department of Atomic Energy	8367	10	6
Council of Scientific and Industrial Research	7133	8	6
Ministry of Environment & Forests	3779	4	3
Department of Science & Technology	2990	3	2
Department of Biotechnology	945	1	1
Department of Ocean Development	848	1	1
Indian Council of Medical Research	863	1	1
Ministry of Information & Tech	621	1	0
Ministry of Non-Conventional Energy Sources	90	0	0
Total for this list of agencies	72234	83	56

Source: Calculated from DST (2002), Table 4.

Assessing the effectiveness of this state investment in research is not easy for me to do. I will attempt only a few ill-informed comments on the non-industrial research and then focus on CSIR, which accounts for the bulk of industrial research in India. Defence, Atomic Energy and Space account for over half of central government funding. India can point to major successes in space technology – locally-built satellites and a rocket-delivery system that is claimed to cost a fraction of the US and EU equivalents. In Atomic Energy, well, India is now estimated to have about 100 nuclear war-heads, all capable of hitting Pakistan. The effectiveness of India’s nuclear umbrella (I prefer the term “lightning rod”) will hopefully never be tested, especially since one can still hear serious comments about India’s 100 war-heads eclipsing Pakistan’s 20 – 30 (India’s 30th largest city takes one fairly far down the list, well past #8, Pune, the city where I live!). Apart from nuclear weapons, India has an ambitious atomic energy programme, with 2700 MW of installed capacity as of 2003 with another 4000 MW under construction to go on stream by 2007. In Defence R&D, there would seem to have been some successes at the low profile end – ammunition, enhancement of older imported weapons technology – and some high profile failures. The two highest profile defence projects have been the Light Combat Aircraft and the Main Battle Tank (I seem to remember writing about these for a course on the economics of technology with Nate Rosenberg in the mid-80s, so the projects might date back twenty years!). The LCA finally flew for the first time a year ago; I believe the MBT is still some way from completion. India still relies overwhelmingly on

imported weaponry for anything halfway sophisticated. This is no different to all but a handful of countries world-wide, but given India's long-standing objective of self-reliance it raises questions about the utility of the research effort. In Agricultural Research, there have been major successes – in many crops, and targeted at many areas. India is today a major exporter of agricultural products, and the contrast with the PL480 era of the 60s is a story of the green revolution written by agricultural research.

Since this paper is not about Scientific Research per se, but Scientific Research and Industry, let me focus on industrial research.

3. What is industrial R&D?

Policy-makers, academics and business see R&D as a well-defined term. The Prime Minister exhorts India to 'treble the percent of GNP spent on R&D to 2 percent'. An academic studying responses to liberalisation by firms notes the 'absence of a strong R&D base'. A businessman in the US seeks to 'redirect R&D activities to research directly relevant to the firm's strategy'. All think they are talking about the *same* thing, indeed the same *well-defined* thing. This is not so. It is the content of R&D which matters, and here understanding is very limited outside of a few technology-leading firms. I will draw on work done on R&D in different Indian firms which has provided insight into what is actually happening when a firm or institution is said to be doing R&D.

R&D is hugely concentrated world-wide. Most R&D is done in a handful of countries: of a total of \$526 B spent on global R&D in 1998, the top five countries accounted for 87 percent, with Industrial R&D at about two-thirds of the total. Within industry, it is highly concentrated in a few industries: the top five industries – IT hardware, automobiles, pharmaceuticals, electronics and chemicals – account for 77 percent of the total. And within those industries, it is highly concentrated in a few companies: the top twenty companies account for 20 percent of global industrial R&D, the top 300 companies for 60 percent.⁵¹

I have so far used "R&D" as a single term, indeed a single term almost interchangeable with "research". It actually covers a range of activities ranging from minor product changes or process improvements through major product development projects in industry to basic research with no specific application in mind. Conventionally, R&D is classified into Basic Research, Applied Research, and Development. As Nathan Rosenberg has pointed out, this classification, while useful as an analytical tool, is not particularly robust and clean-cut: fundamental additions to human knowledge often result from very practical investigations, while the most basic research undertaken with no practical

⁵¹ See Forbes and Weild (2002), pp 124 - 9, for more detail and listings of countries and firms.

purpose has often resulted in highly utilitarian results. In developed countries, Research accounts for around one-half of total public R&D while two-thirds of industrial R&D expenditure is Development. Most Basic Research is publicly funded and done at universities in OECD countries (in the US, for example, universities account for 60% of national Basic Research). Taken as a whole, though, R&D is largely D, with Development in the US, for example, accounting for 61% of national R&D in 1998 (NSF, 2000).⁵² If R&D is overwhelmingly D in technology leading countries, then it should certainly be so in a technology follower like India. The figures however indicate otherwise, with India spending over 50% of total national R&D on research.

Industrial R&D as many beasts in India⁵³

The normal mental construct for the role of industrial R&D is the development of products new to the world but R&D is a many-faceted activity. Dave Wield and I explored five distinct roles for R&D in a country like India in our recent book, *From Followers to Leaders*. In an import substitution environment, R&D can mean indigenisation. Indeed, through to 1991 that is almost entirely what industrial R&D meant to Indian firms: if it was imported, do it locally. Indian firms each employed dozens of engineers whose sole purpose was to develop locally manufactured components.

In an environment of catching-up with the developed world, R&D can mean learning from other firms. In Korea in the 70s, this is exactly what it meant, and one can read almost identical descriptions of Indian firms doing in the 90s what Korean firms did in the 70s. To take one example, a description of Tata Engineering's Indica car project of the late 90s is remarkably similar to Hyundai's Pony car project of the mid 70s: teams of R&D engineers sent abroad to work alongside foreign design firms, the same teams returning home and taking apart foreign cars to learn from them, and aggressive bench-marking with comparative products and processes throughout the process.

In labs everywhere R&D means improving existing products. A good Indian example is Hindustan Lever developing a range of sachet-products (shampoo and toothpaste) to suit low unit purchasing power requirements in India. The work done may sound unexciting, but it grew HLL's share of the Indian market for

⁵² As Rosenbloom and Spencer (1996) point out for the US, "Anecdotal evidence suggests that major industrial firms, such as Xerox, IBM, and AT&T, devote less than 20% of their R&D to research." (p. 8)

⁵³ This section draws heavily from Forbes and Wield (2002), Chapter 6. It pays to advertise!

shampoo (India has 28 percent of the world's hair) from 40 to 66 percent, and today 70 percent of their shampoo sales are from sachets.⁵⁴

With the abundance of low-cost highly qualified people that we discussed earlier, R&D can be the core business of the Indian establishment itself. According to one survey, India accounts for two-thirds of all TNC off-shore labs in Asia. Software accounts for half of the total, but that still means that India exceeds the number of TNC R&D labs in Singapore, Hong Kong, China, Taiwan, Malaysia, Indonesia, and Korea put together.⁵⁵

Finally, R&D can mean research aimed at producing new knowledge. The Indian pharmaceutical industry is a great success story. Today, Indian firms dominate an industry where the big multi-national drug firms had a 90 percent share thirty years ago. They have done so through the legal (under the 1970 Indian Patent Act, which recognised only process patents for drugs) copying of new drugs discovered elsewhere. Under India's accession to the Uruguay Round IPR provisions, this route to new products closes in 2005. Several Indian pharmaceutical firms have launched their own drug discovery programmes, and the initial results are very positive. However, the twenty largest-spending Indian pharmaceutical firms *together* still spend one sixth of what the twentieth largest international firm spends on R&D. Still, the spending is growing fast and the costs of drug discovery in India are thought to be one-twentieth of what it is in the US (because of lower cost research people, and *much* lower costs for clinical trials). An increasing share of Indian pharmaceutical R&D is now research.

When we explored these five roles in detail for our book, we aimed to distinguish just what R&D entailed in each role. We did not imply that any of these roles for R&D are trivial: indigenization and learning from other firms is not necessarily an easy process. Neither is "mere" copying. Particularly if the product involved is complex, and involves much tacit knowledge, indigenization and learning to become competitive is hard. As Nelson and Pack put it recently: 'there is nothing automatic about the learning business'⁵⁶. What matters to us in this paper, though, are the demands this in-house R&D places on the public research system. Indigenisation, learning, incremental product improvement, and contract research are all perfectly valid roles for R&D but they have no connection with scientific research. In-house *research* aimed at producing new knowledge then becomes a necessary pre-condition to using the output of the public research system, and for those industries where research is being done, public scientific research could be justified.

⁵⁴ Ibid, p 118.

⁵⁵ Prasad Reddy (2000)

⁵⁶ R. R. Nelson and H. Pack, *ibid*, Chapter 1, 1999

4. CSIR and Industrial R&D

The government industrial R&D lab infrastructure largely comes under CSIR, which advertises itself as “the world’s largest public funded industrial R&D agency”.⁵⁷ CSIR was set up in 1943 as an umbrella organisation for industrial research, modeled on the British DSIR.

"The charter of objectives of CSIR enunciated then and unchanged till today is all-encompassing. This includes promotion, guidance and coordination of scientific and industrial research, collection and dissemination of information on research and industry, founding of laboratories to further scientific and industrial research and exploitation of the research results for development of industry."⁵⁸

Through to 1970, CSIR accounted for more R&D spending than the total of public and private sector firms, but in-house spending within industry has become increasingly dominant as one would expect (Table 9). CSIR consists of over 10,000 scientists working in 40 research laboratories, with an annual budget of Rs. 10,000 million in 2002-3.

Table 9: Share of Industrial R&D spending in India (percentage)

	1960	1970	1980	1990	1996
CSIR	96	53	25	20	16
Public sector firms	0	8	31	36	19
Private sector firms	4	39	44	43	65

A vast cultural change

Several parliamentary committees set up to review CSIR’s functioning concluded that its contribution to Indian industry was negligible. An early response in 1953 was to set up the NRDC, an organisation committed to transferring technology *from* the research laboratories *to* industry. Indeed, CSIR was not permitted to deal directly with industry; it was supposed to get on with its job of producing technology with NRDC responsible for all contact with the industries that would commercialise it. The results were no better, and successive studies continued to show CSIR's almost total lack of contribution to Indian industry.⁵⁹ Excerpts from the 1986 parliamentary committee report provided a gloomy picture of CSIR's contribution:

"The constitution of our Committee was based on the obvious perception that the work of CSIR was out of step with the needs of the nation" (p. i)

⁵⁷ There are a few labs that come under the Ministry of Bio-technology, the Ministry of IT, the Ministry of Electronics and the Ministry of Science and Technology, but their share in the total is small relative to CSIR. What is said about CSIR could be said to apply to all of these more generally.

⁵⁸ Report of the CSIR Review Committee, 1986, p. 19.

⁵⁹ The latest was the fourth parliamentary committee investigation of CSIR, completed in 1986, chaired by Abid Hussain (1986).

"... there has been a disproportionate emphasis in terms of work on known-products and known-processes akin to reinventing the wheel. The work of CSIR, in some areas, can be characterised as solutions looking for problems." (p. ii)
 "... an ambience in which science has perished while a few scientists have flourished." (p. iv)
 "In caricature form, the industrial sector believes that the CSIR laboratories are incapable of useful and timely research, while the CSIR system believes that manufacturing firms, which have no capacity for technology absorption and development, always prefer the soft option of importing proven technologies."
 "... the culture of work in the CSIR ... has two distinct attributes. There is little reward for performance and no penalty for non-performance It is ironic that the culture of the Government has become dominant while the culture of science has become subordinate in the CSIR." (p. 4)

The report (over 90 pages) went on to suggest various changes in the system, many of which have now been put into effect.

The most focussed and serious attempt to improve CSIR is being led by a dynamic Director-General, Ramesh Mashelkar. In Vision 2001, a pamphlet published in 1995, he spelt out the future goals of CSIR. These goals were of exemplary clarity and provide for accountability that is unheard of in the Indian public sector:

Funding: a targeted percentage of funding (20%) must come from private industry

Quality: a targeted number of international patents must be filed annually

Accountability: the targets were quantified and set for 2001, two years before he was due to retire⁶⁰.

To my knowledge, no evaluation of Vision 2001 has been made public, but several indicators point to wide-reaching change. Several laboratories – NCL, IICT, Oceanography – have developed reputations for doing world-class work, and some of the world's leading firms sponsor research projects there. The targets for private funding have been exceeded by specific laboratories and about a quarter (Rs 2450 m) of CSIR's expenditure of 8770 million in 2001 is from external sources (both private and public research sponsorship). In patenting, CSIR has been very successful – with annual international patent filing rising from 71 in 1997 to 452 in 2001, with CSIR as the dominant Indian origin patenter in the US for the last five years.

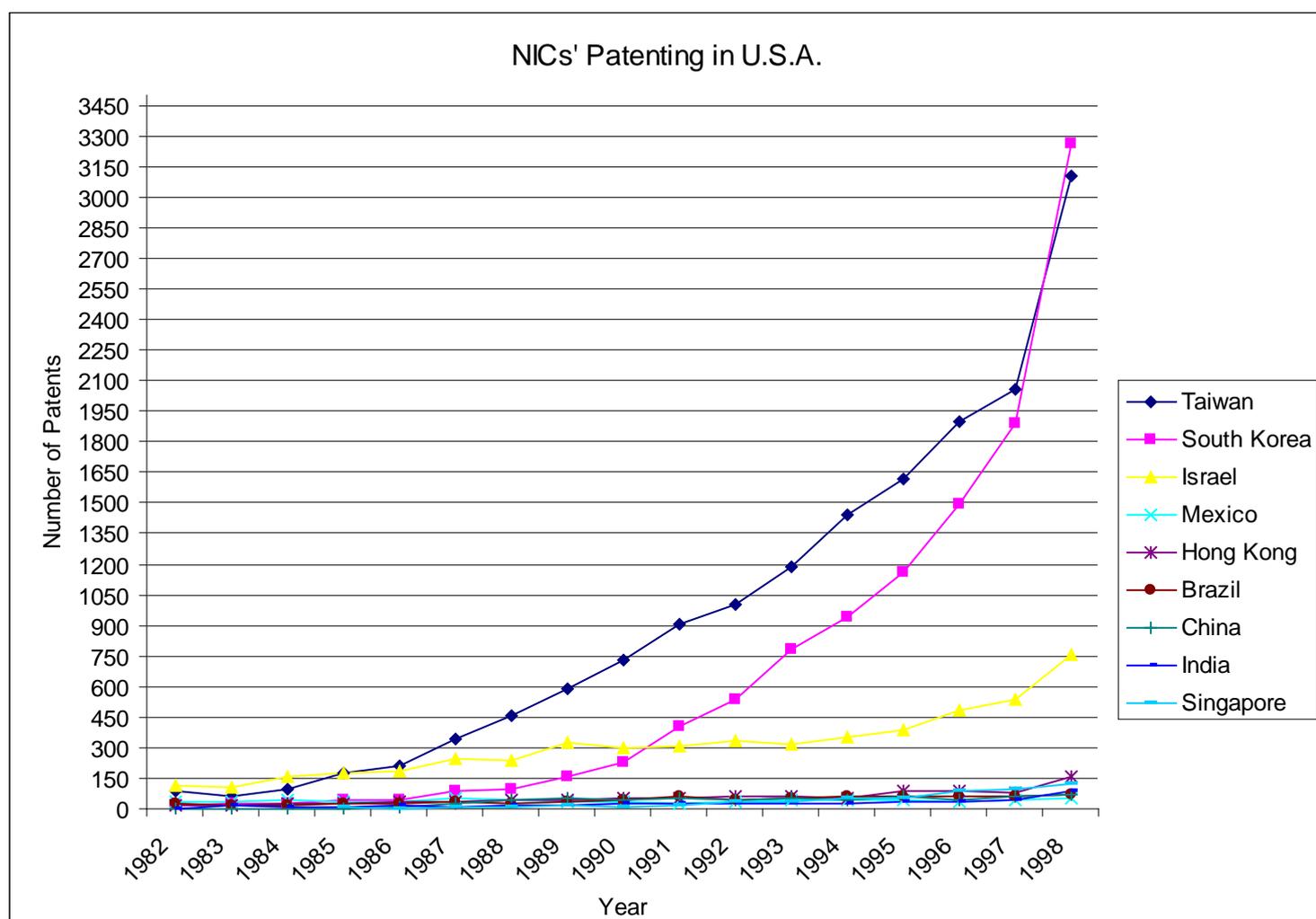
A few of the better CSIR labs have responded very effectively to this new regime. World-class scientists at labs such as the National Chemical Laboratory today have close links with industry. Recent reports indicate that NCL today funds well over 50% of its budget from contract research, with 40% of its budget from private industry. The problem is that three quarters of the industry funding is from *foreign* industry, a share that has been growing in recent years. This is entirely consistent with our analysis in Section II - as we said then, research must follow industrial development, not lead it. If it leads it, then it will wind up being useful to technology-leading industry, more often than not outside the country. As the report of a study of Research and Technology Institutes (RTI) puts it:

"there is a constant risk of moving not *ahead* but *away from* market needs, which is one reason why strong industrial input is needed for the governance and management of RTIs...Research tends to have a higher status than many more 'down to earth' RTI activities, so there is a constant tendency to do too much of it"⁶¹

5. Where has India's early investment in scientific research got us?

Thanks to India's early investment in scientific research, it achieved the levels of a developed country in the primary measure of science output, publications in scientific journals. But this lead in publications did not show up in patents, often used as a measure of the output of technology research, where Korea and Taiwan have been the big new entrants.

Figure 1: Patents by NICs in the US



Indeed, only Korea, Taiwan and Israel show a decent performance, and that too after the mid-80s, by which time Korea and Taiwan were richer than Spain and Portugal. Conspicuously missing from the picture are India⁶² and Brazil,

⁶⁰ A complete contrast from the usual ploy of setting a target for a year after retirement! Dr Mashelkar's term has just been extended by two years to 2005.

⁶¹ Rush et al, (1998), p. 90.

⁶² If this figure is updated for 2002, the number of Indian patents would show some growth, thanks largely to the increasingly strong CSIR patent performance we discussed earlier. CSIR alone filed 145 patents in the US

countries which passed patent laws to help foster local innovation, and which invested earliest in research. One can reasonably conclude then, that by focussing attention on using the results of research, not doing it, one will foster industrial development. Industrial development will in turn then foster doing research, with the indicators of innovation turning positive. India and Brazil will become rich by producing and exporting goods, not knowledge.

Overall, I am not arguing for less research spending, but certainly for less of the kind of research done today by the state. In particular, serious improvement in the contribution of organised scientific research is possible only when it happens at universities, not in autonomous laboratories. The preoccupation with issues of “linkage” indeed winds up being a diversion from the main problem. India’s objective must be to free-ride on the backs of public research done in developed countries. Focussed public research aimed at generating new knowledge must take place only in highly exceptional cases, exceptions which prove that rule. Instead one needs adequate investment in widely-aimed research at universities, research that will largely be cheap repetition of others scientific research, as a ticket of admission to understanding and accessing (free-riding) research done in rich countries.

Indeed, most indicators show India’s scientific research output lagging behind after an early start, as the East Asian NIC’s have moved ahead (Table 10). Note that from a comparable publications-per-population level in the early 80s (not at all easy, given India’s huge population), South Korea and Taiwan have moved rapidly ahead while India’s share of world publications has dropped. I believe that letting industrial development lead scientific research will also in itself sustain and reinvigorate the research system itself.

Table 10: Trends in scientific and technological performance in selected Asian countries

Country	Change in share of publications, 1993/1982	Change in share of US patents, 1993/1982	Publications per million Population, 1980 - 1984
Taiwan	5.97	12.81	23.3
South Korea	5.45	29.79	8.0
Singapore	3.53	3.2	71.6
Hong Kong	2.37	2.42	45.9
India	0.83	2.45	18.1

Source: Pavitt (1998), Table 4

in 200, up from 69 in 2001. However, the overall impact would not change the graph, though the slope is finally right!

6. How India Differs

Looking at the overall pattern of R&D in India, there are three striking differences. First, the share of national R&D done in-house in firms is far lower – around 30%, vs over 60% in every OECD country plus Taiwan. This reflects a low investment in R&D by Indian firms, much more than a high level of state spending.

Second, the big contrast in publicly-funded research with any developed country is the tiny share (under 1%) of spending on medical research (the US spends 24%).⁶³ Medical research fits perfectly with the “what public research should be done” argument of section II, and India clearly funds too little of it. The social benefits of increased public funding for research on diseases of particular relevance to India could justify a much greater focus. And the increasing investment of Indian pharmaceutical firms in in-house R&D means that they would be well-placed to appropriate the benefits of this public research.

Third, as we saw earlier, is the tiny share done in the university system. In OECD countries (including Korea, Mexico and Singapore), Brazil and Taiwan, between 15 and 25 percent of national R&D is done in the higher education sector; in India it is under 3 percent, as Table 11 shows. This difference is at the heart of my major priority for change in this paper, which I will return to in the conclusions.

Table 11: University Research in national R&D: India in comparison

Country	Year	Higher education as %		Year	Source of funds for higher education R&D			
		All R&D	GDP		Govt	Industry	Self	Others
Switzerland	1992	25.0	0.67	1992	91.6	1.8		6.6
Germany	1993	18.1	0.45	1993	91.7	7.0		
USA	1993	15.2	0.40	1993	86.1	5.5	2.5	6.0
France	1993	15.7	0.39	1990	92.7	3.6	2.1	1.5
UK	1993	16.5	0.36	1993	68.7	7.8	16.5	7.1
Italy	1993	20.5	0.27	1993	93.4	4.7	0.0	1.9
Japan	1993	20.1		1993	50.6	2.4	46.8	0.1
India	1998	2.9	0.023	N/A				

‘Self’ = student fees, endowments, etc.

‘Other’ = foundations, etc.

Source: Pavitt (1998); DST (2002)

IV. Higher Education, Scientific Research and Industry: What should our priorities for reform be?

Having discussed both the Higher Education system and the Scientific Research system relevant to industry, let me turn last to some thoughts on what our priorities for reform could be. Our higher technical education system has been characterised by rapid private sector growth. With growth rates of 20%+ a year, they face a huge shortage of qualified faculty. One can see the market eventually taking care of this problem, with teacher quality increasingly a requirement to attract better (and better paying!) students, and with faculty salaries rising as the demand for qualified faculty grows. So I would argue that that problem will take care of itself. A key equity requirement will be to provide access, through a system of student loans for example, to all based on merit regardless of financial background.

The better engineering colleges (and especially the IITs) are attempting to grow their graduate programmes and to develop a research culture. This is no easy task. Their major constraint, again, is recruiting the right faculty, but obviously at a very different level.

Our scientific research system has been characterised by the state funding and doing research, in autonomous R&D institutes, with no linkage with either industry or the higher education system. The better labs do now run PhD programmes (NCL, for example, runs the country's largest chemistry and chemical engineering PhD programme), but the focus is entirely research, not teaching. CSIR's other big challenge in recent years has been an aging scientist workforce, with over half its scientists above 45. As we saw in the last section, after achieving developed country levels of scientific research output (publications), India has seen its share fall in the last fifteen years, as Korea and Taiwan have moved rapidly ahead. At the same time, thanks to dynamic leadership CSIR has seen a sharp rise in international patenting, and an equally healthy rise in sponsored research. This sponsored research has mainly come from foreign firms, though, and the patenting is limited to a few of CSIR's better labs that do world-class work.

With a perspective from Indian industry, then, what priorities can one consider for our higher education and scientific research systems?

1. Industry: Use the availability of skilled people to build a competitive position based on R&D

If there is one area where India has long had a distinct advantage over every other country, it is in the availability of skilled technical people at relatively low cost. It is this advantage that has led to the booming software

⁶³ NSF (2002). In 2001, the US spent \$265B on R&D, with the Federal Government funding \$83B of this. Health R&D, primarily through the National Institutes of Health, accounted for \$19B or 24% of total Federal

industry and more recently to the growth in IT-enabled services. Last year, the estimate is that India created over seventy thousand jobs in call-centres alone. Each of these call-centres recruit graduates – those millions with Bachelors degrees in Arts, Commerce and Science that we saw in Section I. The IT industry draws on India's production of 350,000 engineers annually – compare that with US production of 60,000 engineers and 100,000 Natural Science Bachelors degrees annually. At the height of the Indian software boom in 2000, when that single industry was adding over 100,000 engineers a year, it is striking that no Indian firm in whatever field had problems recruiting fresh engineers. They were still available in abundance, if not in quality. Yes, the best engineers from the IITs and the better colleges were attracted to IT and away from manufacturing, but no manufacturing firm had problems recruiting fresh engineers.

Indian industry has long had this luxury – of an abundance of low cost qualified people. But while engineers have been cheap, they have also been treated cheaply: recruited to perform jobs with undemanding technical content. It is only now, as economic reform has created a demand for product innovation and as engineer remuneration has risen sharply (in 2003, a fresh graduate engineer would earn about five times in real terms what he earned in 1991) that firms expect their average engineer to do work with demanding technical content. Too few Indian firms, though, recognise the huge advantage they have of low cost qualified people in reducing R&D cost, and so building competitive positions based on R&D. The pharmaceutical industry is a major exception: firms like DRL, Ranbaxy, and Nicholas Piramal are betting on India's lower R&D costs as a basis for competing long term in a research-intensive industry. So too is Tata Motors: Ratan Tata believes that India may not be the world's cheapest place to make cars, but it is the world's cheapest place to design them, thus reducing the break-even run for even mass-market designs. But they are still exceptions. What will probably end up selling the merit of doing R&D to Indian firms is multi-national investment in R&D. Astra Zeneca has one of their largest R&D labs outside Sweden in Bangalore, and all their work on tropical diseases is now done there. Cummins proposes to establish a design centre in Pune, that will be its second largest outside the US in three years. And most prominently, GE set up the Jack Welch (he who likes cut-flowers) Research Centre in Bangalore in 2000, which has since become GE's largest R&D facility world-wide. It employs 5000 people, including almost 2000 PhDs, and today has the largest Chemistry and Chemical Engineering PhD concentration in the country.

So my first priority is for industry: to recruit the best talent available and aim it at pushing forward product designs in their own industries.⁶⁴ This talent should aim to learn from the best firms and research world-wide. As firms

Spending. Health spending has shown the largest growth over the last 20 years of all federal R&D spending.

⁶⁴ In our book, *From Followers to Leaders*, we argue that firms should build the capability of pushing out the design frontier within a particular technological paradigm. Our argument was that the design and technology frontiers were distinct, and that pushing out the design frontier was an attractive way adding value in products without the risk involved in attempting to push out the technology frontier: let the world's rich firms make the expensive mistakes, in other words. But building design leadership takes serious investment in skills and building R&D competences that few Indian firms have today.

invest more in research, the demand for graduate engineers and PhDs will also grow. This will tie in nicely with the focus on graduate programmes and research at the IITs and hopefully also at other leading educational institutes. But for now, while GE and Cummins establish large Indian R&D centres built around the availability of cheaper talent, firms such as Ranbaxy and DRL have found it easier to recruit scientists for their more advanced work in the US than in India. Both firms run R&D labs in the US primarily as a means of recruiting the right scientific talent.

All this will amount to an increased investment in R&D by Indian firms. While the percentage of turnover spent on R&D by Indian firms has barely changed in the last twenty years, there has been much change in qualitative terms since 1991. Public sector industry, which almost matched total private sector spending in 1990, is now one fourth of private industry spending. The pharmaceutical industry increased R&D spending from 2 to 6% of sales between 1990 and 2000, and firms such as Tata Motors, Bajaj Auto, Mahindra and Mahindra, and Reliance are all spending a multiple on R&D as a percentage of sales today. The number of such firms is still too small to show up as a big change in the national R&D statistics, but the trend is right.

It is only since 1991 that the industrial environment changed materially enough to affect the demand for innovation, and thus impact R&D investments by firms. These changes have only just begun to reflect in the aggregate R&D numbers today, and that too marginally. The key conclusion is that factors affecting the supply of R&D – qualified people, tax incentives, even institutions – will always be limited in its impact by demand from industry. Demand will come from the demand for innovation, and any analysis of R&D that excludes the context of industrial innovation will be of limited value. The firm, therefore, has to be at the centre of analysis of R&D, both public and private.

Earlier in the year, the Indian government released its Science and Technology Policy 2003, the first such statement in twenty years. The document reads well enough, and there is little in there that most analysts would disagree with. But what is missing is precisely a focus on the firm as the centre of any S&T Policy. Yes, there is an exhortation, repeated twice, for Indian firms to invest more in R&D. But there is little that says why they should do so, what they should do, and how. Perhaps that is too much to expect of a generic policy statement, but to me a policy that talks about national R&D without dealing with the demand for it from firms is not going to deliver a result. How one creates this demand is not easy. The obvious powerful incentive that drives firms world-wide to invest in R&D is that they will otherwise be put out of business by competitors. And it is only an enhanced investment in R&D that will in turn create a suitable ground for utilising the output of public scientific research.

2. Reforming CSIR and other public research institutes: From Scientific Research Institutes to Technology Assistance Institutes

In Section III, we discussed how the most ambitious and hard-nosed attempt to reform CSIR has been underway over the last six years. CSIR has met many of the ambitious objectives it set itself in Vision 2001 including those for international patenting and external finance. I would argue, though, that there are three fundamental points which go beyond the scope of Vision 2001's objectives, that the Vision report provided the right answers but to the wrong questions. First, where should research be done? If my argument is correct, public research should be done not in autonomous R&D institutions but at universities. The solution is not to reduce CSIR's scope but to ensure that each scientist must teach, and that this teaching must be done in the same institution where the research is done. Second, what research is done needs to be focussed on the three areas mentioned in Section II. And third, it is vital to focus on Innovation in Indian industry as the justification for all research effort. The exemplary goals specified in Vision 2001 add up to an objective of making CSIR funding less of a burden on the state and more privately funded. There are explicit goals for CSIR exporting Research. While this goal is radical, the objective for a nation, it seems to me, should be not to *sell* Knowledge but to *use* Knowledge.⁶⁵ Making CSIR more self-funding, especially by foreign firms, will make it less of a burden on the state; it will not increase CSIR's contribution to innovation in Indian industry.

However, it is not that autonomous *Technology* Institutions in themselves make no sense. Instead, one must distinguish between those institutions whose objectives are to provide a wide range of technical services to industry, and those who exist to carry out scientific research. We have the benefit of two systematic international studies of research institutions, both done in the mid-1990s. The first, done by Centrim in Brighton reviewed nine "successful" Research and Technology Institutes (RTI) in different countries, each "considered to be at the forefront of best practice in providing innovative support to industry" (Rush et al, 1995, p. 1).⁶⁶ The study concluded that:

"In practice, we have seen that leading RTIs carry out little advanced research. In contrast with the grand mission statements of some, successful RTIs do not set out to generate innovations for transfer to industry. Few carry out pioneering, leading edge industrial research on their own. The view of RTIs as centres for generating technology for industry is highly misleading and has contributed to the industrial dislocation and ineffectiveness of many RTIs worldwide. It is worth stressing that today, as in the past, the development and diffusion of new innovations is largely the task of industry, not RTIs.(Rush et al, 1995)"

⁶⁵ Perhaps the best illustration of this point is the British experience. All through the 1760 – 1830 period that saw Britain's ascendancy as the world's first industrial nation, it was a net importer of technology. Only after 1850, and after relative industrial decline had set in, did the technology balance turn positive.

⁶⁶ The 1995/1998 studies covered eight institutes in Korea (KIST), Taiwan (ITRI), IPA (Germany), IVF (Sweden), Pera (UK), SISIR (Singapore), HKPC (Hong Kong), CITER (Italy), and Battelle (USA).

The second study done by the World Bank looked at 167 Technology Institutions and 2049 firms in six industrial sectors (foundries, textiles, auto parts, machine tools, software, and polymers) in eight countries (China, India, Japan, Korea, Hungary, Mexico, Taiwan, Canada). The study also found that Technology Institutions had contributed significantly to Innovation in every country. However:

“The overwhelming demand by industrial firms is for services related to what might be called diffusion, that is the transfer and application of known technology. Firms most frequently use services related to information, standards and testing, problem solving (and trouble shooting) and technology training. And even when they use R&D services of TIs, they tend to want answers to particular questions, rather than the development of entirely new technologies. The study unearthed few examples where firms purchased off-the-shelf, self-contained technologies developed by TIs. This is in stark contrast to the claims and publicly projected image of many TIs, particularly R&D labs” (World Bank, 1997, p. 2).

The World Bank even says of Taiwan’s ITRI and Korea’s KIST (the traditional darlings of the technology in development community): “these institutions receive preferential funding and some of their researchers are perceived to be spoiled and arrogant. Their usefulness to the economy is consequently hotly debated” (World Bank, 1997, p. 28).

Thus, we can conclude that while state Technology Institutions can play a useful role in a national innovation, they should not have the objective of carrying out Scientific Research. Instead, both studies (and especially the Brighton study) essentially take for granted that Scientific Research will be overwhelmingly carried out in universities.

The policy implication for a state Research and Technology Institute like CSIR is clear: focus the institute on technical assistance to industry, work that may be mundane but must be useful and fully self-financing. Take the research staff and transfer them, with research facilities, to universities. Locate all research there.

3. An invigorated Higher Education system and an invigorated Scientific Research system: two sides of the same coin

The advantages of doing research in universities are manifold: First is the apprentice-journeyman benefit - the graduates industry hires will come trained in doing research. Second, the industry-research linkage issue is immediately drastically reduced: every university has an automatic, costless and strong linkage with industry through students - each time industry employs a graduate a new link is formed. Students know their professors, and vice versa. Third, as Gerhard Casper argues, not only does teaching benefit from the research-teaching combination, but research benefits too.

Our end objective is clear: we should have a few really first-rate research-teaching centres.

My proposal to reform CSIR is really one to bifurcate CSIR and make it part unexciting-but-useful Technology Assistance Institution and part a huge pool of professors. At the risk of sounding thoroughly crass, a share of those ten

thousand CSIR scientists would be a huge impetus to the national higher education system, particularly graduate education. Even the IIT system has a faculty vacancy rate above 10 percent, and each IIT has the objective of hiring 20% more faculty in the next five years. Where are they all going to come from except from such an initiative?

Getting from here to there:

One of the strongest arguments against locating research in the Indian university system is that it might die there in the absence of a research culture. Building this research culture will be key, and will not be easy. Kenneth Arrow, in his discussion of this paper, points to the example of Stanford University which went through this same process in the 50s, with huge success but with a great deal of pain. India would need to start with a few of the better educational institutes. The IITs, with their high teaching quality, outstanding student pool, abundance of alumni-funding opportunities, and lesser intrusion from the political system are obvious starting places. But we would need to extend out to the University system in general, to build a few first-class institutes. Every college and University I have spoken to has said how much they want to do more research as a top, and in the IIT's *the* top, priority. But are they really willing to change their own recognition and promotion systems to reflect that every faculty member must do research? Conversations with a few academics at our best colleges and universities suggest that they increasingly are, but the process will need to be a highly focussed effort spread over decades.

A National Research Council could be set up to disburse the state funding now going to CSIR and all other state laboratories (including the defence laboratories), with all disbursements on the basis of competitive grants not budgetary support. The autonomous research labs must then become totally self-funding, which would drive their work in the technology-assistance direction. Some institutional reform could make it easier for industry to draw on CSIR facilities. Scientists could also compete for the national research funds with researchers from other institutes and from universities, and student participation could be an advantage in getting funded.

Some research laboratories could themselves become colleges. Several already run PhD programmes and all should be required to. But what is vital is that they extend their teaching role to Masters programmes at the minimum, and even linkages with undergraduate institutes. That would ensure the research-teaching combination advocated throughout this paper.

The easiest reform would also be the most misleading: one could simply require every scientist to teach, full stop. That would probably involve the scientist teaching in the university system, while continuing to do his or her research in an autonomous laboratory. As Roger Noll points out, while basic research in many countries outside the US has grown, the fact that this research is often conducted in autonomous laboratories means that "it has not had a spillover

benefit for higher education, *even though many of the researchers in national labs are also university professors*".⁶⁷ This reform could mislead us into thinking we had achieved the combining of research and teaching – and would miss most of the benefit of doing research in the higher education system of training future researchers.

All of these reforms add up to very substantive change. I would be horrified if someone were lunatic enough to start shifting CSIR labs to universities without further debate! But what I do think is needed is a serious debate on just what should be done to dramatically increase the share of university research to international levels, which would be over five times what it is now (3 percent to 15 percent). Surely a rejuvenated scientific research system in CSIR (where a well-recognised problem is an aging scientist core) is the other side of the same coin of a university system that does dramatically more research.

The pain that will accompany these changes will be considerable – and not just for CSIR. Changing the basis of recognition and promotion within the university system will not come easily. The opportunity though is immense. The last ten years have seen a huge interest in India's human resource capability. The IT services business, the R&D facilities that hundreds of MNCs run in India, and the interest that many leading firms show in sponsoring research at the national labs are all built around our abundant qualified people. Gaining from our low cost R&D potential has spread from GE to Ranbaxy and Tata Motors; it needs to spread to Indian industry writ large. Building a few select research universities out of our better educational institutes would be a logical extension of an education system that already produces huge numbers of engineers at the low end.

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