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India's National Innovation System:

Transformed or Half-formed?

Naushad Forbes[1]

Indian industry has changed beyond recognition in these 25 years. From operating in a protected home market, often producing old designs of indifferent quality, in sector after sector there are today no product gaps between what is available in India and what is available in the rest of the world. We take this for granted today, but in 1991 as an affluent Indian I was fortunate enough to buy a new car which was only 10 years out of date (replacing my old new car, which was 25 years out of date), I bought most of my clothes overseas, no decent cheese or processed food was available in the country, we booked phone lines five years ahead of when we thought we might need them, our one domestic airline Indian Airlines published its time-table for the sole purpose of enabling you to calculate how late you were, and television consisted (on Doordarshan) of picking between the news and a stimulating programme on animal husbandry. Contrast that with 2016, when what we enjoy in each large Indian city is on par with most large international cities. (And if you take a flight today from New York or London to Bombay or Delhi you leave a third-world airport and arrive at a first-world one.)

So India's product and service markets have been transformed in the last twenty-five years. Has India's Innovation System been similarly transformed? If you are a macro-economist, the answer is No. If you are a micro-economist, the answer is Maybe, somewhat. In brief, the macro innovation data shows no or modest change in the proportion of GDP spent on R&D, in who spends on R&D, and in where it is done. There is some change in the sectors where R&D effort is concentrated. The import of technology shows rapid change. And the individual firm story is one of very rapid change. In particular, a focus on learning has completely changed what products are made, and how often new products are introduced. And the basis of survival has dramatically changed the efficiency with which firms operate. Let us flesh out this picture of half-formation rather than transformation. I will focus on

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learning and R&D, leaving discussion of changes in the higher education system, trade policy, business, and manufacturing to the specialized chapters in this book. I end with a discussion of what we must do to move from this half-formed National Innovation System to one that is transformed. In particular, I argue that India's unusual[2] pattern of specialization in skill-intensive and capital-intensive manufacturing demands much more investment in innovation than currently happens.

I. A few building blocks to understand technical capability, R&D and innovation

The importance of technical capability in economic growth is well-recognised. From the very first growth-accounting exercises of the 1950s for the US economy[3], through analyses of Japan, South Korea and Taiwan in their catch-up stories, to China today, technical change is estimated to account for over half of all economic growth.[4] Technical change shows up in the economy as Innovation, as doing new things for commercial advantage. Innovation largely happens in firms, which must be at the heart of any such analysis. The innovative capacity of firms will be affected by both what they do themselves, and the institutions around them. The education system provides skilled labour, engineers and researchers. Where publicly funded research is done affects how it connects with industry. Public policy can provide incentives for investing in R&D, either directly or through patents. The trade regime can foster local production and/or an outward mindset. The culture of entrepreneurship affects investment in different kinds of capabilities. And broader cultural factors can influence how entrepreneurs define "good". A framework of a National Innovation System brings these factors together.[5] It enables a more systematic comparison across countries of the drivers of technical capability. Although R&D is the most studied component of Innovation, it is good to always keep in mind that Innovation – defined as something new for commercial advantage – is a much broader concept and applies to all firms in all sectors. Innovation matters as much to a garment firm introducing a new design or a start-up launching a local-transport App (activities which rarely involve R&D but are

[2] For a lower-middle income labour-surplus country

[3] Independently by Moses Abramovitz and Robert Solow

[4] Although the contribution of technical change to economic growth is well appreciated, it is still calculated as the residual in Total Factor Productivity calculations, after subtracting the contribution of capital and labour.

[5] The concept of National Innovation Systems followed from books by Richard Nelson (1993) and Bengt-Ake Lundvall (1992?)

still highly innovative) as to a pharmaceutical firm developing a better cure for a disease involving years of research. R&D is, however, the most directly connected with the study of Innovation, so we focus our analysis there.

R & D is highly concentrated

R&D is hugely concentrated world-wide. Most R&D is done in a handful of countries: of a total of around $ 1.5 trillion spent on global R&D in 2014-15, the top five countries accounted for 66 percent, with Industrial R&D at 71 percent of the total[6]. It is highly concentrated in a few industries: the top five industries – Pharmaceuticals, Automobiles, Technology Hardware, Software and Electronics account for 68 percent of the total of Industrial R&D. And within those industries, it is highly concentrated in a few companies: the top 20 companies account for 21 percent of global industrial R&D, the top 300 companies for 67 percent[7].

India as Outlier in R&D spending

Table 1: R & D as % of GDP over time in leading Newly-industrialising Countries[8]

Country	R&D % GDP in								
	1980	1984	1988	1992	1996	2000	2004	2011	2014
South Korea	0.6	1.2	1.9	2.1	2.2	2.2	2.5	3.8	4.3
Taiwan	NA	NA	NA	NA	1.8	NA	2.6	3.0	3.0
Singapore	0.3 (1981)	0.5	0.9	0.9 (1990)	1.3	1.8	2.1	2.2	2.2
China	NA	NA	0.7	0.6	0.6	0.9	1.2	1.8	2.1
Brazil	NA	NA	NA	0.8 (1994)	0.8	1.0	0.9	1.2	1.2
India	0.6	0.8	0.9	0.7	0.6	0.7	0.7	0.8	0.9

6 Total global R&D in nominal terms for 2014-15 calculated using nominal GDP data from the IMF World Economic Outlook Database April 2016, available at https://www.imf.org/external/pubs/ft/weo/2016/01/weodata/index.aspx and GERD as a percentage of GDP from UNESCO Institute for Statistics, UIS.stat, available at http://data.uis.unesco.org/. The figure for total industrial R&D was obtained from the EU Industrial R&D Investment Scoreboard (2015). Figures in Euros were converted to Dollars using the EUR-USD exchange rate of 1.21 as at 31 December 2014 as mentioned in the EU Industrial R&D Investment Scoreboard.

7 EU Industrial R&D Investment Scoreboard (2015); Centre for Technology, Innovation and Economic Research (CTIER)

8 The term “Newly-Industrialising Countries” almost always includes the eight countries of Table 1 plus Malaysia and Indonesia. Turkey, South Africa and Hong Kong are also often included, and on occasion Chile, Argentina, Colombia, Egypt and Vietnam.

Mexico	NA	0.6	0.2	0.2	0.3	0.3	0.4	0.4	0.5
Thailand	0.4	0.3	0.2 (1987)	0.2 (1991)	0.1	0.2	0.3	0.4	NA

Source: UNESCO Statistical Yearbook (1999) for data from 1980-1996; UNESCO Institute of Statistics (various years), *UIS.stat*, available at: http://data.uis.unesco.org/ for data on China, India, Mexico, Singapore, South Korea, Taiwan and Thailand and Brazil (pre-2000); World Development Indicators (various years), *Indicators*, available at http://data.worldbank.org/ for data on Brazil (2000gg-14); Author's estimate for India 2014.

Table 1 shows that India was an early investor in R&D, with R&D as a % GDP being higher than for countries that were considerably richer at that point in time. However, India's investment in R&D has stagnated over the last thirty years, ranging between 0.6 and 0.9% of GDP while South Korea, Taiwan, Singapore, China and to some extent Brazil have substantially increased their investments. Mexico and Thailand (and Malaysia and Indonesia, as other leading Newly-Industrialising Countries) reflect much more subdued investment in R&D, throughout this period.

Table 2: Who does the R&D?

Country	Total R&D Expenditure (USD billion)	GERD as a Percentage of GDP	Corporations (% of Total)	Public Research Institutes (% of Total)	Universities (% of Total)
United States	473	2.7	71	11	18
China	213	2.1	77	16	7
Japan	164	3.6	78	8	14
Germany	111	2.9	68	15	17
France	64	2.3	65	13	22
United Kingdom	51	1.7	64	8	28
Korea	60	4.3	78	11	11
Canada	28	1.6	50	9	41
Australia	31	2.3	56	11	33
Russia	24	1.2	60	30	10
India	17	0.9	35	61	4
World	**1500**	**1.7**	**71**	**12**	**17**

Source: UNESCO Institute for Statistics (various years), *UIS.stat,* available at: http://data.uis.unesco.org; Department of Science & Technology (DST), Inbbdia, Research and development statistics at a glance 2011-12; Author's calculations and estimates based on 2010-2014 data; Centre for Technology, Innovation and Economic Research (CTIER)

Table 2 shows that the bulk of R&D spending worldwide happens in firms (around 71% of the total). The balance is publicly funded research, most of it done in Universities (17%), with a smaller share in autonomous R&D Institutes (12%).[9] India is an outlier on three counts. First, the share of industry in total national R&D is the lowest of any major economy at 35%.[10] This share was 25% in 1991, so the rise (of a rapidly growing GDP) is significant but not dramatic, and keeps India an outlier. The split of industrial R&D in India has changed significantly – in 1991, the 25% industry share split 15% private industry: 10% public sector industry; today the 35% industry share splits 30% private industry: 5% public sector industry. [11] Second, publicly funded R&D in India at 65% is the highest among all major economies. China also used to be high, but in this same period has seen the publicly funded share fall to 16 percent (from 50% in 1991[12]). Third, where publicly funded R&D is done is again dramatically different in India. The bulk of public R&D (over 90%) is done by the government in its own autonomous R&D Institutes. A small share of publicly funded R&D (< 10% of the public share) is done within the University system, giving the Indian Higher Education sector the lowest share of national R&D (4%) of any major economy.

Publicly-funded research and industrial innovation

The popular 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

[9] There is a difference in many countries between who funds and who does research. In most major economies, the state funds the bulk of research undertaken in universities, whether public or private. In some economies like the US, Israel and UK, the state also funds a substantial part of the defence research expenditures of private industry. In India, there is essentially no gap between who funds and who does: publicly funded research is done in government laboratories (overwhelmingly) or in government higher education institutes (to a minor extent). Private industry funds the great bulk of its own R&D.

[10] There is a serious problem with Indian R&D statistics. No government agency can provide overall data. The Centre for Technology Innovation and Economic Research (CTIER) estimates that if we include contract R&D done in India for foreign firms in the total, the R&D share as a percent of GDP would rise to 1.2% with the public and industry shares at 50:50 and the industry share in turn splitting roughly equally between R&D done for use within the country and as contract R&D that is exported.

[11] Department of Science & Technology (DST), India (various years)

[12] OECD Statistics (1991), *OECD.Stat*, available at http://stats.oecd.org/

finds itself into production and the market. This mental model, referred to in the literature as the linear model of innovation[13], is attractively simple - but is also simplistic. Over the last fifty 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 – and quite limited - role that scientific research plays in industrial innovation.

De Solla Price showed some fifty years ago 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 scientific 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 globally 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 field[14]. This "reinvigoration" typically takes the form of a new technological paradigm for industry – on-line music taking over from compact discs, say, 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"[15]

But what about 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. Only when particular industries – such as semiconductors in Korea and Taiwan or cars in Korea – approach the

13 See, in particular, the late Steve Kline's many insightful attacks on the linear model (Kline 1987, 1989)

14 Hounshell, 1996.

15 Nelson, 1992, p. 175.

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 (imperfect) evidence … is that the causal links run from the national technology system to the national science system."[16]

Where should publicly-funded research be done? University research as an end in itself

Although India was an early investor in scientific research, this investment went overwhelmingly into autonomous Scientific Research Institutions. The end result has been for research to bypass the university system, a point long understood everywhere except India.[17] For example, the Council of Scientific and Industrial Research encompasses 37 laboratories employing 4000 scientists: assessments of CSIR's contribution to Indian industry (its reason for existence) have shown little connection with industry. 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. This lesson is just not being learnt: the 11th plan (2007 – 12) set up 14 new autonomous institutes, and the 12th plan (2012 – 17) proposed 7 more. We could at least grandfather the problem and allocate incremental public research funding to the higher education sector.

Combining research and teaching will benefit both. The huge growth in higher technical education in India has all been at the undergraduate level; graduate technical education has stagnated. As the better institutes, and in particular the IITs, attempt to grow their graduate and 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, 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, by the 1980s it had 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

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16 Pavitt (1998), p 800.

17 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 1999).

new entrants. And in the last twenty 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.[18] 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 investment in in-house R&D by specific Indian firms and industries such as pharmaceuticals. The more advanced technological sectors in Indian industry are 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.

II. R&D in Industry

Table 3A: Industrial R & D by Sector for the top 2500 global R & D spenders in 2014-15

Rank	Sector	R&D expenditure 2014 (USD million)	R&D % of Total (top 2500 spenders)	No. of Companies				
				Total	India	China	Korea	US
1	**Pharmaceuticals & Biotechnology**	133284	18%	316	8	21	10	161
2	**Automobiles & Parts**	114708	16%	155	6	28	10	24
3	**Technology Hardware & Equipment**	114412	16%	316	0	37	7	130
4	**Software & Computer Services**	76764	10%	275	5	32	4	161
5	**Electronic & Electrical Equipment**	55709	8%	229	0	39	9	50

[18] See Pavitt (1998)

6	**Industrial Engineering**	29608	4%	199	1	30	2	41
7	**Chemicals**	25307	4%	133	0	10	7	38
8	**Aerospace & Defence**	24593	3%	56	0	6	0	19
9	**General Industrials**	21466	3%	96	0	15	7	24
10	**Oil & Gas**	16281	2%	49	1	6	3	10
	Top 3 Sectors	362404	50%	787	14	86	27	315
	Top 10 Sectors	612132	83%	1824	21	224	59	658
	Total (2500 firms)	734936	100%	2500	26	301	80	829

Source: EU Industrial R&D Investment Scoreboard (2015). Figures in Euros were converted to Dollars using the EUR-USD exchange rate of 1.21 as at 31 December 2014 and as mentioned in the EU Industrial R&D Investment Scoreboard; Reliance Industries Ltd. was classified under Chemicals in the EU Industrial Scoreboard and has been moved to Oil&Gas (which includes Oil&Gas producers as well as Oil&Gas equipment, services & distribution companies); Centre for Technology, Innovation and Economic Research (CTIER).

Table 3A shows data by sector for the top 2500 R&D spending firms worldwide (who account for over three-quarters of global industrial R&D spending). Note that of 26 Indian firms (against 301 Chinese firms and 80 South Korean firms), 19 are in just three sectors – pharmaceuticals, automobiles, and software, and India has no firms in five of the ten top R&D intensive sectors worldwide. Part 1 of the explanation of why industrial R&D in India lags is this absence of several sectors which are R&D intensive.

Table 3B: R&D Intensity (R&D as a % of Sales Turnover) by Sector (2014-15)

Sector	Company	Reported R&D Intensity	Top 2500 Global Average R&D Intensity
Pharmaceuticals & Biotechnology	Dr. Reddy's Laboratories Ltd.	11.8	15
	Cadila Healthcare Ltd.	9.5	
	Lupin Ltd.	8.9	
	Cipla Ltd.	8.2	
	Sun Pharmaceuticals Industries Ltd.	7	
Automobiles & Parts	Tata Motors Ltd.	6.1	4
	Mahindra & Mahindra Ltd.	3.7	
	Bajaj Auto Ltd.	1.7	

	Ashok Leyland Ltd.	1.4	
	Maruti Suzuki India Ltd.	1.3	
Technology Hardware and Equipment	Zen Technologies Ltd.	16.6	8
	Genus Power Infrastructures Ltd.	10.6	
	Astra Microwave Products Ltd.	3.7	
	I T I Ltd.	2.1	
	Bharat Dynamics Ltd.	0.8	
Software & Computer Services	Oracle Financial Services Software	7.1	10
	Infosys Ltd.	1.3	
	H C L Technologies Ltd.	1.1	
	Tata Consultancy Services Ltd.	1	
	Wipro	0.5	
Electronic & Electrical Equipment	Electronics Corporation Of India Ltd.	3.6	5
	Crompton Greaves Ltd.	0.9	
	Bharat Electronics Ltd.	0.5	
	Philips India Ltd.	0.3	
Industrial Engineering	Bharat Heavy Electricals Ltd.	3.3	3
	B E M L Ltd.	2.7	
	Escorts Ltd.	2.2	
	T R F Ltd.	1.8	
	Cummins India Ltd.	0.6	
Chemicals	Syngenta India Ltd.	3	3
	U P L Ltd.	1.4	
	Hindustan Unilever Ltd.	0.2	
General Industrials	Hindustan Aeronautics Ltd.	6.7	3
	Titan Company Ltd.	0.2	
Oil & Gas	Oil India Ltd.	0.7	0.5
	Oil & Natural Gas Corpn. Ltd.	0.5	
	Reliance Industries Ltd.	0.3	
	Indian Oil Corpn. Ltd.	0.1	
Construction and Materials	Larsen & Toubro Ltd.	0.4	1

	Indian Hume Pipe Co. Ltd.	0.3	
	V A Tech Wabag Ltd.	0.1	
	Rail Vikas Nigam Ltd.	0.03	

Source: Department of Scientific & Industrial Research (DSIR), India Annual Reports (various years); Annual Reports (2014-15) of Indian companies. EU Industrial R&D Investment Scoreboard (2015); Centre for Technology, Innovation and Economic Research (CTIER)

Tables 3B and 3C provide Part 2 of the explanation: Leading Indian firms invest somewhat less in R&D as a percentage of sales than their global counterparts. But a much more dominant explanation than the proportion of sales spent on R&D is the absence of really large R&D spending firms. No Indian firms, for example, figure in the Top 25 R&D spenders world-wide.

Table 3C: Top 25 R &D Spending Firms world-wide

Global rank	Name	Country	Sector	R&D expenditure (USD million)	R&D as a % of Sales
1	VOLKSWAGEN	Germany	Automobiles & Parts	15,875	6.5
2	SAMSUNG	South Korea	Electronic & Electrical Equipment	15,258	7.9
3	MICROSOFT	US	Software & Computer Services	12,005	12.9
4	INTEL	US	Technology Hardware & Equipment	11,498	20.6
5	NOVARTIS	Switzerland	Pharmaceuticals & Biotechnology	9,943	16.7
6	GOOGLE	US	Software & Computer Services	9,799	14.9
7	ROCHE	Switzerland	Pharmaceuticals & Biotechnology	8,981	18.8
8	JOHNSON & JOHNSON	US	Pharmaceuticals & Biotechnology	8,465	11.4
9	TOYOTA	Japan	Automobiles & Parts	8,299	3.7
10	PFIZER	US	Pharmaceuticals & Biotechnology	8,282	16.8
11	GENERAL MOTORS	US	Automobiles & Parts	7,375	4.7
12	MERCK US	US	Pharmaceuticals & Biotechnology	7,328	17.4
13	FORD	US	Automobiles & Parts	6,877	4.8

14	DAIMLER	Germany	Automobiles & Parts	6,837	4.4
15	HUAWEI	China	Technology Hardware & Equipment	6,584	14.0
16	CISCO SYSTEMS	US	Technology Hardware & Equipment	6,186	12.6
17	ROBERT BOSCH	Germany	Automobiles & Parts	6,101	10.3
18	APPLE	US	Technology Hardware & Equipment	6,021	3.3
19	SANOFI	France	Pharmaceuticals & Biotechnology	5,823	14.2
20	HONDA	Japan	Automobiles & Parts	5,538	5.0
21	BMW	Germany	Automobiles & Parts	5,525	5.7
22	ORACLE	US	Software & Computer Services	5,505	14.5
23	QUALCOMM	US	Technology Hardware & Equipment	5,459	20.7
24	SIEMENS	Germany	Electronic & Electrical Equipment	5,296	6.1
25	IBM	US	Software & Computer Services	5,246	5.7
	Total			**200,104**	

Source: EU Industrial R&D Investment Scoreboard (2015). Figures in Euros were converted to Dollars using the EUR-USD exchange rate of 1.21 as at 31 December 2014 and as mentioned in the EU Industrial R&D Investment Scoreboard; Centre for Technology, Innovation and Economic Research (CTIER).

III. What would transformation look like? A comparison with South Korea and China

Table 4A: R & D and Industrial R & D in India and South Korea

	1970	1980	1990	2000	2010	2014
India						
R&D as % of GDP	0.35%	0.6%	0.6%	0.7%	0.8%	0.9%
Share of Industry in total R&D	15%	20%	25%	30%	33%	35%
Korea						
R&D as % of GDP	0.4%	0.8%	1.9%	2.7%	3.7%	4.2%
Share of Industry in total R&D	13%	36%	81%	74%	75%	78%

Source: UNESCO Institute of Statistics (various years), *UIS.stat*, available at: http://data.uis.unesco.org/; World Development Indicators (various years), *Indicators*, available at http://data.worldbank.org/; Research and development statistics at a glance 2011-12, Department of Science & Technology (DST), India; Author's estimate for India 2014.

Table 4B: R & D and Industrial R & D in India and China

	1996	2000	2005	2010	2014
India					
R&D as % of GDP	0.6%	0.7%	0.8%	0.8%	0.9%
Share of Industry in total R&D	25%	30%	30%	35%	35%
China					
R&D as % of GDP	0.6%	0.9%	1.3%	1.7%	2.1%
Share of Industry in total R&D	43%	60%	68%	73%	77%

Source: UNESCO Institute of Statistics (various years), *UIS.stat*, available at: http://data.uis.unesco.org/; World Development Indicators (various years), *Indicators* , available at http://data.worldbank.org/; Research and development statistics at a glance 2011-12, Department of Science & Technology (DST), India; Author's estimate for India 2014.

South Korea saw two transformations in the twenty years from 1970 to 1990. First, the proportion of R&D done by firms and the state essentially reversed. Second, the share of R&D in GDP rose strongly. Absolute investment by firms in R&D rose dramatically: a rising share, of a rising share, of a rapidly growing base means a double multiple. The industrial share of total R&D increased from 13% of national R&D spending to 81%, at a time when R&D increased from less than 0.4% of GDP to 1.9%, during which South Korea was growing at 8% a year. The same is true in China over the last twenty years: the industrial share of total R&D almost doubles, at a time of a trebling of the share of GDP spent on R&D, while China was growing at over 10% a year.

How has this transformation in industrial R&D happened? There is a double source. First, South Korea especially but also China has seen substantial structural change in lead industrial sectors. Textiles & apparel and food processing (low R&D intensity sectors world-wide) have seen their share in industrial output fall. Automobiles, semiconductors, electronics and IT hardware (high R&D intensity sectors worldwide) have seen their share rise. In India, automobiles are the only R&D intensive sector to substantially increase their share of industrial output, so much more modest structural change.

Table 5A: Manufacturing Value-added % by sector over time in South Korea, China and India

Country	Sector	1970	1980	1990	2000	2010
China	Food, beverages and tobacco	-	10	15	14	12
	Textiles and clothing	-	18	15	11	10
	Machinery and transport equipment	-	19	16	14	24
	Chemicals	-	11	13	12	11
	Other manufacturing	-	42	42	48	43
India	Food, beverages and tobacco	13	9	12	13	10
	Textiles and clothing	21	21	15	13	9
	Machinery and transport equipment	14	17	17	16	19
	Chemicals	14	14	14	21	15
	Other manufacturing	39	39	42	38	48
South Korea	Food, beverages and tobacco	26	17	11	8	6
	Textiles and clothing	17	19	14	8	4
	Machinery and transport equipment	7	9	30	41	50
	Chemicals	11	10	9	10	7

	Other manufacturing	40	44	36	33	32

Source: World Development Indicators (various years), *Indicators,* available at http://data.worldbank.org/

Note: 2010 numbers reported for China are from 2009

Second, within industrial sectors, both South Korea and China have invested more in R&D: semiconductors especially in South Korea. This reflects a deepening of technical capability within sectors. This shows particularly in the growth of R&D spending at a few giant R&D spending firms, as Table 6 below shows. If we consider the top 10 R&D spending firms in each of South Korea, China, and India, the emergence of firms like Samsung (at $ 15.3 B, close to India's total investment as a country in R&D) and Huawei (at $ 6.6 B higher than India's total industrial investment in R&D) illustrates the impact of a few large firms. It brings us back to our earlier point of R&D being highly concentrated; a few giant firms invest giant amounts in R & D. South Korea and China has seen their emergence as they have deepened their technical capability, India still needs to. Some of this gap is to India's entire advantage: the single big cost in R&D is people. Costs in India are still between one-fourth and one-half that of an equivalent engineer or scientist in South Korea or China, presenting an opportunity I will return to later.

Table 6: Top R & D spenders in South Korea, China and India

Country	Company Name	Sector	R&D Expenditure (USD million)	R&D as % of Sales
India	TATA MOTORS	Automobiles & Parts	352	6.1
	SUN PHARMACEUTICAL INDUSTRIES	Pharmaceuticals & Biotechnology	312	7.2
	MAHINDRA & MAHINDRA	Automobiles & Parts	245	3.7
	RELIANCE INDUSTRIES	Chemicals	195	0.3
	DR REDDY'S LABORATORIES	Pharmaceuticals & Biotechnology	190	11.8
	LUPIN	Pharmaceuticals & Biotechnology	175	8.9
	HINDUSTAN AERONAUTICS LTD.	General Industrials	167	6.7
	BHARAT HEAVY ELECTRICALS LTD.	Industrial Engineering	162	3.3
	CIPLA	Pharmaceuticals & Biotechnology	135	8.2

	INFOSYS	Software & Computer Services	96	1.3
China	HUAWEI	Technology Hardware & Equipment	6,584	14.0
	CHINA RAILWAY	Construction & Materials	2,996	1.6
	PETROCHINA	Oil & Gas Producers	2,132	0.6
	ZTE	Technology Hardware & Equipment	1,678	12.6
	LENOVO	Technology Hardware & Equipment	1,160	2.5
	BAIDU	Software & Computer Services	1,137	14.2
	TENCENT	Software & Computer Services	1,131	8.8
	SAIC MOTOR	Automobiles & Parts	1,113	1.1
	CHINA STATE CONSTRUCTION ENGINEERING	Construction & Materials	925	0.7
	CHINA PETROLEUM & CHEMICALS	Oil & Gas Producers	916	0.2
South Korea	SAMSUNG	Electronic & Electrical Equipment	15,258	7.9
	LG	Leisure Goods	3,142	5.9
	HYUNDAI	Automobiles & Parts	2,178	2.1
	SK HYNIX	Technology Hardware & Equipment	1,442	9.3
	KIA S	Automobiles & Parts	1,015	2.4
	KOREA ELECTRIC POWER	Electricity	495	0.9
	POSCO	Industrial Metals & Mining	479	0.8
	KT	Fixed Line Telecommunications	434	2.0
	SK TELECOM	Fixed Line Telecommunications	356	2.3
	HYUNDAI HEAVY INDUSTRIES	Industrial Engineering	264	0.6

Source: EU Industrial R&D Investment Scoreboard (2015). Figures in Euros were converted to Dollars using the EUR-USD exchange rate of 1.21 as at 31 December 2014 and as mentioned in the EU Industrial R&D Investment Scoreboard; Annual Reports (2014-15) of Indian companies; Figures in Indian Rupees converted to Dollars using the USD-INR exchange rate of 62.7 as at 31 December 2014 according to Federal Reserve Bank of St Louis; Centre for Technology, Innovation and Economic Research (CTIER).

The Trade Regime: A separate chapter in this book covers our trade policy and export achievements; I provide only a few brief comments of the impact on technical capability.

A critical component of the success of South Korea (and also Taiwan, Singapore, and China) in moving up the value-chain and deepening investments in technical capability was their export-orientation. Domestic protection was often combined with export promotion – indeed exports were often required as a condition for continued domestic protection. This had a dual benefit: first, export success forced firms to be competitive, and this had efficiency benefits for domestic production too. But there was also a direct impact on technical capability. Exporting provided for a substantial flow of technology from demanding buyers. Studies of how South Korea and Taiwan built their technical capacity identified technical flows from overseas buyers as the most important source of technology for firms - ahead of in-house R&D, technology licensing and domestic R & D institutes. This reflected the industries involved – textiles and garments, consumer goods, and as OEM suppliers of appliances and electronic assembly. None of these required substantial investment in R&D. As the industrial structure changed towards automobiles, semiconductors, and IT hardware, greater investment in in-house R&D supplemented - and eventually replaced – these flows of technology from buyers.

Anecdotal comments from the two industries in India that are strongly export-oriented – software services and pharmaceuticals – says technical flows from demanding buyers have played a similarly important role. But the absence of export orientation for most of Indian industry has deprived it of this flow of technology.

Imports and Exports of Technology and In-house R&D

Table 7A and 7B show the growth of Technology Imports into India compared with other countries. Note that until the 1990s import of technology into India was severely restricted. In recent years ($ 5 B in 2014) payments for technology are comparable to total in-house investment in R&D ($ 6 B in 2014). Exports of technology – in the form of contract research – have also been growing, if not as strongly. We often have a mental construct of technology import – bad – exports – good. This is wrong. Growing technology imports together with growing in-house R&D reflects strong investment in technology by Indian firms. In the same way, I have long viewed the export of technology as benefiting the buyer more than the producer. In short, technology is not the product: firms and countries get rich by turning technology into products and services, not by selling technology. [19] As Table 7B shows, the most successful periods of rapid industrialization across countries – Japan in the 50s and 60s, South Korea and Taiwan in the 70s and 80s, China since 1990 – have been accompanied by significant imports of technology – considerably higher levels than in India until the noughties. Much innovation happens without recourse to formal R&D. R&D started to contribute significantly to Korean and Taiwanese industrialization only in the 80s, and to China's only in the 2010s. As we saw earlier, industrial development must precede the choice of investing in R & D.

[19] My most telling example is that of Great Britain. Britain was a net importer of technology throughout its heyday as the world's workshop (on exhibit at the Crystal Palace in 1853). It was only in the latter half of the 19th century that Britain became a net exporter of technology – at about the time that relative industrial decline set in.

Table 7 A: Charges for the Use of Intellectual Property (2014)

Country Name	Payments (USD Million)	Receipts (USD Million)	Deficit/Surplus (USD Million)
United States	42124	130361	88237
China	22614	676	-21937
Japan	20942	37336	16395
United Kingdom	11225	19826	8601
Korea	10546	5167	-5379
Germany	9311	14993	5681
Russia	8021	666	-7356
Brazil	5923	375	-5548
India	4849	659	-4190

Source: World Development Indicators (2014), *Indicators,* available at http://data.worldbank.org/

Table 7 B: Technology Imports into India compared, 1960 – 1998

Year	Japan	Korea*	Brazil	India	Israel	Mexico
1960	**95**	**-**	**-**	**-**	**-**	**-**
1965	**170**	**0.2**	**-**	**-**	**-**	**-**
1970	**430**	**10**	**-**	**-**	**-**	**-**
1975	**710**	**20**	**-**	**-**	**-**	**-**
1980	**1,440**	**100**	**300**	**-**	**-**	**-**
1985	**2,075**	**303**	**150**	**25**	**50 (1987)**	**230 (1987)**
1990	**6,040**	**1,360**	**150 (1989)**	**70**	**70**	**380**
1995	**9,400**	**2,385**	**530**	**90**	**160**	**480**
1998	**9,000**	**2,370**	**1,075**	**200**	**210**	**450**

Sources: Data for Japan and Korea till 1985 from H. Odagiri and A. Goto, 'The Japanese system of innovation', and L. Kim, 'National system of industrial innovation', in R.R. Nelson (ed.) *National Innovation Systems,* Oxford

University Press, 1993, and IMF thereafter; data for Brazil till 1990 from C.J. Dahlman and C.R. Frischtak, 'National systems supporting technical advance in industry', in R.R. Nelson, op. cit., 1993, IMF thereafter; data for India, Israel and Mexico from IMF.
Note: Data till 1985 is five year averages starting from 1962.

Searching for an explanation: why does Indian industry not invest more in R & D?

<u>The share of manufacturing in GDP</u>**:** China's manufacturing sector is today over 10 times India's ($ 3.7 T to India's $ 330 B). But Chinese firms today invest over 25 times what Indian firms do ($ 164 B in R &D vs Indian firms $ 6 B). and the comparison extends beyond manufacturing.

<u>The scale and profitability of firms</u>: are Indian firms just too small to invest in R&D? The general understanding from the field is that there is a threshold level beyond which scale economies do not apply to R&D, and Indian firms in many sectors are today well beyond that threshold. Our ten largest pharmaceutical, IT services, chemical, and engineering firms all have a turnover of $ 500 m or more, which most would consider to be beyond this threshold level. Are Indian firms not profitable enough to invest in R &D? Even after five years of slow industrial growth, average corporate profitability in India (a Return on Sales of 10%) compares well with China or South Korea.

Table 3B showed that Indian firms invested somewhat less in R&D as a percent of sales than their global counterparts. This is true in both our most R&D intensive sectors of pharmaceuticals and auto, where our firms invest roughly half as much as a percentage of sales as the global leaders. But this is particularly true in software. Compare the software industry in China and India (Table 8). The top 10 companies in China invest 8% of turnover in R &D; in India the top 10 companies invest 1% in R&D. An obvious explanation is that India's software companies are software service firms, not product firms. But most Indian software companies are worried about how long the existing model of labour arbitrage combined with excellence in project execution can continue to drive growth. No one would consider TCS, Infosys, or Wipro to be either small or unprofitable. They just invest little in R&D.

Table 8: Top 10 Software companies in China and India

Country	Company	R&D expenditure (USD million)	Sales (USD million)	R&D as a % of Sales
China	TENCENT	1131	12856	8.8
	DIGITAL CHINA	70	8782	0.8
	BAIDU	1137	7989	14.2
	AISINO	51	3230	1.6

	NETEASE.COM	216	1908	11.3
	QIHOO 360 TECHNOLOGY	405	1386	29.2
	LESHI INTERNET INFORMATION & TECHNOLOGY CORPORATION	131	1101	11.9
	DHC SOFTWARE	29	822	3.6
	YOUKU TUDOU	66	678	9.8
	SHANGHAI BAOSIGHT SOFTWARE	78	659	11.8
India	TATA CONSULTANCY SERVICES LTD.	145	15106	1.0
	WIPRO	40	7547	0.5
	INFOSYS LTD.	96	7422	1.3
	H C L TECHNOLOGIES LTD.	29	2735	1.1
	LARSEN & TOUBRO INFOTECH LTD	9	771	1.2
	ORACLE FINANCIAL SERVICES SOFTWARE	48	678	7.1
	ROLTA INDIA LTD.	33	583	5.6
	MINDTREE LTD.	3	581	0.6
	POLARIS CONSULTING & SERVICES LTD.	2	267	0.6
	3I INFOTECH LTD.	1	216	0.4

Source: Annual Reports (2014-15) of Indian companies. EU Industrial R&D Investment Scoreboard (2015); Centre for Technology, Innovation and Economic Research (CTIER)

IV. From Half-formation to Transformation: What should our priorities for reform be?

The purpose of a National Innovation System is to build competitiveness in the long run. As wages rise, as natural resources are consumed, as the easier catch-up options are exhausted, it is the National Innovation System that should enable an economy to keep growing value-added over decades. This is particularly vital for India. It is entirely possible for an economy focused on labour-intensive manufacturing – textiles and apparel, footwear, food processing – to grow rapidly for years so long as wages remain low: that is the source of comparative advantage. The East Asian NICs did so for years until rising wages forced a move to higher value-added sectors – and with it, forced investment in innovation. But as Table 5A showed, Indian manufacturing is not concentrated in these labour-intensive sectors: for various historical reasons going back to the 50s, and unchanged even through the reforms of the 1990s, Indian manufacturing has not focused on labour-intensive manufacturing. Kochhar and her impressive roster of co-authors made just this point:

> "… it is striking that India's share in skill-intensive manufacturing, which was already high in 1980 despite its lower level of per capita income, has been increasing and is at levels reached by Malaysia or Korea at much higher levels of per capita income. There is also a striking contrast with China. China's share of output in skill-intensive industries is lower than India's and has been virtually flat whereas India's level has been higher and rising. The move towards skill-intensive goods is also reflected in India's exports: the share of exports of skill-intensive goods has risen sharply from about 25 percent in 1970 to about 65 percent in 2004".[20]

In Section III above, I have argued that India must transform its National Innovation System in the next twenty years, just as Korea did between 1970 and 1990 and China did over the last twenty years. It is instructive that near the *beginning* of this transformation, India already has a lower share of manufacturing coming from these labour-intensive sectors of textiles, apparel and food-processing (19% in 2010) than Korea (25% in 1990) or China (22% in 2010) near the *end* of theirs. In other words, we have for various reasons hopefully explained elsewhere in this book[21], for long had a manufacturing structure out of synchronization with our comparative advantage. We have a manufacturing structure focused on skill-intensive and capital-intensive sectors – sectors which require constant innovation, <u>and constant and substantial investment in innovation</u>, to be competitive over time. It is time our National Innovation System matched our industrial structure. So what must we do?

1. Adding dimensions to Structural Change – an aside and a point

A key driver of economic growth as countries catch up is the movement of people from lower value-added activities into higher value-added activities. Given our poor employment data[22], it is difficult to say specifically

[20] Kochhar, 2006, p 22. This paper is worth reading both for its outstanding content and for the co-authors, which include Raghuram Rajan and Arvind Subramanian. Note also that the China comment reflects when the paper was written, in 2006. Today, ten years later, as wages have risen Chinese industry has become more skill-intensive and we see the investment in R&D we discussed earlier.

[21] Hope springs eternal!

[22] If our R&D statistics are of poor quality and out-of-date, our employment data is simply awful. For example, total registered employment in the country in construction is 120,000 and in retail 600,000. If manufacturing employment is as under-reported, then all is robust and healthy!

how many are employed where and how this is changing. In spite of adding 10 m people annually to the work-force, there does not seem to be a drastic increase in those looking for work. In the absence of real data, simple observation says that we have been creating employment by the million quite successfully, though the bulk of the jobs created are in service sector and support jobs. My favourite example is drivers in Delhi: Delhi accounts for a quarter of all cars sold in India, one third of which are chauffeur-driven. That says Delhi has added over 1 m drivers in the last decade or so, but no employment data captures this. Add jobs in hospitality, retail, delivery, and construction and many Indian cities report reasonably tight labour markets: people are available for jobs, but they need to be attracted to better jobs from the ones they already have. So the problem is not jobs but good jobs. What is a good job? One which has higher value-added, and higher potential for improving value-added over time. This is why manufacturing matters. As Arvind Subramanian pointed out in a recent Economic Survey, "if the entire Indian economy were employed in registered manufacturing, India would be as rich as say South Korea."[23] Large-scale labour-intensive manufacturing matters for just this reason. So although an aside to an analysis of our National Innovation System, fixing employment in India requires making labour-intensive manufacturing dramatically more attractive. A second aside is that given that most employment creation has been in services, we need to understand how to grow productivity in services over the long run. Productivity growth in manufacturing is well understood internationally, less so in services.

But coming back to the National Innovation System, we need to see a much stronger presence in those sectors which are the most technologically dynamic worldwide. Table 3A listed the top 10 R&D intensive sectors: Pharmaceuticals, Auto, Technology Hardware & Equipment, Software & Services, Electronic and Electrical Equipment, Industrial Engineering, Chemicals, Aerospace & Defence, General Industrials and Oil & Gas. We have a small – or even non-existent - manufacturing base in sectors like Technology Hardware, Electronic Equipment, and Aerospace & Defence. So our priority must be to establish a strong industrial presence in these sectors. The government's initiative to attract investment by firms such as Foxconn and Flextronics, the world's largest technology hardware manufacturers, is very welcome. As their presence grows, this will create a pull on component

[23] Economic Survey, 2014-15

manufacturers to establish a local presence. As the component manufacturers in turn grow, the competitiveness of other (and smaller, and higher value-adding) downstream assemblers will also be enhanced.[24]

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

India has long had a distinct advantage over every other country in the availability of skilled technical people at relatively low cost. This is the source of our software industry and the growth in IT-enabled services. The IT industry has drawn on India's massive production of 1.5 m engineers annually– compare that with annual US production of 140,000 engineering (including computer science) and 160,000 natural science undergraduate degrees.[25] At the height of the Indian software boom in 2000, when that single industry was recruiting 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.

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 as economic reform has created a demand for product innovation and as engineer remuneration has risen sharply (in 2016, a good graduate engineer with 5 - 10 years of experience would earn about five times in real terms what he or she earned in 1991) that firms expect their average engineer to do work with more 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, Sun Pharma, and Cipla are betting on India's lower R&D costs as a basis for competing long term in a research-intensive industry. So too are auto firms like Tata Motors and Mahindra and Mahindra. But they are still exceptions. Multi-national investment in R&D in India has been much more widespread. 83 of the top 100 global R&D spenders are reported to have an R&D presence in India[26]. For example, Astra Zeneca has one of their largest R&D labs outside Sweden in Bangalore, and all their

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24 The knock-on benefits from vertical integration is not a new idea. Albert Hirschman wrote about it in 1958 in The Strategy of Economic Development.

25 National Science Foundation, Science and Engineering Indicators, 2016

26 "Currently, India has as many as 847 MNC R&D centres, representing about 83 per cent of the top 100 global R&D spenders and half of the top 500 global R&D spenders" http://www.rediff.com/business/report/column-fdi-can-spur-innovation-ideas-and-industries/20140808.htm; Centre for Technology, Innovation and Economics Research (CTIER)

work on tropical diseases is now done there. Cummins has a design centre in Pune, that became its second largest (after the US) in three years. Emerson employs 4000 engineers at their R&D centre also in Pune. Bosch employs 13,500 R&D engineers in India, their second-largest facility worldwide, and have announced a major expansion of their R&D presence in India. And most prominently, GE set up the Jack Welch Research Centre in Bangalore in 2000, which has since become GE's largest R&D facility world-wide. It employs 5300 people, including almost 2000 PhDs, and today has the largest Chemistry and Chemical Engineering PhD concentration in the country.

So industry must recruit the best talent available and aim it at pushing forward product designs in their own industries.[27] This talent should aim to learn from the best firms and research world-wide. As firms 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 progressively at other leading educational institutes.

Our major software service firms have a long record of success with rapid growth and high profitability sustained over decades. As we saw earlier, this success has not been accompanied by substantial investment in R&D. As the opportunity of further growth built around labour arbitrage[28] decreases, the pressure to grow through innovation in both product and service will rise.

All this will amount to an increased investment in R&D by Indian firms. 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. When Tata Motors and DRL become more typical of their industries, as sectors such as software start investing a share of turnover in R&D comparable internationally, and as new R&D intensive sectors such as technology and electronic equipment and defence grow, the investment in R&D by firms will meet the 1% of GDP set as a national target.

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27 In our book, From Followers to Leaders, Dave Wield and I 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 of 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.

28 Many in the software industry would argue with my use of the term 'labour arbitrage' today, pointing to the substantial capabilities built up in large-scale project management and execution excellence. I agree, but what share of our total software sector would exist if we needed to pay salary levels local to the market?

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, 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 world-class research-teaching centres. The 2016 Budget announcement of developing ten public and ten private universities into world-class institutions is most welcome; but where will we get our highly qualified research faculty from?

I would suggest we bifurcate CSIR and make it part unexciting-but-useful Technology Assistance Institution and part a large pool of professors. The four thousand CSIR scientists would be a huge impetus to the national higher education system, particularly graduate education. The IITs are best off, but even they have faculty vacancies of over 20%. Where are they all going to come from except from such an initiative?

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 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, and form permanent 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"*.[29] 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. We need a serious debate on 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 (4 percent to 20 percent). Surely a rejuvenated scientific research system (a well-recognised problem in our autonomous laboratories 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 DRL and Tata Motors; it needs to spread to Indian industry writ large.

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[29] Noll (1998), p 18. The emphasis is mine. The quote is from his introductory chapter in the edited volume, 'The American Research University: An Introduction'.

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.

4. The role of Policy

We have already covered the key policy role played by the State worldwide - to fund public research generously and broadly, and to do so in the higher education system. We also discussed the value of focused effort to attract investment in those hardware manufacturing areas which are largely missing in India. There are two more roles that the State can valuably play to build technical capability[30]:

To set the tone for discourse on technology: the great Indian cartoonist, R K Laxman, drew one of my favorite cartoons over 30 years ago. It shows a doctor examining a patient's eye: "You have some foreign matter in your eye. Would you like to keep it since it is foreign"? 70 years after independence we still have a nodding acquaintance with our colonial past. Some public sector firms specify in tenders that some products must be made in Europe or the US – regardless of local availability of better products. Several new shopping malls reserve prime Ground floor space for foreign brands, pushing Indian brands to upper floors. The state can help Indian brands and Indian technology – not by the socialist rhetoric of the past or by subsidies or by reserving procurement to local suppliers, but by setting a tone of wanting the best and encouraging local brands and technology to be that best. (It can also shame those errant public sector firms and private malls into change.) For many products, India is not a lead market – the product is developed for a different market, and made available in India through import or local manufacture.[31] Can the government launch a series of projects on particularly Indian problems – building flyovers in four weeks, or addressing waste and sewage across a hundred cities at a time, or providing clean drinking water to 600,000 villages? The government could fund R&D in both universities and private firms to develop solutions to these problems, in the process creating capabilities that could be used more broadly.

Just in case the reader thinks I'm heading in a Swadeshi direction, let me set the balance right with my next point.

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30 The late Nathan Rosenberg, whose writing and teaching greatly enriched my understanding of technology and economics, would always react if one used the term "Technology Policy". The policies that affect the building of technical capability most fundamentally are beyond those specifically concerning technology. Trade Policy and openness are usually more important than Research Policy. Education Policy affects a firm's ability to build technical capability more directly than a tax subsidy for doing R&D.

31 I owe this insight on lead markets to Gopichand Katragada, the CTO of the Tata Group.

Trade Policy which embraces the world: For too many years, India's trade policy stance has been largely defensive – focused on limiting access of foreign firms to Indian markets. We need to adopt a more positive and outward-looking trade policy. How can we improve access for Indian firms to emerging markets in South-East Asia, in Africa, in Latin America and the Middle East? Can we propose FTAs with the emerging markets where market needs are similar to India? And can we open our own market to foreign competition as the best way of forcing Indian firms to invest in technology: 25 years after serious reforms began, we still impose high tariffs on automobiles, auto-components and a range of consumer products. The threat of being pushed out of business is an impetus to invest in technology like no other.

R&D and the Tata Group

The Tata Group has long been India's leading enterprise, not only in turnover but in showing the way – whether this was the introduction of new industries (Tata Steel, a hundred years ago, or more recently TCS, and the software services business), global ambition (international acquisitions, which have taken the group's international turnover to over half), or setting standards (the Tata Business Excellence Model in quality or the Tata Code of Conduct in ethics). In the last few years, innovation – and with it growing investment in R & D – has become an area of focus. The group appointed a Chief Technology Officer in 2014, as a part of its increasing investment in R & D. In 2015, the group invested $ 3 B of its $ 100 B turnover in R & D.

While investment has been growing, it is still uneven across group companies. There are still some group companies that invest under 0.5% of turnover in R&D. The Group CTO, Gopichand Katragada, believes that one needs an investment above 1% of turnover to start seeing outcomes, and that more like 4% is needed to build leading positions in sectors that are technology intensive.

The group works to three time-horizons. In the 0 – 3 year horizon, the innovation focus is within each company and aimed at technology differentiation. Board level reviews take place of each company's innovation and technology road map. An explicit assessment of innovation and technology has been included in the Business Excellence Model, with a CTO-team trained in evaluation.

In the 3 – 5 year horizon, the group technology function brings multiple companies together, to work on technology and product development at the intersection of companies. Beyond 5 years, there is group-level collaboration with universities globally. A research centre in graphene has been set up at IIT Madras, and initiatives at the Royal Society in the UK, and at Harvard and Yale are underway.

5. And finally, to firm strategy and entrepreneurship

In the mid-2000s, a new confidence seemed to be spreading across Indian industry. This showed in international acquisitions, which have ranged from disastrous (eg Tata Steel and Corus) to brilliant (eg Tata Motors and JLR). But it also showed in a few Indian firms choosing to become multinationals and combining this choice with strong investment in technology. No group illustrates this better than Tata, India's largest group, with over half of its $ 100 B in revenue coming from outside India and investing just under $ 3 B in R&D world-wide. Tata is betting in business after business – energy, food and wellness, automobiles, digital consumer products – on building an international business resting on proprietary technology. Tata is not alone. Mahindra, Sun Pharma, DRL, Cipla, Kirloskar, Forbes Marshall, United Phosphorus, SRF, Triveni and a hundred other firms have all been expanding investment in both international markets and R&D. The slowdown of the 2010s has dampened confidence but it has not retrenched ambition. India needs a thousand multinationals, operating around the world, in every sector, building brands and reach. Our industrial structure, as we saw earlier, is already concentrated in skill and capital-intensive sectors. Building leading international positions in engineering or machinery requires substantial investment in innovation. A hundred Indian firms must match GE and Bosch and Emerson in each employing thousands of engineers in R&D. Our design institutes must produce world-class graduates that define new product functionality. Research-intensive higher education institutes must provide a standard of graduate education second to none. And a combination of trade policy and firm strategy must push firms overseas, deploying their technical capability worldwide. As our firms grow into multinationals, a few could emerge as giant firms with the wherewithal to be leaders in R&D. The aggregate data will then finally reflect a transformed National Innovation System.

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