Science, Technology and the Economy
An Indian Perspective

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Abstract

During the first three decades after 1947 India saw economic growth at only 3% but a vast expansion of the infrastructure for science and technology. In later decades, in particular during the last few years, the economy has grown much faster, but the S&T system has not experienced the transformation that business and industry have. The net result is that the public sector S&T system is facing a major crisis even as the private sector contributes little to the national R&D effort. Wealth generation in the country by private S&T services, most familiarly in Information Technology, has led to greater prosperity for the educated middle-class, but has also led to greater inequalities in income. The national scene is generally one of uneven achievement and extraordinary potential. It is argued that unless another major shift in S&T policy occurs in the country, there is a real danger that India will not go beyond being a blue-collar S&T power in the world.

Keywords

India's economic growth; Technology development in India, Indian space programme, Basic sciences, Blue-collar Science and Technology, Indian S&T policy

1. Introduction

In 1947 – with the end of British rule imminent – Jawaharlal Nehru prophesied to the Indian Science Congress [1] that

> as soon as we get over our present troubles, there will be a flowering of science and other activities in India which will probably astonish the world.

Sixty years after that speech, it is legitimate to ask: has the world been astonished by what India has done?

In its issue of 13 August 2007, *Time* magazine answered: 'the world's largest democracy is living up to the dreams of 1947'. As far as the economy is concerned, some 25 years ago it breached what had been called the Hindu rate of growth (of about 3%), and is today growing about thrice as fast. Indian businessmen are making waves around the world, acquiring foreign assets in what even a few years ago would have been inconceivable scenarios. And there are now more billionaires (in dollar terms) in India than in any other Asian country. As a kid I had been taught that the Nizam of Hyderabad was the fourth richest man in the world. The position is once again occupied by an Indian – this time by an industrial rather than a feudal baron [2]. At the same time about 25% of

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the population lives below the poverty line according to the Government of India, and many more according to others.

Turning to science and technology (S&T), economists suggest [3] that about half of economic growth in industrialized countries is due to technical factors. What role have such technical factors played in India's economic growth? The question demands a far more elaborate analysis than this essay can give. On the one hand, western media are full of stories about how S&T jobs are being lost to India (and China), how India is one of the best platforms in the world to do high-tech R&D (as *Business Week* said a few years ago) and so many multinationals (MNCs) decide to shift large chunks of their R&D to India, how the engineering graduates from the IITs (the Indian Institutes of Technology) are among the best in the world, how India has built a prolific, world class space programme on a 'shoestring' budget (according to *Aviation Week and Space Technology*), and so on. On the other hand stories about the ineffectiveness of Indian public S&T, the large cost and time over-runs on national projects, the pathetic state of most of our universities and the poor quality of their graduates fill the pages of the national media.

So what is the truth? The simple fact of the matter is that, compared to any other major nation with ambitions in S&T, India's performance is singularly uneven. The best in the country is often about as good as anywhere else in the world, but the worst is poor; tall peaks tower over a low average. The scene is thus full of stark contrasts: the richest and the poorest, the brightest and the darkest live side by side, but in a milieu where expectations are now rising fast. In Jeffrey Sachs's classification, India is divided into technologically adaptive and technologically excluded regions, the dividing line running approximately north west to south east across the middle of the country; no part of India is still technologically innovative. So the picture is mixed, but amidst the contrasts one can see how an ancient civilization is transforming itself – in its own way, at its own pace.

What this essay attempts is an examination of how science and technology in India have influenced and in turn been influenced by economic policy and strategic considerations. We do this by taking a broad historical view. Within the short length of this essay it will be difficult to cover all aspects of the subject, so I shall pay greater attention to those areas of S&T with which I am more familiar. Thus I will spend more time on aerospace, both because of my own experience with it and because the space sector provides a striking illustration of a particularly successful public sector technology development programme, unlike its aeronautical cousin which has a different dynamic altogether. Sectors other than aerospace, e.g. agriculture, steel, electronics, nuclear energy, also grew in the same period and have their own special characteristics, but they are beyond the scope of the present essay.

It is convenient to divide post-independence developments into three phases. In the first, lasting about three decades, a vast S&T infrastructure was built up as part of a socialistic effort to transform the country. Between 1980 and 2000 the economy began to be liberalized, creation of wealth began to be perceived as a worthwhile and respectable goal, and the private sector slowly began to assume a larger role in the scheme of things. In the new century the reforms have been more widely accepted and more vigorously pursued, and the accompanying rapid growth of the economy and of a consumerist class has had a strong but unexpected impact on the Indian S&T system, which has not yet quite adapted itself to these changes. The current scene is full of paradoxes, and the future should be interesting.

2. The early decades after Independence

The origins of the current science and technology system in India can be traced to the establishment of the first scientific agencies that the British found necessary to manage and expand their Indian empire in the 18th and 19th centuries. The Survey of India goes back to 1767, and the India Meteorological Department to 1875. Several of these agencies grew under some outstanding British leaders who (working with Indian assistants) left enduring imprints on their disciplines and on the organizations they headed (e.g. Sir Gilbert Walker in meteorology, Sir Ronald Ross in health). The establishment of institutes for carrying out more general scientific research or technology development in modern terms was more difficult. The landmarks here were usually due to Indian enterprise rather than British patronage. For example the Indian Association for the Cultivation of Science was established in Calcutta in 1876 by a remarkable doctor, Mahendra Lal Sircar. The Indian Institute of Science at Bangalore, whose establishment was resisted by British commercial interests for many years, finally started operating around 1909 as a result of a unique three-party agreement between the commercial house of Tatas, the Maharaja of Mysore and the British Viceroy's government. Beginning in the 1930s, the Indian National Congress, under the leadership of Jawaharlal Nehru and Subhash Chandra Bose, started planning for science and industry, almost as if in anticipation of the times when they would be able to make and execute national policy under their own government. British policy during and between the two world wars faced the difficult problem of striking a balance between responding to the demands of prosecuting war in distant colonies cut-off from Britain and ensuring that no commercially or militarily sensitive technology became available to the 'natives'. Meanwhile many Indian scientists, most notably C V Raman, S Ramanujan, M N Saha and J C and S N Bose, made international reputations from their strikingly original scientific work. Basic science, rather than technology or economics, was in fact a major cultural force that changed the country's perception of itself and its people's abilities.

It is against this background that one can understand how the advent of self-rule saw an immediate and dramatic increase in the attention devoted to science and technology. In 1946, the highly regarded Indian political leader C. Rajagopalachari was already presiding over the governing body of CSIR (Council of Scientific and Industrial Research), which had been set up in 1942, incidentally under pressure and even with offers of support from technology-starved Indian business interests [4]. CR (as he was known) joked with the scientists, hoping that they 'will look upon us [politicians] as one of those many natural forces you have got to cope with'. On 23 August, barely a week after he had taken over as Prime Minister of an independent India that was burning in the fires of a disastrous partition, Nehru called for an inter-ministerial meeting on science [4]. Nehru had taken the tripos in natural science at Cambridge, and used to speak nostalgically of the days when he haunted its laboratories. He looked upon science, and a 'scientific temper', as the solution to the problems 'of a rich country inhabited by starving people'. He declared that it would have been better for him to be 'the Director of this [the National Physical] Laboratory, if I had the competence, than to be the Prime

Minister'. The agnostic *pandit* reserved his sacred rituals for a new god: he liked 'to burn incense at the altar of science', and saw dams and factories as modern temples. He considered scientists and engineers more important than administrators and lawyers, and dismissed businessmen as unlikely to play a part in national development 'because of their limited outlook'. In 1958 he had Parliament pass a scientific policy resolution, which said in part that 'it was an inherent obligation of a great country like India with its tradition, scholarship and original thinking and its great cultural heritage to participate fully in modern science, which is probably mankind's greatest enterprise today'. Science and technology, therefore, were tools with which Nehru was going to transform a civilization in distress.

For about thirty years the public science and technology system that Nehru and his scientist collaborators like the nuclear physicist Homi Bhabha and the chemist S S Bhatnagar built seemed like a model for the developing world. The Atomic Energy Commission was established in 1948, and the civilian CSIR and the Defence Research and Development Organization grew dramatically in the 1950s and 60s. In education the IIT system was established, and the Indian Institute of Science and the Tata Institute of Fundamental Research grew substantially.

Nehru advocated a *socialistic* pattern of society, choosing this diluted term presumably to signal that the country's economy (unlike its science [1]) was not going to be completely state-run. The economy remains mixed to this day, although the proportions between private and public have varied over time. Given his opinion of Indian business it was natural that his government set up several modern industries in the public sector. These included machine tools, electronics, heavy electrical machinery, telephones, aircraft, airlines and many others.

Further initiatives were taken in public sector S&T by Nehru's successors (Nehru passed away in 1964), in particular Mrs. Indira Gandhi (who was Prime Minister for two terms, 1966-77, 1980-84). One of these had to do with agriculture. The experience of the mid 60s when India was forced to import large quantities of food grains (and, as the saying went, live from ship to mouth), demonstrated that food security had become a major problem. With the assistance of the US in particular, a green revolution was ushered in, and adequate food stocks were created and maintained to be able to tide over bad monsoon years. The food problem that had plagued India for centuries was solved in about a decade.

The other major development was that several new science departments were set up in the central government. These included the departments of science and technology, biotechnology, non-conventional (now renewable) energy sources, ocean development (now part of earth sciences), scientific and industrial research, and perhaps most significantly, space. As a remarkable indicator of national potential, space deserves some special attention.

3. The space programme

The space programme started in June 1972 as a project in the Department of Atomic Energy. Space has now become the most heavily supported civilian S&T

programme in the country: in the Tenth Five-Year Plan it accounted for nearly $ 2.6 B (at Rs.45/$), constituting 45% of the Plan budget [5] of the six major S&T Departments of the Government of India (excluding Defence). The father of the programme, Vikram Sarabhai, came from a well-known and wealthy family of businessmen and industrialists in Gujarat, but science was his career of choice; Mahatma Gandhi was a close family friend. When I first met Sarabhai in 1963 at Trivandrum, two things struck me: the Nike-Apache launch from the beautiful palm-fringed beaches of Kerala in south-west India, and the company Sarabhai was travelling with. It included not only some of the engineers and scientists who were then working with him, but also artists, dancers, journalists, and a group of distinguished foreign scientists (science was again a part of culture for him). Sarabhai insisted that India was not doing space for prestige, and, like a good businessman, suggested that sound economic evaluation of the required resources was necessary before embarking on the programme. He saw an opportunity in space science and technology for India to leap-frog from its backwardness and poverty. Having trained as a physicist who used balloons for cosmic ray work, it was natural for him to think of sounding rockets as another tool that would help his research. The first rockets launched in Trivandrum had to do with the upper atmosphere and the so-called electro-jet, a huge river of electric current that flows over the southern tip of India. Later the achievement of societal goals became the primary force driving the emerging space programme.

Unfortunately Sarabhai died when he was only 52. He was succeeded by Satish Dhawan, who set up a space establishment in the country that would realize Sarabhai's dreams. In 1972 this establishment took shape in the form of a Space Commission (a high level policy-making body), a Department of Space (part of the Government's administrative machinery) and ISRO, the Indian Space Research Organization (the technical executing arm) – a system that borrowed its structure (with some modifications) from the one devised by Homi Bhabha for atomic energy. In succeeding years ISRO went on to become a superb technology delivery system. Dhawan was also keenly sensitive to social and environmental issues; even as he led big science he showed great respect for little science. (So it was no wonder that he found bird-watching at the Sriharikota Range relaxing, and wrote a little gem of a book about bird flight.)

Pursuing the original vision, the ISRO programme eventually led to a series of satellites for communication, meteorology, broadcasting, natural resource surveys, education, and more recently cartography, telemedicine, ocean resources etc. Strong commitment to developmental goals kept space away from anything connected with defence. In 1975-76 ISRO used the US satellite ATS-6 for a Satellite Instructional Television Experiment (SITE) which broadcast a series of educational TV programmes on health, family planning, agriculture and related subjects to more than 2,500 villages in the country – and in many different languages. For its time (and perhaps to this day), SITE was the largest societally motivated experiment ever conducted in the world using space technology.

The visionary commitment of the founding fathers slowly got translated into reality. On 19 April 1975 India's first satellite called Aryabhata was launched from the Soviet Union, and on 18 April 1980 the Rohini satellite was launched by India's own launch vehicle SLV-3 from the Sriharikota Range. Since then there have been more than fifty satellites, of which about half are Indian launches, some into low-earth and others on geostationary orbits. Around ten have been launched for foreign customers [6]. With the recent successes of the polar (PSLV) and geostationary (GSLV) satellite launch vehicles, the country now has a robust capability to launch satellites of 3-ton class into geostationary orbits, and has achieved the objectives it set for itself twenty years ago. A lunar orbiter is scheduled for launch in 2008. All of this has been achieved on a budget which over twenty five years has grown to about $ 1 B (annual) currently.

What the space and some other programmes have thus shown is that, given the will, both technical and managerial skills are available in the country for running complex S&T enterprises, and even achieve societal goals in large measure [7].

4. The economic reforms

During the thirty-year socialistic period the 3% growth of the economy was not much higher than that of population, so the country was not getting much more prosperous. Towards the end of the period it was however probably more secure – not only in food. After the Bangladesh war and the 1974 Pokhran nuclear test, and the extensive industrial infrastructure that had been built up, a certain threshold of strategic autonomy had once again been recovered [8] since the 1962 debacle against China and the 1964 Chinese nuclear test. Development, which had followed a low-slow-steady approach (with low investments sustained over long periods), was visible but not spectacular [9]. It had turned out bright young people at the central institutes, but many of them began to go abroad and stayed there, reaping rewards for their contributions that were inconceivable back home.

All these factors combined to provoke the country to reexamine the philosophical roots of its economic policy. The visible and dramatic gains made by its south east Asian neighbours around that time and by China sometime later, adopting a model of growth that was seen as more pragmatic, could not be ignored. Changes in economic policy were accelerated by the advent of a young Prime Minister in Rajiv Gandhi, who (as a former airline pilot) was at home in modern technology. During his short tenure (1984-89) he advocated the wide use of computers and talked about building an India for the 21st century. Although his vision of the future did not gather much immediate support, there can be no doubt that it shook the country up.

In retrospect we can now see that, starting around 1980 an economic liberalization had been initiated without any fanfare, and the rate of growth of GDP went up to nearly 6% and stayed there for another two decades [10]. However in 1991 a balance of payments crisis led to a more explicitly articulated reform regime. Although at first resisted by both leftist political forces and Indian business interests, the positive aspects of change soon became so evident that in recent years the policy has ceased to be questioned.

During this period, once again in retrospect, no major initiatives in public S&T, of the kind that had characterized the earlier decades, seem to have been taken. There was however considerable consolidation. Businessmen entered government councils and public sector boardrooms – to the dismay of the socialists. Fundamental questions about the way that the S&T system was run began to be asked. There was a major review of CSIR, and constant questioning about why Indian S&T needs to keep reinventing the wheel. The period did produce some tension, but at the same time brought into open questions that had remained publicly unarticulated for a long time.

In aerospace, that consolidation also saw the initiation of the Light Combat Aircraft (LCA) project and maturing of the Advanced Light Helicopter (ALH). The LCA has not yet entered service and is unlikely to do so for another few years, but there is an order for twenty from the Indian Air Force. And the ALH, now named *Dhruv*, has been certified in several variants and seems to have established itself as a very useful product of the aircraft industry. Space and atomic energy continued with their programmes, the former with development of the early satellite launch vehicles and the design and manufacture of a series of remote sensing and other satellites, the latter with more nuclear power stations and a second round of nuclear test explosions in 1998.

The most striking development of these decades, however, was the unforeseen and spectacular growth of the IT services industry, which had never figured in the official five-year plans. Not many would have predicted that computers would so rapidly affect virtually all walks of life, or that making the right software could prove to be a major global challenge. Even fewer people could have imagined a rewarding opportunity for India to emerge seemingly out of nowhere, so to speak, to provide the world with a huge, unsuspected reservoir of technical talent that would become a source of excellent software skills.

Although the IT phenomenon owed little directly to the government, it would be only fair to recognize that it was rendered possible by the vast expansion of S&T education (even if of highly variable quality) in earlier decades, and the popularization of computers by a young Prime Minister. Before the 1980s the major employer of outstanding graduates in S&T was the public sector – research institutes, national laboratories, high-end (public sector) industry etc. The new opportunities unveiled by the computer revolution were often seized by those who learnt some basic skills at one of the roadside computer schools that began mushrooming in cities like Bangalore. It is impossible to resist the temptation to attribute at least part of this phenomenon to a cultural advantage that Indians derived from their own classical science. That the numeral system that is internationally used today can be traced to India is well known. Perhaps not so well known is the fact that the computational power unleashed by the new system led to an extraordinary flowering of numerical mathematics between the third and sixteenth centuries in India. This came to be known in the west only through contacts with the Arabs in the early centuries of the second millennium. The primacy given to number in India, in combination with Indian appreciation of linguistics and grammar as primary sciences, suddenly became relevant to the creation of modern software. (So there was a point to the mention of cultural heritage in the 1958 scientific policy resolution.)

5. The new century

With the recent spurt in growth rate to the neighbourhood of about 9%, GDP is now about a trillion dollars, and pictures of India rising or shining have been constantly projected before the world, leading to an unprecedented bullishness about the Indian economy. The changes that have occurred in the business scene are indeed striking. The country has a healthy foreign exchange reserve, raising capital has become easier; population growth has slowed down. The economic reforms have been embraced across the political spectrum including the leftist governments in power in a few states. The emergence of the call-centre and BPO sectors has led to worries about lost US jobs. Although that loss is minute, reports about how US workers are worried about being 'Bangalored', as the phrase went, changed the way that both Indians and Americans looked at economic reforms and globalization. Indeed, to this long-time resident of Bangalore, it is clear that the recent prosperity of the city is due to these changes in the economy – although many of us are dismayed at the price that the city has paid in terms of pollution, congestion and a failing infrastructure for what is still largely selective prosperity.

Given the new growth rate, personal income in India should make it a middle income country around the 2020s. Many leaders, and in particular the last President Dr Abdul Kalam, have held up as a viable national target its transformation to a developed nation by 2020. Whether this will happen will in part depend on the definition of 'development'. If there is no major political, military or financial upheaval, and Europe is not going to be counted as a single unit, the Indian economy will in all likelihood be the third largest in the world before 2020.

The effects of the growth in the services sector in the new century are very visible. In the late 80s we were promised that the waiting time for telephone connections would be reduced from three years to two by 2000, and that the fraction of the population possessing telephones would go up from 2 to 3%. Thanks in part to the opening of the telecommunication sector to private enterprise, and to dramatic changes in technology through mobile telephony (with 200M mobiles in the country now) telephones are no longer the possession of a privileged class. Similarly television now reaches more than 90% of the population. Air traffic is growing at 20-25% per annum or more, and sleepy airports of yester years are now milling with passengers. Till the 1980s it used to be said that most of the air traffic in India was the movement of civil servants at public expense. Now civil servants constitute only a small fraction of those flying on Indian airlines.

This recent boom has not been without its problems. Apart from urban chaos, large sections of the population have not benefited significantly from the boom. Without the boom they would probably have been worse off, but that is no consolation. The middle and upper middle classes (now about 25% of the population) have gained a great deal, and some businessmen have become super-rich, but the far-too-slow trickle down the economic ladder has become a serious problem. The government claims that the population below the poverty line has now declined. Although the decline itself cannot be in doubt the numbers quoted are open to question; the official Indian definition of the poverty line is any way so low that there are a lot of poor people even above the line [11]. Certainly the gap between the rich and the poor has widened.

Literacy levels in the country vary widely, from nearly 100% in states like Kerala to only about a third among women in states like Bihar. The national average is just barely more than 60%. Water and public health remain problems across the country.

There is a chronic shortage of energy, and although innumerable analyses of the problem have been made, the country has been unable to meet its needs. Oil prices rise, loss and theft of power in transmission continue, little R&D is done on new technologies (e.g. clean-coal, photo-voltaics), and pricing policies offer free power to farmers with the power generators being left to resort to some cross-subsidy. Economic growth may in coming years be seriously hurt by severe energy shortages.

6. Technology

There are several questions here that we need to ask ourselves. First, what have been the relations between the economic reforms initiated during 1980-2000 and the development of science and technology in the nation before and after the reforms? Did the infrastructure of public science and technology built up before 1980 have anything to do with the accelerated economic growth of the last few decades? What of the future?

In strategic technologies other than space, the country has two operational missiles designed and manufactured in India, namely the *Prithvi* and the *Agni* series. There is an Indo-Russian cruise missile called the *Brahmos*. We have already mentioned *Dhruv* and the LCA. The main battle tank *Arjun* is also now under manufacture. Many of these projects have taken a long time to complete; and some (like the LCA) are still on-going. A strong policy of self-reliance, the prevalence of international technology denial regimes which became stricter after the 1998 nuclear tests and the consequent need to develop some crucial technologies from scratch, frequent problems with funding, all these have combined to extended project time schedules.

But the counter examples of space and atomic energy, subject to even stricter technology denial than aircraft, demand an explanation for their relatively greater success. It appears as if management through a Commission/Department/Organization structure and steady support at the highest political levels have favoured the space and nuclear sectors. Paradoxically, therefore, long-term technology development programmes subjected to the strictest denial regimes have eventually done better than military programmes where foreign systems – usually of an earlier generation – have been available for import. This is not so much because military requirements have in principle to be met on tighter time schedules, but rather because of lack of well-defined make-buy policies and inappropriate management structures. The so-called mission agencies have gained from formulating very clear goals within a well-formulated long-term perspective – sometimes very long indeed. For example, the thorium-based strategy for nuclear energy was proposed by Homi Bhabha in the 1950s, but an operational system is unlikely within the next three decades: so we are talking about total time scales approaching a century. The long-term programmes for development of space technology drawn up in its initial decade have taken nearly three decades for realization. But in a way the low-slow-steady policy has in fact borne fruit. After all, when India's first commercially successful automobile was launched in 1998, there had already been eight Indian-made satellites put in orbit on Indian rocket systems. As another example, there were operational parallel computers in the country without a hardware industry, and well before the software boom. So there *has* been a bit of leap-frogging!

What the successful mission agencies have shown is that development and deployment of sophisticated technology in India is not only feasible, but can be cost-effective. Estimating an overall rate of return for the space programme, for example, is not easy, because some of its societal services are offered free (e.g. radio); also capital and other facilities available to a government department do not operate at market rates. However, a detailed exercise can be carried out in such cases as transponders for communication satellites. The conclusion from such a study carried out recently by Sankar [12] at the Madras School of Economics is that effective lease charges on an ISRO transponder are 64 to 75% of equivalent low-cost transponders available in the global market. (The factors are respectively for high- and low-power C-band transponders.) These studies show beyond doubt that India can be competitive in the international market for high-technology products. Although the space programme (like the nuclear) has not been required to be commercially successful, this does not appear to be beyond them, as some of their corporate off-shoots have indeed been profitable. Furthermore, such successes in technology delivery suggest that failures in other cases are often due to inappropriate management structures and policies, lack of political will, commercial non-viability and the seduction of alternative imported systems. *Success in India is now policy-limited, not skill-limited.*

In the private sector pharmaceuticals and chemicals have done very well. The automobile industry has shown the capability to come up with advanced designs that can withstand competition from foreign brands. Biotechnology and aerospace design (and more generally engineering) services are likely to follow suit.

However, India still relies on import for its more technology-intensive products in the large majority of cases, including all civilian and most military aircraft, a variety of defence equipment, most automobiles, drugs, computers, communication equipment etc. Thus, the successes constitute only a small fraction of the total technology market in the country.

Indeed, the economic reforms have triggered a vast internal migration of skills to sectors that are directly in wealth creation, particularly in the export of services. (The service sector now accounts for more than 50% of the Indian economy). So the reforms have indeed been successful in this respect! But major new initiatives in science and technology, public or private, have been fewer. With rare exceptions, India still remains predominantly a recipient rather than source of technology. Local talent is being increasingly used by MNCs and foreign enterprises to develop systems elsewhere that might be sold back here. There is no pressure yet in the present economic system to create wealth through technology development and intellectual property generation within the country.

7. Basic science

The national science base is one essential ingredient of an innovative technology system. One widely used measure of global standing here is the number of internationally recognized publications originating from the country. Table 1 collects some interesting statistics. In 1997, the number of publications from China began to match those from India, each being less than 5% of the US figures. In 2006, the numbers for China, India, and the US had gone up by 360%, 60% and 18% respectively. India's proportional contribution to the global scientific literature has for many years stagnated at approximately 2 %, while those of Brazil, China and Korea have improved by factors of 3 to 10 in the last ten years. In global ranking of impact-making science India is now number 22, below China, South Korea and Poland, and far below the US (which is number one by a large margin), the major European powers and Japan [13].

Table 1 also confirms that India is the most cost-effective source of open R&D in the world (as it is in successful science-intensive technology development). Comparison on an institution-wise basis (not shown here) suggests again that the leading centres of academic research are competitive in performance with much better-funded international institutions.

India's investment in R&D is one of the lowest in the world for a major nation: about 0.8% of GDP, compared to more than 2.6% in South Korea and the US and 1.3% in China. South Korea is a particularly interesting case for comparison. Its GDP, as well as the government's investment in R&D, are about the same as in India. But the private sector in Korea invests twice as much in R&D as the Government does, whereas in India it is less than a third. This indicates that in India *neither academia nor industry finds the other necessary for its prosperity*. Similarly the small number of PhDs in engineering and technology is another indicator that most private industry does not depend on local R&D. There are however exceptions: there is more private R&D in biotechnology and pharmaceuticals, where India has some international presence.

India has the potential to become a global centre for high-level undergraduate education because of its vast experience with the successful IIT system, but national efforts in this direction are still very weak.

Table 1 : Some S&T Indicators for Select Countries

Country	Total no. of publications (2006)[a], (change over 1997)	High-impact publications % (change)[b]	GDP, \$ T (2003)[c]	Investment in R&D, % GDP[d]	Investment R&D, \$ B	\$ M/ publication	PhDs in E&T[e] per year
USA	451 028 (+ 18%)	63% (– 4%)	10.9	2.68%	292.0	0.65	8000
China	78 671 (+ 358%)	0.99% (+125%)	1.42	1.31%	18.6	0.24	9000
South Korea	(+ 290%)	0.78% (+178%)	0.61	2.64%	16.1	0.60	
India	26 963 (+ 60%)	0.54% (+69%)	0.60	0.77%	4.6	0.17	700
UK	~ 122 000	12.8% (+25%)	1.79	1.89%	33.8	0.28	

[a]NB [b]King [13] [c]NSR [14] [d]NSR [14] [e]Wadhwa 2007*Issues* [15]

8. The stark contrasts

So on the bright side we have an elite educational system that produces a small number of excellent engineering graduates (3,500 selected in competition for the IITs from nearly 5,00,000 candidates) at a fraction of the costs in the US, an R&D system that produces international publications at the lowest unit cost among major nations, and the largest and best space programme in the world in societal applications crafted on a 'shoe-string' budget. More than 300 MNCs have set up large R&D centres in India to use Indian talent [16]. The country has a youthful demographic profile, with more than half the population being younger than 30 years. Young people in India still *like* to study science and engineering. Indian business is going aggressively global.

On the dark side, the traditional universities are in bad shape. According to the National Assessment and Accreditation Council of the University Grants Commission (reporting in 2007 [17]), 90% of the colleges and 68% of the universities are rated middling to poor, and 57% of the faculty in colleges have no post-graduate qualifications. Many universities cannot even hold examinations on time, and have no credible grading systems in place. Industry leaders complain that many engineering graduates are unemployable. The Union Minister for Human Resource Development admitted that higher education is a 'sick child' [18]. Inaugurating the Indian Science Congress earlier this year Prime Minister Manmohan Singh said that he was troubled by the decline in the standards of research in the universities (and even, he added, in advanced research institutes).

In 2001 there were still some 350 million illiterates. Although there is nearly 100% enrolment in primary education, drop-out rates are high. Only 7% of the eligible group is enrolled in universities. Vocational education is neglected: much native talent that could be very productive remains untrained in new skills.

Careers in S&T, especially in a public sector saddled with archaic recruitment and assessment policies, are no longer attractive to most young Indians; both junior and senior staff are lost every year. The IITs cannot fill the faculty vacancies they have.

Young talent – even when deeply interested in a particular field of S&T – often therefore turns to the more rewarding opportunities that are rapidly opening up outside S&T. For all these reasons the public S&T system in India seems to be heading towards a crisis. Paradoxically, even the private sector industry that needs more scientists and is willing to pay well cannot find the right kind of people for their laboratories, so the present educational system is not training the right kind of graduates in sufficient numbers.

9. The Role of Indian S&T policy

How has national S&T policy evolved in response to perceived needs and external factors over the last sixty years? Nehru's scientific policy resolution of 1958 was basically a declaration of faith, and promised to promote science, educate and train scientists and technical personnel, encourage individual initiative and secure for the country the benefits of scientific knowledge. Scientists were promised good service conditions and an honoured place in advisory roles to government. The foundations that the policy laid led to an S&T infrastructure that was remarkable for its times but is now experiencing difficulties. But the slow economic growth that characterized the period began to tell: in 1963 Nehru himself said he wanted a society where it was 'open to every person to lead what may be called the Good Life'. One of Nehru's constant advisers had been the distinguished British physicist and Labour peer Lord Blackett, who in 1967 warned India that 'science is no magic wand to wave over a poor country to make it a rich one'. He emphasized the importance of the whole innovation chain – an idea that has come to be appreciated only forty years after his report.

With the advent of Mrs Gandhi as Prime Minister there was greater concern for national security. In her addresses to the Science Congress [19] she spoke about maintaining independence of judgement and action, and mildly chided the scientific community for being 'unduly influenced by the technological styles of the affluent west'. Self-reliance and national strength were the goals of *her* 'pilgrimage' towards science. Twenty five years after her father's scientific policy resolution she announced India's first technology policy statement, whose very first objective was to

> attain technological competence and self-reliance to reduce vulnerability, particularly in strategic and critical areas, making the maximum use of indigenous resources.

Economic liberalization that started in the 1980s gave more space to private industry. The period coincided with the beginning of the computer revolution in India. This proceeded apace after 1991. Formal recognition of these changes had to wait till 2003, when a new S&T policy was enunciated by the Vajpayee government explicitly recognizing the importance of innovation, of involving the private sector and of protecting intellectual property rights. The economy became now the centre of attention.

Have these policy statements any connection with reality? Certain long-standing issues have always been mentioned, but not resolved to this day: water, literacy, energy, poverty alleviation are examples. Certain other features have always been implemented, irrespective of the party in power: programmes in the strategic sector (the one exception here was the Morarji Desai government of 1977-80), agriculture, special new technologies like ICT and bio-technology. Others reflected adjustment to changes that occurred without explicit domestic policy initiatives, often in response to global forces; e.g. IT, wealth creation, IPR.

10. The Future

The Indian experience shows how, even within the framework of its political and bureaucratic machinery it is possible to build major technological capabilities that can deliver. However, apart from that part of the strategic sector subject to strict technology denial regimes, it has been difficult to scale up the underlying national dynamic.

Computer and internet technologies have made a great impact because they revealed to Indian engineers a field where their culturally inherited skills matched those in global demand. Coupled with the advantages of living on the other side of the world from the US, enabling work round the clock and globe, IT created a large number of lucrative jobs for an educated middle class that had been starved of opportunities. So, perhaps for the first time in the country's history, knowledge of a certain kind could be converted to wealth with relative ease, provided only that one was willing to work hard.

Indian skills have been chiefly tested and used only in IT *services.* The hardware industry is weak, and even the software side has found it more profitable to help *foreign* businesses run better. Industry finds it easier to create wealth by manufacturing to imported designs, and has not found it necessary to undertake much technology development, by itself or in league with R&D and academia. Even those who do not take easily to software development find that the salary sacrifices demanded by public S&T are unacceptably high. A telling instance is provided by the response of young people to the biennial air shows in Bangalore. On the public days the Yelahanka air base where the show is held is filled with excited young boys and girls, thrilled by the aircraft on static and flying displays. Few of them however seek aeronautics as a profession, for it is unattractive in remuneration, and is dominated by a bureaucratic public sector. Similarly the widespread liking (about 30%) for mathematics among the young [20] does not translate to careers in the subject. An unanticipated effect of the reforms has therefore been to weaken public S&T.

On the whole, *the public Indian S&T system has not been directly benefited yet by the economic reforms.* The *josh*, the exuberant and aggressive confidence that characterizes Indian business (who have a regime they are happy with) has not yet touched the scientists. Although one sees innumerable examples of innovation in daily life – from marketing to fixing things to getting things done in a difficult bureaucracy, the overall climate for high-level technological innovation is still lacking. If the country wishes to move away from being a mere blue-collar S&T force and become instead a source of innovative technology, not just a recipient, another shift in the S&T policy regime is necessary. Such a shift has to take into account the new realities of a rapidly growing, globalizing economy. The most important change that is required is the creation of effective networks involving academia, government and business to promote innovation. Perhaps things are changing: the Indian automobile industry is conceiving and developing its first innovative products.

To remove the shackles on education and R&D so that the innate innovative energies of the people are released, a more integrated view of national S&T is needed, cutting across fields but serving a clearly stated, easily understandable national goal. Such a goal might be the emergence of India as a developed nation or a harmonious society or a renewed civilization, with a specific definition of what would constitute that achievement. Many components of such a goal would be social, but those that involve S&T and the economy might include the following:

- Making India a middle-income country on a per capita basis (average income of order US $ 3000 per year at current rates), and at least the world's third largest economy in national terms.

- Literacy rates exceeding 90% across the country, irrespective of caste, religion, gender.

- Guaranteed university education to all who pass a national eligibility test, supported by a massive system of fellowships (funded largely by private industry) to all who are in need of material support for carrying on with their education.

- A diverse, more flexible education system, welcoming private investment, separately or in partnership with the public sector, with disproportionately generous tax incentives for large investments.

- Encouragement of close links between academic and industrial research, through attractive matching grants, and of innovation, by enabling talent to move easily across the country and the globe, and between academia and business.

- An economic liberalization of the S&T system, with an extensive performance-linked reward system, and encouragement of faculty setting up their own technology enterprises (subject to appropriate monitoring mechanisms that chiefly demand transparency).

- An imaginative and comprehensive plan for creating an S&T ecosystem, and a complete innovation chain including the banking system, with high rewards for successful technologies developed with substantial contributions from within the country; in particular, a special system for helping the end-game in product development.

- An honoured place for basic research, with a system of higher remuneration for academic scientists combined with generous awards for outstanding performance.

- Establishment of world-class universities where undergraduate and post-graduate education are combined with the highest international standards in research, and significant faculty strength in relevant social sciences.

If major initiatives along the above lines cannot be taken, there is every likelihood of India remaining an efficient blue-collar S&T nation that provides R&D services that help more aggressive innovators elsewhere in the world, from one side an outsourcing of services being matched by a corresponding outsourcing of innovation from the other.

Fortunately, there are indications that education is beginning to get the attention it needs. And Indian industry is slowly moving up the innovation chain, based on work in India in some cases and on technology acquired from abroad (through corporate mergers and acquisitions even) in others. There are outstanding innovators in India – but their numbers are still too small. Perhaps India is in another time of transition.

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