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Rocket Science, Other Science
A trajectory of Indian Science &Technology from the 20th to the 21st century

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> *The untapped resource of technical and scientific knowledge available in India for the taking is the economic equivalent of the untapped continent available to USA 150 years ago.*
> – Milton Friedman 1955 Report to Union Ministry of Finance

I feel greatly honoured at having been invited to present the 2009 K R Narayanan Oration at this renowned university. Shri Narayanan was a person that I came to know, and quickly learned to respect, especially during the period (1986-89) that he was Union Minister for Science and Technology – a period that started shortly after my own tenure at the National Aerospace Laboratories began. It was both a pleasure and a privilege to have a Minister of Shri Narayanan's erudition, with a keen appreciation of the role that science and technology could play in India's development, and a regard and sense of friendship that he and the scientific community shared with each other. When in 1986 NAL embarked on a parallel computing project, Shri Narayanan was one of the closest friends and supporters we had. This friendship continued even after he became the President of the Republic, and I have the fondest memories of his visits to the National Institute of Advanced Studies and the Jawaharlal Nehru Centre for Advanced Scientific Research, where he showed once again his warm and almost personal interest in the future of Indian S&T and the men and women who pursued science in India.

It is a privilege therefore for me to be able to pay a tribute to a great scholar, gentleman and friend of science, and I am grateful to my hosts at ANU for providing me an opportunity to do so.

It seems appropriate to use this occasion to sketch a personal view of the path that India has followed in science and technology since 1947, the year that

signaled the end of British rule, although (as I shall argue briefly later) the roots of national policy in this period are intimately connected with developments in Indian science in the first half of the 20th century. This lecture however is not intended to be a comprehensive survey of all the significant developments that took place during this period. Some of them have already formed the theme of previous Narayanan orations. Instead I shall describe the path that has been followed in areas in which I have myself been involved in some way, in particular aerospace and computer technologies.

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Let me begin with space. The first and indeed the most remarkable aspect of India's space programme is how long ago it started. The Indian National Committee on Space Research was established in 1962 as a part of the Department of Atomic Energy by Homi Bhabha, with Vikram Sarabhai as the Committee's chairman. I shall return to the great impact that these two leaders have had on Indian S&T in the last half-century, but let me only note here a Bangalore connection. The speed with which space research was made part of the national agenda was perhaps in part due to the visions that Bhabha and Sarabhai shared on the way to build S&T in India. Both had been at the Indian Institute of Science during the war years – Bhabha having been prevented from resuming his career at Cambridge by the war, and Sarabhai having been forced to wait to go to Cambridge to complete his doctoral degree. As Amrita Shah says in her fine biography of Vikram Sarabhai (2007 Penguin),

> It is tempting to speculate that Vikram and Bhabha, the two princes of Indian science, used their youthful days in Bangalore to spin dreams for the future . . . sharing their precocious hopes in the rambling wild landscape of the IISc or sealing a blood pact under the bright lights of the West End [Hotel] . . . because of the uncanny sureness with which they set about their plans and the suggestion of complicity in so many of their actions.

The modest National Committee set up in 1962 was eventually to lead to what is probably India's most striking technology development programme today.

Vikram Sarabhai came from a well-known and wealthy family of businessmen and industrialists in Gujarat, but chose science as his career. When he first invited me in 1964 for a personal discussion at Trivandrum, two things struck me. The first was the dramatic Nike-Apache launch from the beautiful, unspoiled palm-fringed beaches near Veli Hill. And the second was the company that Sarabhai was travelling with. It included not only some of the engineers and

scientists who were then working with him, and a group of distinguished foreign scientists, but also artists, journalists and various other friends. Sarabhai asserted that India was not doing space for prestige, and, like the good businessman he was, insisted that sound economic evaluation of the required resources was necessary before embarking on the programme. He also saw space science and technology as offering an opportunity for India to leapfrog from its backwardness and poverty. In the debate that still sometimes goes on between the virtues of leapfrogging vs. those of piggybacking, Sarabhai (like most scientific leaders of his time in India) was definitely for leapfrogging. Having trained as a physicist who was used to balloons for cosmic ray work, it was natural for him to think of sounding rockets as providing 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 magnetic equator that lies across the southern tip of India.

Unfortunately Sarabhai died when he was only 52. He was succeeded by Satish Dhawan, my own guru at the Indian Institute of Science, and it was left to him to 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) and a Department of Space (part of the Government administrative machinery), which in another few years took charge of the Indian Space Research Organization (the technical executing arm) as well. In succeeding years Dhawan went on to build the superb technology delivery system that ISRO has now become in India.

Dhawan vigorously and single-mindedly pursued the idea of using space technology for national development, and presided over a programme that eventually led to a series of satellites for communication, meteorology, broadcasting, natural resource survey, education, and more recently cartography, ocean resources etc. He showed his deep commitment to developmental goals by preserving space as an open, purely civilian organization. In 1975-76 he used the US satellite ATS-6 for a Satellite Instructional Television Experiment (SITE), which broadcast a series of educational TV programmes on such subjects as health, family planning and agriculture to more than 2,500 villages in the country – and in many different languages. For its time, SITE was seen as the largest societally motivated experiment ever conducted in the world using satellite technology.

Dhawan also was an unusual man. Even as he led big science he retained great respect for little science. He was keenly sensitive not only to social issues but also to environmental ones. So it was no wonder that he handled in a most sensitive spirit the displacement of the inhabitants (including the cattle!) of Sriharikota Island, which houses ISRO's satellite launch complex at what is now

the Satish Dhawan Space Centre. He found bird-watching at the Sriharikota Range very relaxing, and even as he built and ran his space empire made time to write a little gem of a book about bird flight. He spent much time charting the future of the space programme in India, often with sketches and charts drawn in his own hand. And he realized that the programme often called for unconventional methods.

The visionary commitment of these founding fathers slowly got translated into reality. On 19 April 1975 India's first satellite called Aryabhata, after the great Indian astronomer-mathematician (5th c. CE) was launched from the Soviet Union. On 18 April 1980 the Rohini satellite was launched by India's own launch vehicle SLV-3 from the Sriharikota Range. On 10 April 1982 the first Indian geostationary satellite INSAT-1A was launched from the US, and on 17 March 1988 the first Indian remote sensing satellite IRS-1A followed. So by the 1990s the programme was beginning to achieve the objects that it had set for itself. By 1997 India had launched 8 satellites on its own rocket launch vehicles (and 12 more on others') by the time it could put its own automobile on the roads (Indica in 1998). So there *had* been some leapfrogging. With the more recent successes of the Polar Satellite Launch Vehicle (PSLV) and the geostationary launch vehicle (GSLV), the country now has what seems like a robust launch capability in satellites up to the 3-4 tonne class for geostationary orbits. India's entry into inter-planetary exploration has been signaled by Chandrayaan 1, a remote-sensing lunar orbiter. Although prematurely terminated recently, it has acquired much new data on the lunar surface, and in particular provided the strongest evidence yet of the presence of water on the moon. And the rest of the world is taking notice of these developments. The US magazine Aviation Week and Space Technology, the most widely read periodical in the field, has at various times run stories on India's 'prolific space programme', called in 'world class', and pointed out that it is run on a 'shoe-string budget' (currently of the order of about a billion US dollars a year).

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To understand the early genesis of the Indian space programme we must appreciate that, in the India of the 1950s and 60s, there was widespread faith in the idea that modern science and technology can solve many of the nation's old problems. Most Indian scientists believed this, and Jawaharlal Nehru, the first Prime Minister of the country, was a most eloquent and powerful advocate of the idea. Soon after the end of British rule, India set out (under Nehru's inspiration) on a spree of establishing new laboratories, agencies, industries and academic institutions. As Nehru happily laid one foundation stone after another, he confessed that he would much rather be the Director of one of those laboratories, if he had the competence, than be the Prime Minister of the country. He

advocated science with almost religious zeal. He saw dams, factories, and laboratories as modern temples; and when he inaugurated the Indian Science Congress year after year he would say that he had come to 'burn incense at the altar of science'. In 1958 he had Parliament pass a Scientific Policy Resolution which declared Government's determination to participate fully in the march of science, which Nehru called 'probably mankind's greatest enterprise today'.

Nehru's vision was that science, and in particular what he called the scientific temper, was an instrument for nothing less than civilizational revival. This vision was shared by virtually all Indian scientists of that time. Among these the most dynamic and charismatic was Homi Bhabha (1909-1966), who set up the country's atomic energy programme – which incidentally became first the father of the country's space programme (as we have already seen), and later a model for it when it became independent. Bhabha invented, with Nehru's encouragement, the administrative and scientific mechanisms that made it possible to pursue national science and technology goals in a focused way.

How was it that in 1947 Nehru and people like Bhabha could have had such extraordinary faith in the path of science, as well as the confidence that its pursuit would first of all be feasible, and secondly successful? One part of the answer to these questions lies in Nehru's unique educational background, for he studied natural science in Cambridge before his forays into law and politics. Equally important was the knowledge that, in the first half of the 20th century, a number of Indian scientists had begun to make such outstanding contributions as to attract attention all over the world. The remarkable thing about these scientists was that they were all nationalists in some sense – not in a jingoistic or xenophobic way but rather as those intent on recovering lost civilizational pride. The most famous of these was C V Raman, who won the Nobel Prize for physics in 1930. Then there was Meghnad Saha, who through his well known thermodynamic analysis of ionization was a pioneer in theoretical astrophysics; Satyendra Nath Bose, who invented quantum statistical mechanics even before quantum mechanics had been properly founded; M. Visweswaraya, an engineer who promoted new industry as the dewan (Chief Minister) of the Maharaja of Mysore, and became India's most eloquent and passionate advocate for industry and technology, often crossing swords on these subjects with Mahatma Gandhi. Earlier Jagadish Chandra Bose had made a microwave device that was the precursor of Marconi's radio. Then there was S. Ramanujan, the one least directly influenced by Western scientific thinking, but also the one to make the most striking impact on it by his vast outpouring of extraordinary mathematics. He was not just a much better mathematician than the rest, but (to borrow a description used by Mark Kac in another context) he was a magician. The methods he used to obtain his extraordinary results can only be ascribed to deeply rooted cultural instincts and

weapons that he trained on modern mathematics, rather than on anything much he learnt directly from the West as method.

As I said, the confidence that people like Nehru and Bhabha had in the potential of Indian science was inspired by the knowledge that some Indian scientists had done outstandingly well against heavy odds. That faith was clearly shared by the well-known American economist Milton Friedman (Nobel Prize 1976) whose opening sentence in his 1955 report to the Finance Ministry provides the theme of this oration.

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It is useful to realize that Indian policy in many of its major technology programmes was for long based on what may be called the low-slow-steady approach. The funding in any given year may not be very high: but budgetary support has been steady, and the country has shown that it has the patience to learn everything from scratch as a technology is painstakingly developed. This policy has paid rich dividends. We thus have not only a very good foundation but even an impressive super-structure in some of the fields in which the country has invested.

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But times have changed. The economic reforms initiated in the early 90s have over the last fifteen years taken root. These reforms have been responsible for spectacular growth in many ways. From the point of view of a Bangalorean, IT and the software business come most immediately to mind. Growth in some of these areas cannot be attributed to direct government support. They just happened because of government's new economic policies. But as economic growth picks up pace in the country, time becomes a more important value than it was before. The need now is to make things faster and cheaper and hence to create wealth. So we should ask ourselves what set of policies we might now adopt that will do for the future what, 30-40 years ago, Sarabhai and Dhawan did for the present.

I would like to suggest that there are a couple of options that the country may be ready to examine. (I must emphasize at this point that I do not speak here as a Member of the Space Commission.) First, in line with the changed economic thinking, we may ask ourselves whether a much more vigorous commercialization of space is feasible and necessary. ISRO has done a commendable job of involving private industry in their programmes. But should we do that in an even bigger way, so that the publicly supported space programme can direct its manpower to taking a lead in things that private enterprise will not or cannot do? – such as, for example, developing entirely new technologies, say reusable launch

vehicles. As another example, take science and research such as the recent unmanned mission to the moon, Chandrayaan 1, or the proposed new satellite for astrophysical research, called Astrosat.

The potential for the use of satellite technology in providing almost universal access to education is immense, but in spite of the recently launched Edusat, the potential is inadequately tapped in India. This is in fact strange from one point of view, because 40-50% of the Indian population is still illiterate, and in many ways satellite telecasts might provide an excellent medium for raising literacy levels, diffusing a variety of skills, and making the methods and the wisdom of the best teachers in the country available to huge numbers of people.

I should mention in particular satellites for weather and climate research. The space programme has already taken several initiatives in the atmospheric and oceanic sciences. The INSAT series provided imageries of the earth in both visible and infrared parts of the electromagnetic spectrum, and offered communication channels for transmission of meteorological data. The geostationary satellite Kalpana, launched by PSLV, was meant exclusively for meteorological applications. Two Oceansats provide much data on the ocean surface, including sea-surface temperature and winds.

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A major step forward will be taken in 2010 with the atmospheric research satellite Megha-Tropiques. As the name indicates (Megha is cloud in Sanskrit, and Tropiques is the tropics in French), the satellite is a collaborative effort between India and France devoted to the study of tropical convective systems. The tropics are driven by solar radiation and moist convection, so the satellite focuses on water-cycle and energy budget issues in the tropical atmosphere, and will provide data over the tropical belt of approximately 30^0S to 30^0 N. A unique feature of the satellite is its repetitivity: the same tropical site is visited four to six times a day over the heart of the tropics, enabling valuable data to be acquired over the whole diurnal cycle.

The mission objectives are:

1. To collect a long-term set of measurements with good sampling and coverage over tropical latitudes, to understand better the processes related to tropical convective systems and their life cycle
2. To improve the determination of atmospheric energy and water budget in the tropics on various time and space scales

3. To make detailed studies of special events like cyclones, floods, droughts etc.
4. To carry out analyses that can improve forecasting skill the on monsoons
5. To provide to forecasting centres / groups real-time data that can be assimilated into operational or research models to enhance their performance

The objectives are sought to be achieved through four payloads.

o MADRAS (Microwave Analysis and Detection of Rain and Atmospheric Structures),
o SAPHIR (Sounder for Atmospheric Profiling of Humidity
o SCARAB (Scanner for Radiation Budget)
o GPS Radio Occultation Sensor

MADRAS will provide data on rain above the oceans, integrated water vapour, liquid water in clouds, rain over sea, ice in cloud tops etc. SCARAB will provide visible and long wave radiative fluxes; SAPHIR will provide humidity profiles. The GPS ROS will provide temperature and water vapour profiles.

Megha-Tropiques promises to provide unique data sets. It follows TRMM (Tropical Rainfall Measuring Mission), the joint US-Japan tropical radar satellite, whose current life is set to end in 2010, and may well turn out to be the harbinger of the international Global Precipitation Mission, which envisages a whole constellation of satellites launched by several international partners.

The Megha-Tropiques will be launched from Sriharikota on ISRO's PSLV, and signals the India's entry into joint international projects on earth science related issues using the best available space technology. The tropics are a frontier area of meteorology. The three major countries in the global tropical belt are India (approximately 8^0N to 36^0N), Australia (approx. 11^0S to 39^0S over the mainland) and Brazil (approx. 5^0N to 32^0S). Given both the scientific challenge and the extraordinary relevance of the tropics to its own inhabitants and the rest of the world, more major international projects in the field are bound to contribute to the well-being of the planet. Nearly half the land area and nearly half the population of the world live in the tropics. The tropics receive two-thirds of total world rainfall; they also receive relatively more solar radiation, and export the excess to higher latitudes keeping them warmer than they would otherwise have been. Interestingly, meteorological connections exist between India and Australia, as foreseen in the 1920s by Sir Gilbert Walker who, as head of the India Meteorological Department, reported the significant correlation between rainfall in India and pressure at Port Darwin and Southeast Australia, for example

(envisaging what is today called ENSO, the El Nino / Southern Oscillation phenomenon).

Such initiatives should become more feasible as the space programme tends towards greater self-sustainability. Thanks to the extraordinary progress that has been achieved by Indian space scientists and technologists, that now no longer seems difficult to achieve. Globalization should make international projects more attractive, provided geo-political considerations do not intrude. There is an excellent chance that such international ventures can in fact lead to both faster and cheaper projects and services for both collaborating parties. AWST talked about ISRO's shoe-string budget; a study carried out at the Madras School of Economics (U Sankar 2007 The Economics of India's Space Programme: Oxford, New Delhi) shows in specific cases how cost-effective the programme is. So we may need a two-pronged policy. On one hand it could be more oriented to commerce and wealth creation (which Sarabhai the scientist-businessman would surely have approved). On the other it could emphasize the vigorous use of satellites in education and scientific research (helping to enhance the value of our human resources), including in particular the earth system (which Dhawan the humane technologist would have approved). This would still be part of the developmental process that ISRO's founding fathers placed before us. Commerce, basic science, education, land, water and the earth system as a whole can form a sustainable complex of goals.

These goals, in part new and in part only a new version of the original vision, can be pursued with confidence, because of the sustained achievements of Indian space scientists in the last 40 years.

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I would now like to consider computer technology, which has some interesting parallels with space but also some striking differences. In the 1980s it started with the need felt in India for high performance computing systems on a variety of national projects. However it was soon discovered that because of the technology embargoes prevailing at the time it was not possible to import any of the supercomputers of that era to India (the exception was a Cray machine that was acquired by the National Centre for Medium Range Weather Forecasting at Delhi for numerical weather prediction).

In the early 1980s some scientists both in Europe and US had started experimenting with parallel computing, i.e. achieving higher computing speeds by using a large number of processors that would work in parallel. During the time that I was at NAL we began a parallel computing effort in a small way in 1986. To our (and everybody else's) pleasant surprise my colleague at NAL, Dr U N

Sinha, was able to put together, before the end of the year, a small parallel computer that was already faster than the large mainframe that NAL had been using at that time. The demonstration of the way that the Flosolver (as the NAL parallel computer was called) could solve for example the transonic small perturbation equations faster than the mainframe removed all skepticism on the possibility of using parallel computers for tackling problems in fluid dynamics. (By the way that skepticism was shared by many people in the west as well and so was not limited to Indian scientists.) Through the Scientific Advisory Committee to Prime Minister Rajiv Gandhi, a proposal was made to the Government in 1986 for pursuing a major national initiative in parallel computing. As is well known Mr Gandhi was a great advocate of computers in the country at the time, and I recall that the less than ten minutes that had been allotted to me to make a presentation to the Prime Minister extended itself to 90 minutes – because of his extraordinary interest in the project. At the end Mr Gandhi said that the question was not whether we should make parallel computers but how fast we could make them and at what cost. (He was also all for leapfrogging.) Very quickly thereafter several parallel computer projects were undertaken in the country. These had different philosophies, and it was decided that each of them was valid in its own way and should continue with further development. I must mention here that Mr. K R Narayanan, as Minister for Science & Technology at the time, was a great supporter of the Flosolver project, and he kept asking me years later (even after he had become the President of the Republic) how the project was going. What started as a small effort to acquire some additional computing power has now gone through six generations (Mark 7 is now operational), and has led to new technology development and new architectures (some of them patented). All this has been done at low costs compared to international levels, and with huge and enthusiastic student participation.

But as these computers went from one generation to the next the most important applications also slowly changed. Currently modeling of the atmosphere and the oceans takes precedence over the other applications. Considerable commercial interest has been shown on the possibility of using these computers for financial modeling. A separate project, through a scheme called the National Millennium Initiative for Technology Leadership in India and conceived by CSIR, has selected modeling monsoons as a targeted application. Forecasts are now being continuously made and sent to the India Meteorological Department for their use.

An interesting aspect of the parallel computing effort in India is that over the years four distinct groups emerged, including one at the Centre for Development of Advanced Computing at Pune whose machines, known as the Param series, have probably had the widest use in the country (some of them even

exported). Nevertheless none of these efforts can be called a strong commercial success. At the time that the projects were undertaken commercialization was not ignored, but it would be correct to say that non-vulnerability to technological embargoes was an even more important consideration. After all, the first objective of Mrs. Gandhi's Technology Policy of 1983 was 'to attain technology competence and self-reliance to reduce vulnerability. . .'. To that extent the projects have been most successful. But in spite of serious efforts it has not been possible to get the involvement of private industry in the project, although it has often shown considerable interest. The question of forging stronger links between the laboratory and the market place is one of major interest and continuing importance in India today.

A similar problem has also affected another computing initiative relating to what came to be known as the Simputer. The roots of this project can be traced to a meeting that was organized by the National Institute of Advanced Studies as part of the first Bangalore IT.COM show (as the series got to be known later), held in 1998 with the support of the late Mr Sanjoy Dasgupta who conceived the idea. As part of the first event NIAS organized an international seminar that considered the future of IT in developing countries. In keeping with the broad objectives of NIAS, which in particular emphasize the bringing together of people in science, technology, the humanities and a variety of other sectors including business, industry and the political leadership, we included in the NIAS team that organized this event both distinguished academic scientists like Prof Vijay Chandru of the Indian Institute of Science, industry experts like Mr Vinay Deshpande, sociologists like Prof M N Srinivas and others. In fact a Bangalore Declaration was passed at the meeting and had the wide approval of both the developing and the developed countries whose representatives were present at the meeting.

That declaration highlighted a major concern at the time, which was what has been called the digital divide. In trying to see how the problem represented by the divide, between those who have access to (for example) the Internet and those who do not, the idea came up that what India needed was a small hand-held computer which could sell for a few thousand rupees (something less than $ 100). This led to the concept of the Simputer, which excited a lot of attention from across the world: the New York Times called it the most significant innovation in computing technology in 2003, Time magazine said it was "one of ten technologies to know on the planet", and the MIT *Technology Review* rated it among the top ten innovations of the year. Some examples of the Simputer were made, the product was officially released, and something like a thousand test pieces were sold on a very special application – to the great satisfaction of its fastidious customer. Nevertheless the Simputer did not become a commercial success.

In retrospect, it is being slowly learnt that it is not enough to have a brilliant idea; to convert idea into reality in the market place takes a variety of other resources, capabilities and skills that together constitute what may be called the innovation eco-system. This eco-system has technology and the technologists as one component, but includes financing, promotion, advertisement, large scale applications, the ability to take risks and accept failures and, increasingly, a globalized business model. That eco-system is not yet in place in India, especially for the technologist-entrepreneur. At the time the Simputer was first made it could not break into the market, for whatever reason; but it looks as if it has now acquired a second life as newer applications are making demands for which it appears a very appropriate solution.

But the Simputer is only one of the most well known instances of a good idea that did not reach the market. There have been others which have had a similar experience. It has to be hoped that as the country breeds more technologist-entrepreneurs the rest of the eco-system that is needed to convert such ideas into wealth will emerge before long.

Meanwhile a major commercial entry into the supercomputer market is represented by the computer Eka, which the Tata Computing Research Laboratories in Pune have designed and constructed. At the time that it was put into operation (in 2007) the Eka was the fourth most powerful computer in the world; it remains to this day the most powerful in Asia. It is being used for scientific research, technology development, weather prediction and a variety of other applications. It appears that this project works to a different business model. Here much of the system may carry imported components, but the basic concept, the financial risk involved in the project and the business model supporting it are all completely Indian. The fact that private industry in India is now willing to undertake such projects (either moving away from piggy-backing to leapfrogging, or making a pragmatic mix of the two) marks a significant departure in the way that technology development can take place in India. The Eka appears more ambitious than the interesting developments in some other sectors, for example pharmaceuticals. Nevertheless the number of industries where now the country is beginning to see the advantage of technology development within India is slowly on the rise. In support of this view we may also quote the recent example of what may be the world's cheapest car, namely the Nano. The interesting thing about both Eka and Nano is that they are primarily inspired by the needs of the Indian market, with the realization that success achieved there may well take the product to other parts of the world.

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All these projects – whether in space or in computer technology – depend critically on the skills and knowledge 'available in India for the taking', as Friedman put it. More and more people are slowly discovering this 'untapped' resource. If India has recently emerged as a major exporter of automobiles and automobile parts, it was because of the discovery that it was not so much cheap labour as cheap skills that India offers. Several years ago Business Week and a whole host of MNCs (led by GE) discovered similarly that India was about the most cost effective place in the world for doing high level R&D. India's scientific output, measured by the number of publications in well-recognized scientific journals, is growing in numbers, although as a fraction of the global output it is stagnant at about 2% (Narasimha 2007 Tech. in Soc.). However it still remains about the most cost effective source of high tech R&D in the world.

We need policies that recognize the natural advantage that India has in its youthful human resources, and provide all the supporting institutions and mechanisms – from education to counseling to encouraging technological entrepreneurship and domain scholarship – that can convert this untapped talent – the economic equivalent of the untapped American continent of the 19th century – into wealth and national well-being.

I have in this lecture tried to trace the way that science and technology have evolved in India in two sectors in which I have some direct personal experience. (I could have added others, like the aircraft industry, where the situation is quite different from its space cousin, but the overall conclusions would not change.) After the economic reforms of 1991 the rate of growth of the Indian economy has risen and has typically been in the range of 6-8% in recent years. Business leaders are tackling more challenging and competitive technology-driven products and systems. The examples I have described show that there is plenty of talent in India to take on the most challenging tasks in modern technology. Both the public and the private sector have demonstrated this, especially in the last five to ten years. This augurs well for the future. At the same time we have instances where brilliant ideas have not made it to the market place. It is my personal view that the eco-system that can make this happen – all those advanced services that include venture capital, market survey, globalized manufacturing, being first to the market place, and many others – are not yet in place. It needs to be a part of national endeavour to put such systems in place as early as possible. Something similar is true in the field of basic science as well: in spite of the many new initiatives taken to promote it, that relentless pursuit of excellence that leads to game-changing ideas has not yet become part of the Indian academic environment.

But things are changing rapidly, and we may expect further initiatives in coming years that will enable India to create systems that can tap its great human resources more effectively.