Role of S&T and Innovation policies in transforming the National Innovation System in China: Lessons for India

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China has earned the distinction of creating new benchmarks of development by developing significant capabilities in several areas of science, technology, and innovation. China has made technological advances in key sectors, such as aerospace, nanotechnology, biotechnology, information technology and telecommunications, pharmaceuticals, automotive industry (Preeg, 2008). S&T and innovation policies of China have played an important role in its transformation as is evident in its transformed S&T infrastructure and S&T capabilities[1]. This paper looks into, how China has performed with regard to S&T and high technology exports and the roadmap taken by it to build S&T capabilities through a judicious mix of S&T and innovation policies. Following issues define the scope of this paper;

1. The performance of China through publications, patents, and high technology exports to understand the development pattern vis-a-vis India.
2. Roadmap of China's transition to build S&T capabilities through a judicious mix of S&T and innovation policies.
3. Summing up and Lessons drawn for India

1. Performance of China and India through standard indicators

China has emerged as a proactive player in the international economy as is evident from its performance through a number of S&T indicators as is seen in the following section. While publications and patents are broadly considered to be the output of scientific pursuits, high technology exports indicate the technological capabilities of the industry of a country; and also act as an indicator of the ability to translate S&T capabilities into production systems and economic gains. The performance of China and India are compared through publications, patents, and high technology exports.

1.1. Publication output

Table 1 shows the total scientific publications of China and India between the years 1990 and 2009.

[1] The analysis draws from `A comparative study on S&T, Innovation and Development strategies of China and South Korea vis-a vis India', Study supported by the Office of the Principal Scientific Advisor to the Government of India, NISTADS, 2012 (Project team: G D Sandhya, Pradosh Nath, N Mrinalini, Parthasarthi Bannerji, Sujit Bhattacharya, Kasturi Mandal, Debanjana Dey; Praveen Rawat; Abhishek Kumar

Table 1: Total publications from 1990 to 2009 (selected years)

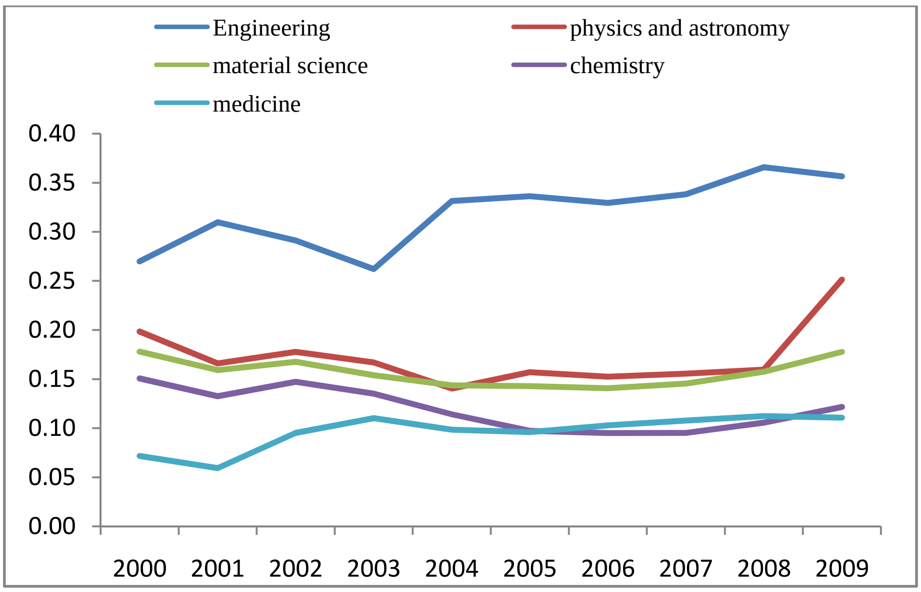
Year	China	India
1990	7,508	10,951
1995	15,371	11,796
2000	44,591	23,158
2005	1,52,545	36,069
2006	1,79,762	41,945
2007	2,03,110	46,769
2008	2,36,014	51,555
2009	2,78,999	57,785

Source: Scopus

China surpassed India in the period between 1990 and 1995 by doubling its publications. And by 2009, China's publications became 5 times that of India.

The fields in which both the countries have been active in publishing are shown in figures 1and 2. The share of the top 5 S&T disciplines in China shows that engineering disciplines constituted as high as 35% of the total publications in 2008. The other active fields are physics and astronomy, material science, chemistry and medicine.

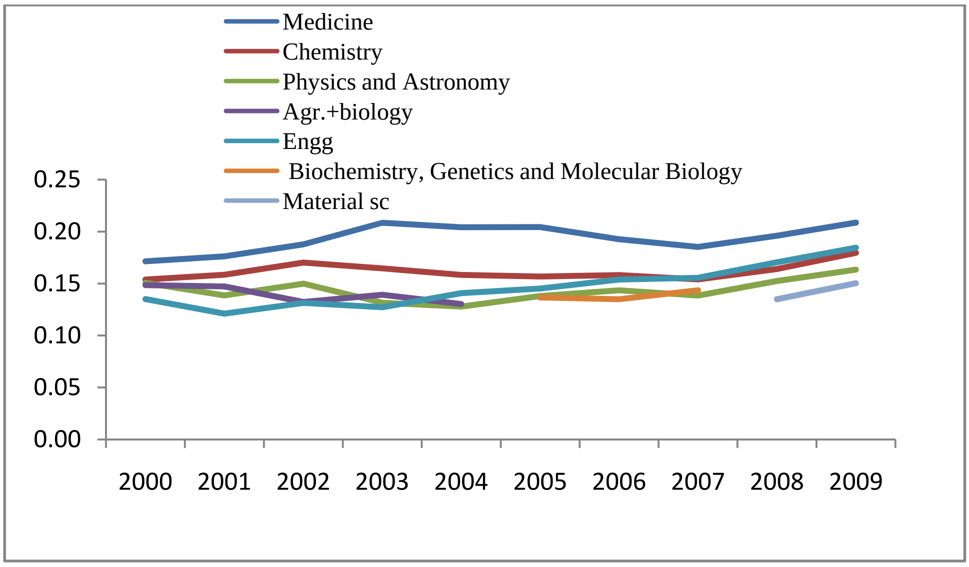
Figure 1: Share of top 5 fields in total publication of China



Source: Scopus

In contrast, the Indian case reflects a different picture with a smaller distributed share in several fields. Medicine occupies the highest share with engineering coming to occupy the second position with chemistry since the middle of 2000. Material science finds a place among the top seven since 2008.

Figure 2: Share of top 7 fields in total publication of India



Source: Scopus

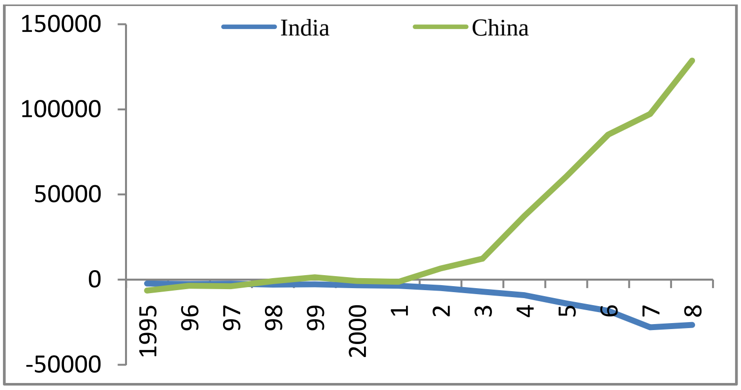
1.2. High Technology Export

High technology exports are indicative of the ability of an economy to derive value from activities which are R&D intensive. China has emerged a leader in high tech exports leaving the US behind.

How did these two countries fare in high-tech trade with the rest of the world? Figure 3 shows the balance of trade (in million USD) for both the countries from 1995 to 2008. While China had wiped out the deficit by 2001, India was facing an increasing trade deficit in high technology export and import.

Here, we elaborate the scenario for both the countries separately and for five important high-tech areas of trade. The areas are communication and semiconductors, computers and office equipment, scientific instruments and measurement, pharmaceuticals, and aerospace. Figures 3, 4 and 5 show the performance of India and China respectively.

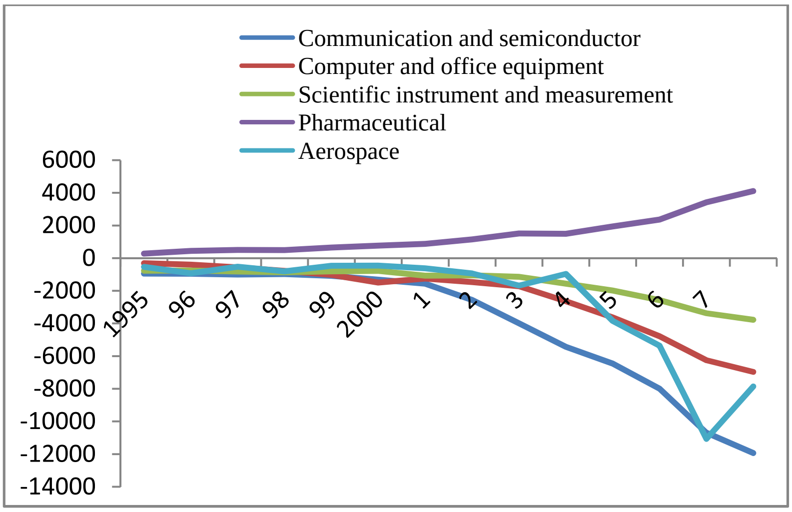
Figure 3: Comparative performance of India and China in high technology trade.



Source: Constructed from www.nsf.gov/statistics/seind10/appendix.htm

India has an increasing negative balance in all areas except pharmaceuticals which has shown a positive balance of trade.

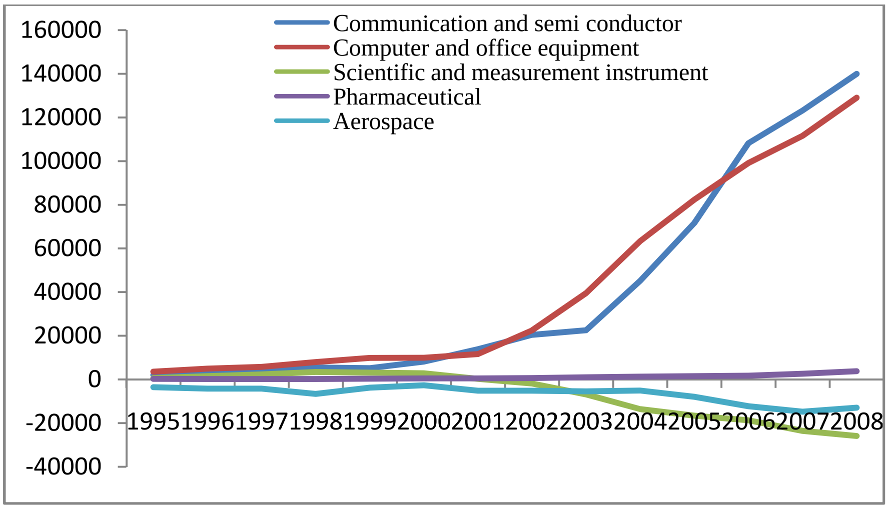
Figure 4: India's performance in the global trade in selected high technology areas



Source: Constructed from www.nsf.gov/statistics/seind10/appendix.htm

China has shown high growth in both communication and semiconductor and computer and office equipment.

Figure 5: China's performance in the global trade in selected high technology areas



Source: Constructed from www.nsf.gov/statistics/seind10/appendix.htm

1.3. Comparative Performance in Patenting

Patenting is an important indicator for assessing relative strength in technology and knowledge generation. We have seen above that in high technology exports, China has performed much above India. The respective strength in technology should also be reflected in the patenting activities of these countries. The patent outputs of China and India in various technology groups from 2003 to 2009 is given in Table 2. The data on patents at the United States Patents Office (both granted and applied for) for both China and India reflect more than three times increase in case of China.

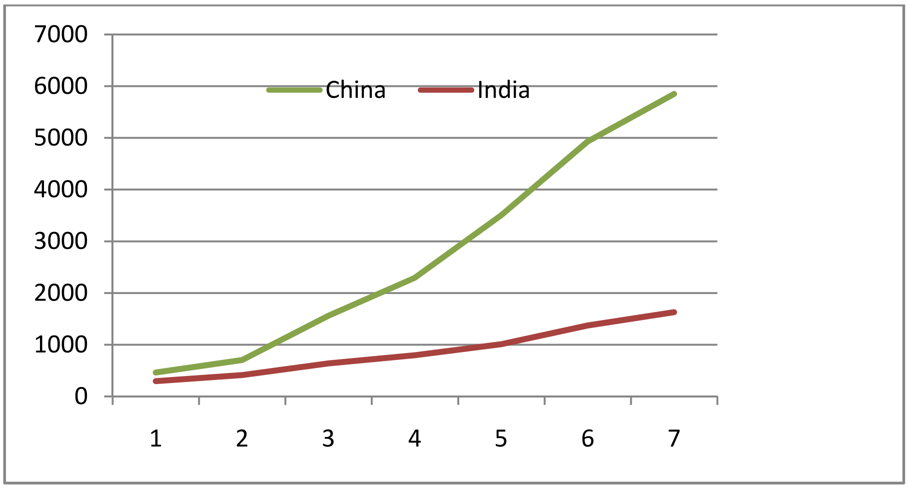
Table 2: Comparative performance of India, China, and Korea in high technology patents

Country	Patent type	Pharma	Machine tool	Office Mach, Computers	Electronic components	Tele com	Audi visual electronics	Motor Vehicle	other transport equipment	Nanotechnology	Bio technology
India	Applied	2925	77	4563	299	1738	318	159	32	35	672
	Granted	1071	13	1726	199	678	80	62	14	10	330
China	Applied	2007	453	7099	1440	5432	977	323	104	244	919
	Granted	578	185	2040	625	1508	191	153	47	45	292

Source: United States Patent and Trademark Office (USPTO)

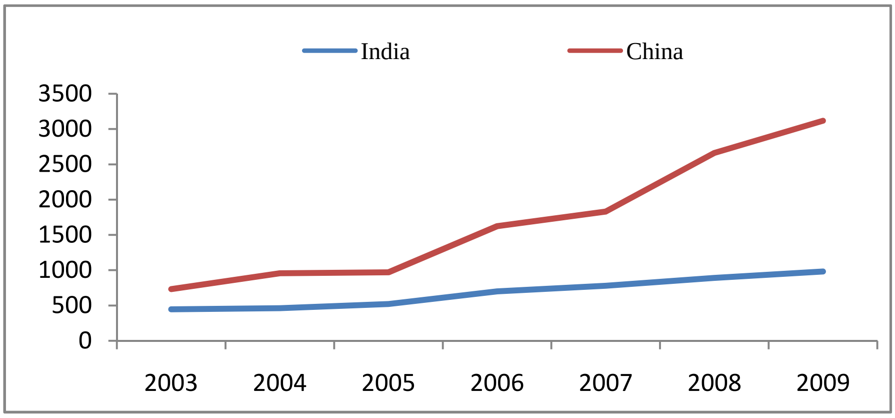
Figures 6 and 7 shows an increasing trend in patenting (both granted and applied for) China, whereas in India, it is quite flat during the same period.

Figure 6. Patents applied for by India and China at the USPTO



Source: USPTO

Figure 7: Patents Granted during 2003-2009



Source: USPTO

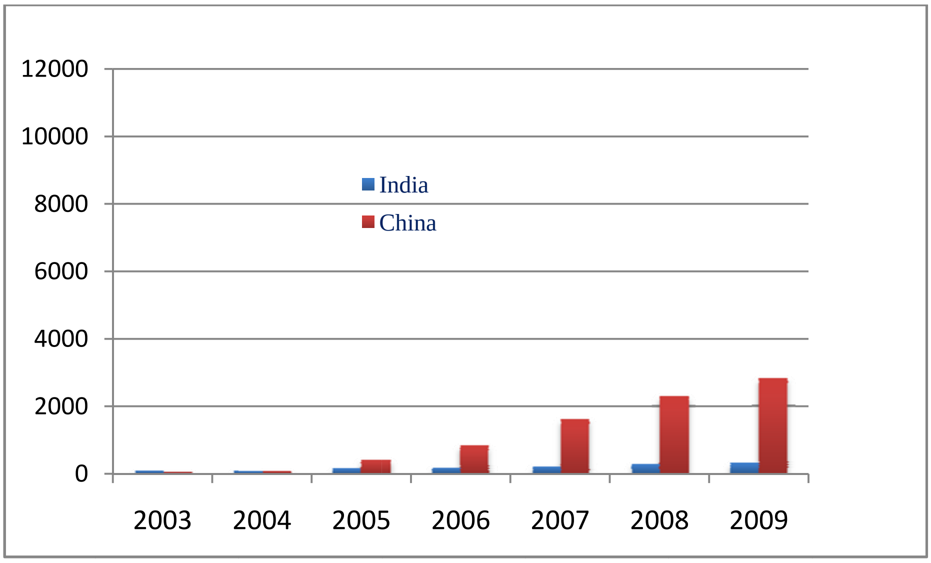
Which are the agencies that are most active in patenting; domestic firms, research organisations, or MNCs? The comparative trends by the three performing actors in India and China are projected in figures 8, 9 and 10.

It is evident that domestic firms are more active in patenting, in both granted and applied for categories in China. The data on patents applied for by the domestic firms show that Chinese firms have maintained a steady growth but Indian domestic firms have hardly shown any growth (Figure 8).

The case of domestic research organizations in China, although not very spectacular in terms of quantum but show a continuous growth. India on the other hand shows a declining trend which raises concerns particularly in view of the fact that three fourth of R&D in India is accounted for by the government. There is a decline in patenting by them (Figure 9).

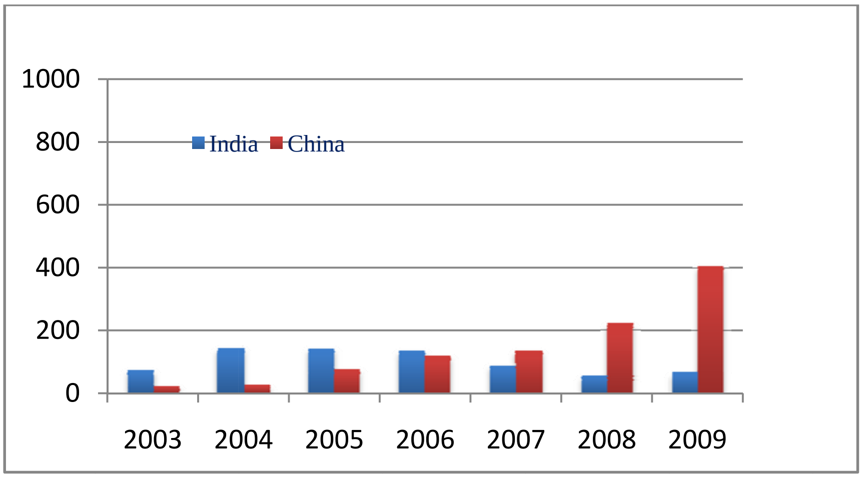
The trends reverse in case of patenting activity by the MNCs from India and China (Figure 10). India has always been ahead of China since 2003 in the patenting activity by the MNCs. The trends are suggestive of India emerging as the most preferred destination amongst the two for the R&D operations of MNCs.

Figure 8: Patents applied for by domestic firms in India and China at the USPTO



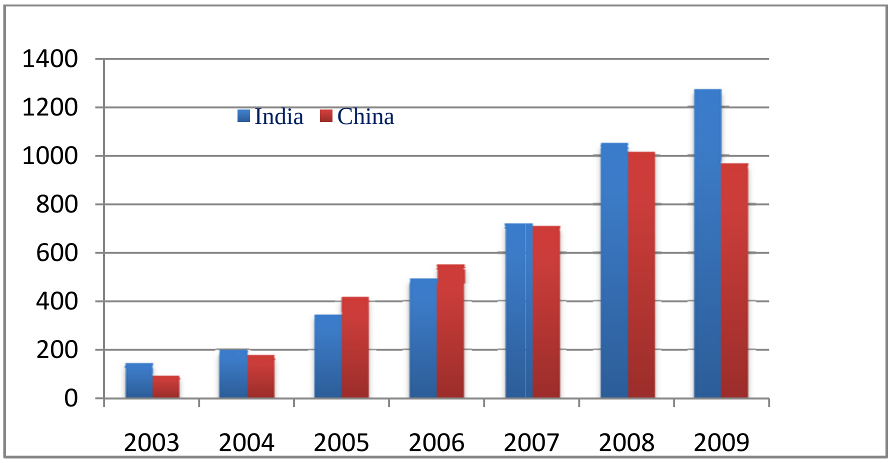
Source: USPTO

Figure 9 : Patents applied for by domestic research organizations in India and China at the USPTO



Source: USPTO

Figure 10: Patents Applied for by MNCs in India and China at the USPTO



Source: USPTO

The above data trends need to be interpreted in the light of roadmap chosen, particularly by China for its consistent growth in S&T. For instance though India led in publications in 1990 but it was overtaken by China by 1995. There is a decline in the contribution of domestic sector and research institutions in comparison to China in the patenting activity. MNCs are emerging as the major patentees from India. India shows a positive trade balance only in the pharmaceutical sector. China on the other hand has emerged in terms of the performance of S&T exhibiting an increasing publication outputs from academia and government research institutions. Domestic enterprises and research institutions show gradually increasing patents output. There is a very distinct increase in the global trade activities of China in select fields. These issues raise very important questions in terms of the roadmap chosen by both the countries and strategies adopted.

The overall output of Chinese publications in comparison to the world has recorded a sharp increase from 26% in 2000 to 85 % in 2009 (Scopus data base). The increasing output of papers published by the Chinese researchers is also accompanied by an increase in key citations in international citation indices in information technology (IT), life sciences including pharmaceuticals, medical devices and biotechnology, electronics, nanotechnology, environment, and energy. China has shown growth in few key areas, which are the declared priority areas designated by the Chinese Government. The priority areas are similar to the prioritisation that is followed in the OECD countries. China has made notable achievements in clean energy, supercomputing, nanotechnology, advanced materials, etc. For instance, in nanotechnology China has now outpaced the US in terms of the output of publications. China has recorded notable achievements in a number of emerging fields such as protein, genomics, etc. Similarly IT, which influences several industries due to its broad range of applications, has remained a consistent priority in China. China's R&D in supercomputing has given a tough fight to the US. Indications are that this could become true for all processing devices manufactured in China (Battele, 2010). The prioritization of IT is based on clear cut targets and goals and combining both hardware and software[2]. In supercomputing, China had developed Tianhe 1 by the National University of Defence Technology in 2009 but with processor chips made by the US companies. This was replaced by Xinguan in 2010 and excelled in speed which was double than Tianhe 1 and was developed by a company and Chinese Academy of Science (CAS). This was toppled by Japanese K computer but Chinese efforts unveiled another fastest computer in 2011, the Sunway Bluelight MPP but with Chinese microprocessor chip[3].

Similarly in clean energy China is gradually outpacing US through a comprehensive strategy by focussing on research as well as manufacturing. The emphasis on clean energy is discernible in almost all the major national programmes. A well developed, long-term strategy of consistent and increased investments in clean energy has enabled China garner clean energy supremacy over its rival countries which though might have been the pioneers in developing the solar PV, wind, nuclear power technology but the ensuing gains have been strategically collated by China.

China has consistently improved its rankings in selected fields which are attributable to its target-centric approach. These are the outcome of consistent and sustained initiatives over a long period of time as will be seen in the following section. These emerge as the key points that summarize Chinese initiatives to manage and co-ordinate its S&T aspirations towards industrial development and help leverage innovation in China.

2. Roadmap of China's transition: A systematic coupling of S&T, innovation and economic policies

The Chinese model of development like the Japanese and Korean has been specialization in select sectors, targeting high growth industries, emphasis on exports and enhancing the technological component of its exports, promotion of the innovation actors, massive R&D investments and protection of the domestic producers. Though China still has a long way to go in creating breakthrough technologies, its reliance on R&D in select fields has enabled it to narrow the knowledge gap with the leaders. The following section deals with some of the major factors that have played a key role in giving directions to the growth of S&T in China.

- ✓ Visionary State Directed 'Targeted' development with appropriate policy concurrence between economic and innovation policies
- ✓ R&D as a complement to competency building with a target-centric approach

[2] During 2006-2010, the Chinese Government targeted Chinese CPUs for all Chinese supercomputers along with software and electronic devices with participation from universities and firms.
[3] http://hothardware.com/News/Chinas-Sunway-BlueLight-MPP-Supercomputer-Skyrockets-On-Most-Powerful-List/

- ✓ Appropriate Resource mobilization: Reforms in the higher education sector, government R&D institutions and creation of an appropriate ecosystem of innovation
- ✓ Organization and Management of R&D and Technology

2.1. Visionary State Directed 'Targeted' development with appropriate policy concurrence between economic and innovation policies

An extremely important factor behind the rise of S&T in China post reforms is the highly interventionist role of the government in directing S&T as a complement to economic transformation. The vision of S&T based development and narrowing of the knowledge gap with the developed countries formed the foundation of vision discernible in adroitly crafted strategies. These were operationalized through a large number of policy instruments. The major policy slogans from the Chinese political leadership have subsequently been strategized into action plans manifested through several national level S&T programmes and series of initiatives to strengthen the ecosystem for innovation.

China's growth strategy as reflected through its policy trajectory has unfolded in stages. It has displayed an innovation plan in which strengthening of innovation has been strategized gradually with both a medium and long-term focus. China has boosted investments in S&T and also taken steps to build its National Innovation System by enacting various policies and laws in its ongoing transition to an innovation-based economy. By the year 2002, China had issued over 500 policy recommendations dealing with science, technology, and innovation, of which tax policies accounted for about 25 per cent of total S&T policies and laws (Rongping, 2004). China embarked on a series of policies and programmes to boost its S&T capabilities and catch up with the world.

China inherited a Soviet model of S&T the dismissal of which proved to be the turning point in the Chinese S&T system, which was plagued by basic defects and was a closed one in which the existing S&T system suffered due to a lack of horizontal linkages with education and business; inappropriateness of the structure to facilitate technology diffusion due to a lack of Intellectual Property Rights (IPR) or mechanisms of technology transfer; hindrances in private initiatives in scientific enterprises due to direct interventions from the administration, and the hampering of enthusiasm and creativity of R&D personnel due to the rigid structures of research institutes (Xin, 2010; Yuan 2005). The introduction of reforms by the Chinese Government involved a series of initiatives to catch up with the world. The reform measures implemented by the leadership included dismantling the old unproductive structures, restructuring and creating new institutions. A series of organizational and structural changes were strategized for revamping the S&T system.

Chinese policy making had addressed a range of issues impacting Chinese S&T through new management principles and organizational structures. Post 1990, there was a surge in measures related to the issue of the importance of human resource. In the period beginning 1998, Chinese policy making shifted its concerns to the National System of Innovation and the Knowledge economy.

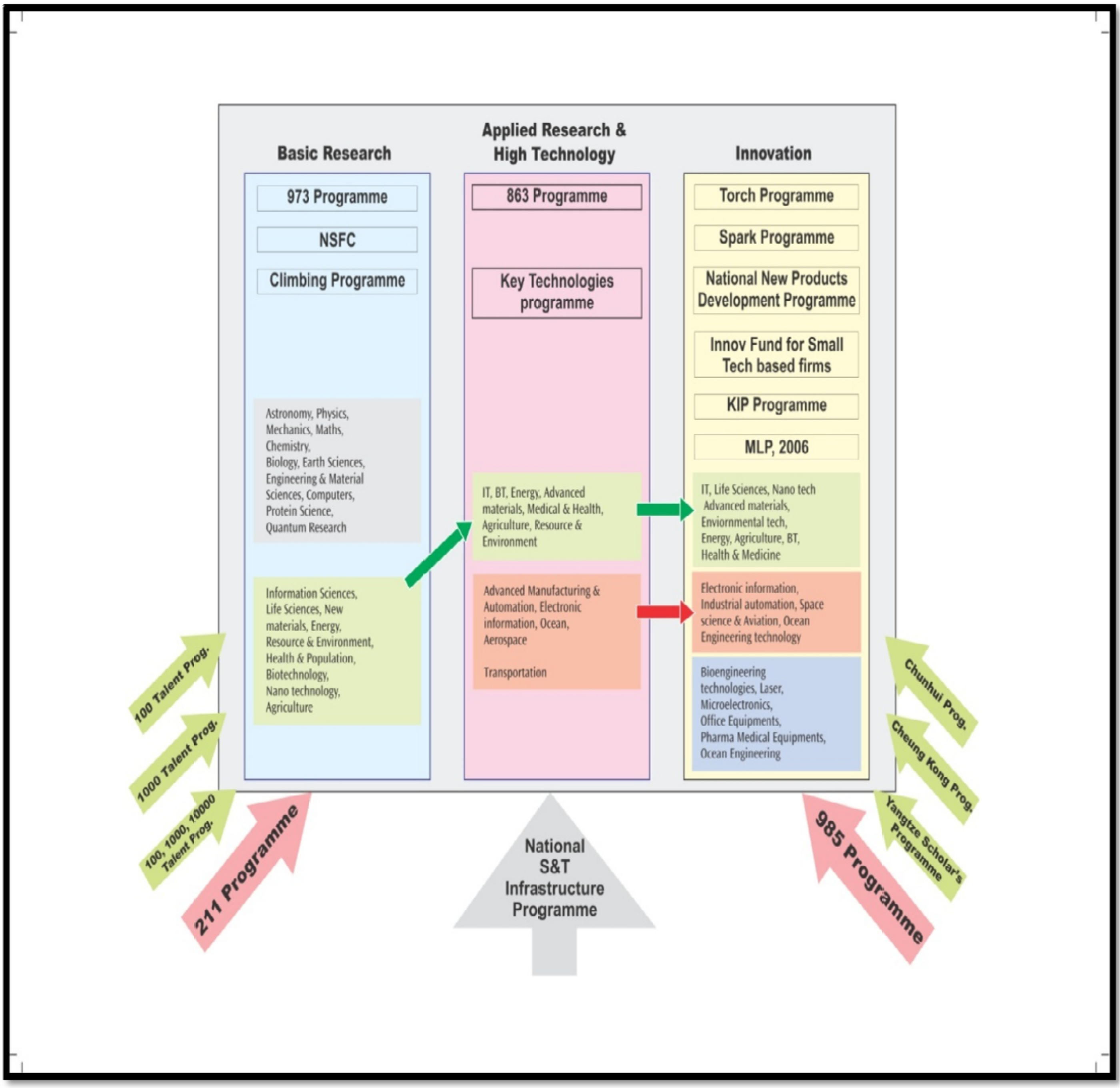
The major policy decisions which charted China's overall direction for orienting S&T and laid a framework were the following;

- ✓ The 1985 Decision on the Reform of Science and Technology Management System,
- ✓ The May 1995 Decision of Accelerating Scientific and Technological Progress,
- ✓ The Medium and Long-Term S&T Development plan (MLP) in 2006.

These were followed by massive conferences to identify the problem areas and also identification of policy instruments to attack the problems. For instance, while the 1985 Decision on the Reform of Science and Technology Management System by the Chinese Government adopted a multipronged approach to revamp the management and financing of S&T, the commercialization of research results, linking up various stakeholders of S&T, the judicious deployment of resources, management of S&T personnel, autonomy, and the opening up of S&T to the outside world, the 1995 decision took the measure to a higher level. The underlying consideration was that science and technology must contribute to economic development. The 1995 Decision went on to strengthen the link between research and industry, and technology imports and indigenous innovation. The focus was shifted to human resource. These were also accompanied by a number of national programmes with massive investments. The MLP, 2006 was reconfirmation of innovation push.

The jurisdiction of Chinese S&T policies has been the entire innovation infrastructure targeting research institution, universities, S&T Parks, support structures, fiscal and financial instruments, etc. (Sandhya, et.al, 2012). The range of national programmes launched from time to time has covered the entire value chain from basic research; applied research and high technology to innovation (Figure 11). Commonality of priority areas is an important feature that can be seen from the figure. There is connectivity and consistency in chosen focus areas. These were adequately supported by the human resource and infrastructure programmes, some of which are shown in the figure. The programmes depicted through the arrows outside the box highlight human resource initiatives of China for both human resource generation as well as augmentation. The noteworthy point is that the policy for the transition process has taken care of the entire infrastructure relating to S&T, education and others including the policy apparatus. There is timely implementation and evaluation of the policy initiatives (Sandhya, et.al, 2012). The defining features of some of the major national programmes are that these are well resourced with timely implementation and focus on the entire value chain from basic research to innovation with rigorous monitoring.

Figure 11. The spread of State Programmes to support S&T in China



2.2. **R&D as a complement to competency building with a target-centric approach**

The basic agenda of the post-reforms period in China was to catch up with the developed countries and to reduce the gap between them and China by focussing on select streams. China's spending on R&D as a percentage of GDP has grown consistently from 0.6 in 1995 to 1.83 in 2011. Chinese investments on R&D as % of GDP were at par with India prior to 2000 but increased by 161 %. Besides, China has become the second largest country in terms of gross R&D expenditure behind only US. China spent $ 87.4 billion in 2009 (Table 3). The R&D expenditure is estimated to $ 198.9 billion for 2012.

Table 3. R&D as % of GDP in India and China

Country	**Years**						
	1998	2000	2002	2004	2006	2008	2011
China	0.7	0.9	1.07	1.23	1.42	1.54	1.83
India	0.7	0.7	0.74	0.77	0.8	0.8	0.9

Source: National Bureau of Statistics for China and DST for India

It has been seen in the trends in OECD countries that once the R&D/GDP ratio reaches 1%, it rapidly goes up to 2. China made a conscious and deliberate effort to catch-up with the world. China has pumped in massive investments in R&D to *enhance knowledge frontiers in select areas including high technology*. The industries that have been prioritised for exports have also been suitably supplemented with directed R&D.

2.3.**Appropriate Resource mobilization**

Targeting transformation of not only the actors of innovation such as educational and research institutions but also the ecosystem of innovation, supported with the continuity of change with global targets formed the core of S&T and innovation policies in China.

2.31. **Reforms in the higher education sector**

The aftermath of the Cultural Revolution followed by the onset of market reforms necessitated a need in China to chalk out strategies which would fill the void of an educated workforce, and create adequately trained manpower. China gave high priority to its education system in primary, higher education, and vocational education. Revamping human resource through generation and augmentation, targeting global excellence in selected universities and prioritized sectors and formation of global universities, initiatives to attract repatriation of skilled manpower for both universities and research institutions for augmenting the human skills, enhancing the stock of PhD manpower, etc. have been some of the initiatives adopted by China in this direction. The modus operandi of major initiatives is through state level programmes for the generation of manpower, modernization of universities, repatriation of diaspora, so on and so forth (Table 4). Some of the outcomes of these reforms have been: an increase in the enrolment in tertiary education from 5 million to 23 million; an increase in participation for the 18-22 age bracket from 10% to 22%; an expansion in the number of tertiary institutions from 1,054 in 1995 to 1,731 in 2004; and an increase in the number of researchers by 77% between 1995 and 2004, elevating China in world rankings to second position after the USA. (OECD, 2008).

The reforms to modernize and invigorate the education system encompassed organizational restructuring, enhancing university industry linkages by encouraging the universities to get into commercial activities by allowing universities to own up affiliated firms, create university spin offs , which did help in creating a culture of commercialization of R&D. Project 211 and 985 were launched to revamp the higher education in the targeted group of 100 higher educational institutions and forming global universities (Table 4). Similarly the Chinese Government launched several programmes since the mid 1990s to attract expatriates and reverse the brain drain of talented scientists and professionals (Table 4).

Chinese universities have improved in terms of the spread of their activities from education to research. Some universities have improved their world rankings drastically, generated a vast pool of manpower in the field of tertiary education, and have formed links in several dimensions of the innovation chain, exhibiting dynamism in Chinese universities. Regional governments have also played a proactive role in creating a suitable ecosystem by promoting education through infrastructure creation.

These measures related to human resource upgradation and infrastructure have led to 7 Chinese universities emerging in the top 200 universities in the world QS (Quacquarelli Symonds) rankings. More than 700 universities are currently engaged in research and commercialization. The overall output of Chinese publications in relation to the world output has recorded phenomenal growth. While China produced only 26% of the world output in 2000, the figure stands at 85% in 2009 and universities account for more than 80 % of this share in areas such as astronomy, computer science, life sciences, engineering, material science, etc. Chinese universities rank amongst the world’s top hundred in the fields of engineering technology, computer science, chemistry, and maths. In the field of engineering, Tsinghua, SJTU, Herbin, and Zhejiang figure among the top hundred universities. Tsinghua ranks highest in terms of publication count, but ranks lower when cited articles are taken in to account (Academy Ranking of World University 2011). Similarly, in the field of computer science, four Chinese universities rank among the top hundred. One of the contributory factors supporting upgradation of Chinese universities has been the policy of repatriation of researchers and faculties, which has helped in augmenting the faculty resource.

Table 4: Major Programmes for Generating and Augmenting Human Resource

Name of the programme	Year	Implementing agency	Key objectives	Outcome of the programme
One hundred talent programme*	1994	CAS	To recruit scientists from abroad under the age of 45	By 2006 a total of 1051 scholars had joined the programme with more than 95 % having foreign experience. Incorporated into CAS's Knowledge Innovation Programme under `Outstanding Overseas Researcher', `Overseas Well Known Researcher' and `Hundred Talents Programme for Domestic Researchers'.
One thousand talents programme	2008	Dep. Of Organization of CCP Central committee	To target high level talent from abroad to boost China's innovation system	It has attracted number of Chinese expatriates with high credentials. Offer is of the magnitude of RMB 1 million package with salaries determined by the institution that takes them
Hundred, Thousand and Ten Thousand talents programme	1995	MOST, MOE, MOF, NSFC	To attract 100 best scientists to lead, 1000 to lead national programmes and 10000 to work within research network	Approximately 10,000 people till 2004*
Chunhui	1996	MOE	To tap outstanding overseas students	Supported more than 10, 000 outstanding overseas students *
Project 211	1995	MOE	To have global universities (initially 100 universities and key disciplines	To produce high quality research and train human capital. Evaluated in 2001 and 2006. R&D in universities increased by 7 times. No of PhDs increased by 5 times and number of SCI Publications increased by 7 times
Yangtze scholar programme	1998	MOE	To attract outstanding Chinese researchers from china and abroad	Produced more than 1000 researchers
Project 985	1998	MOE	To fund the development of 9 world class universities	Started with 9 universities which later was increased to 30 universities
NNSF for distinguished scholars	1994	NSFC	Support to promising scientists under 45	Return of 1308 scholars up to 2007 (**preference for information, material and life sciences)**
Cheung Kong Scholar Programme	1998	MOE	To target under 45 scientists for universities	Return of 900 professors & 400 lecturers employed **(preferred disciplines are environmental sciences, information sciences, engineering sciences, mathematical and life sciences.)**

Source: Constructed from the programme web-sites; *Numbers by Cao (2008)

2.32. Reforms in the government R&D institutions through organizational restructuring

Prior to the opening up of Chinese economy, Chinese R&D infrastructure was unproductive and far removed from the needs of the industry. The inefficiencies of the public research system stemmed from the problems of research not being linked to industry, poor productivity, lack of links with the industry, etc. The consequent policies in China have targeted funding, commercialization, organizational restructuring and a dual role for Government Research Institutes (GRIs) towards research and commercialization. The basic guidelines for revamping the GRIs[4] were provided by the 1985 Decision on the Reform of the Science and Technology Management System, the 1995 Decision on Accelerating Scientific and Technological Progress, the Knowledge Innovation Programme (KIP) of 1998, and the Medium and Long-Term Programme of 2006. This has led to a revamp of existing structures, mechanisms and governance. The ensuing major policy initiatives targeted funding reforms; restructuring of GRIs; consolidation of links among research, academia, and industry; commercialization by the creation of `Technology Markets, etc.

The Chinese reforms targeted measures related to taking away the assured funding; creating Technology Markets; bringing in structural changes in the existing institutions on the basis of their activities; providing support through national programmes; sharpening the focus of research institutions through mergers and creating new institutions; making them participate in research in priority fields; making concrete attempts to help them enhance the skill base through several national programmes to attract the best; enhancing commercialization by encouraging them to own or float spin-off enterprises; creating S&T parks; making IP laws favourable to this; and so on and so forth. The outcome of the series of initiatives is not just enhanced research outcomes or linkages with the industry but an ecosystem in which the GRIs have a meaningful role to play. The Chinese Academy of Sciences (CAS) is China's highest academic institute and comprehensive research centre in natural sciences. It is the highest advisory body in China on issues of science and technology, plays an advisory role in the formulation of national S&T strategies and national S&T development programmes, and conducts research on major S&T issues.

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[4] There are three types of Government Research Institutions (GRIs). The first type includes GRIs belonging to the Chinese Academy of Sciences (CAS) and universities which are the main research organizations in China. The CAS, which was founded in 1949, manages 91 research institutes, one university, one graduate school and four documentation and information centres. GRIs under the CAS and universities focused primarily on basic research prior to the S&T reforms that began in 1985. The second type includes GRIs affiliated with ministries. There has been hundreds of GRIs under different industrial ministries, with a focus on applied and developmental tasks related to the field of their own ministries. The third type constitutes GRIs at the regional level. They often carry out R&D relevant to the local requirements of their regions. In 2003, there were 4,169 GRIs nationwide, and 82.4% of them were regional GRIs.

The first step taken in revamping the governance of government research institutions was to discourage the government from providing unconditional funding. The transformation of the GRIs was decided on the basis of their activities related to basic research, public goods, and technical development. Financial appropriations too came to be decided on this basis (Wang, 2005). Research institutes that were engaged in basic research were offered full budget-based funding. The similar practice was followed in case of public goods R&D institutes. The technical development institutes or applied research institutes were allotted funds only to make up the balance in the beginning. They were expected to procure funding and revenue mainly from technology contracts through vertical or horizontal channels. . The number of GRIs declined at an average annual rate of 6.1% from 1999 to 2005 (OECD, 2008). These converted R&D institutes changed their organizational structure from their subordination to the government to competitive players in the market as independent legal entities. The industrial conversion of R&D institutes engaged in technical development is reported to have resulted in a fundamental structural change in the Chinese S&T infrastructure, greatly enhancing its innovative capacity (Wang, 2005). The restructuring targeted more than 5,000 GRIs since the 1990s and brought down the number to 3,901 GRIs in 2005.

Restructuring within the basic research institutions in CAS was conducted to strengthen basic research capabilities. By 2008, the academy had brought down 122 research institutions in to 91 from 1985 to 2008.

2.33. Creation of an appropriate ecosystem of innovation

Prior to market oriented reforms, the Chinese S&T activities at GRIs and production activities at the state owned enterprises existed in their own enclaves. The Chinese system of innovation suffered from poor translation of research into applications. Since a large number of programmes were launched in China to promote applied research and high technology in chosen focussed areas, the Torch programme was launched to target commercialization of research results from universities, GRIs, and high tech industries coming from national programmes such as programme 863. The Torch programme was launched in 1988 and was expected to connect to the 863 programme which created research outputs in high tech areas such as IT, BT, new materials, new energy, etc. Through the Torch programme, efforts were made to create an ecosystem that aided and supported commercialization of research results and assist manufacturing.

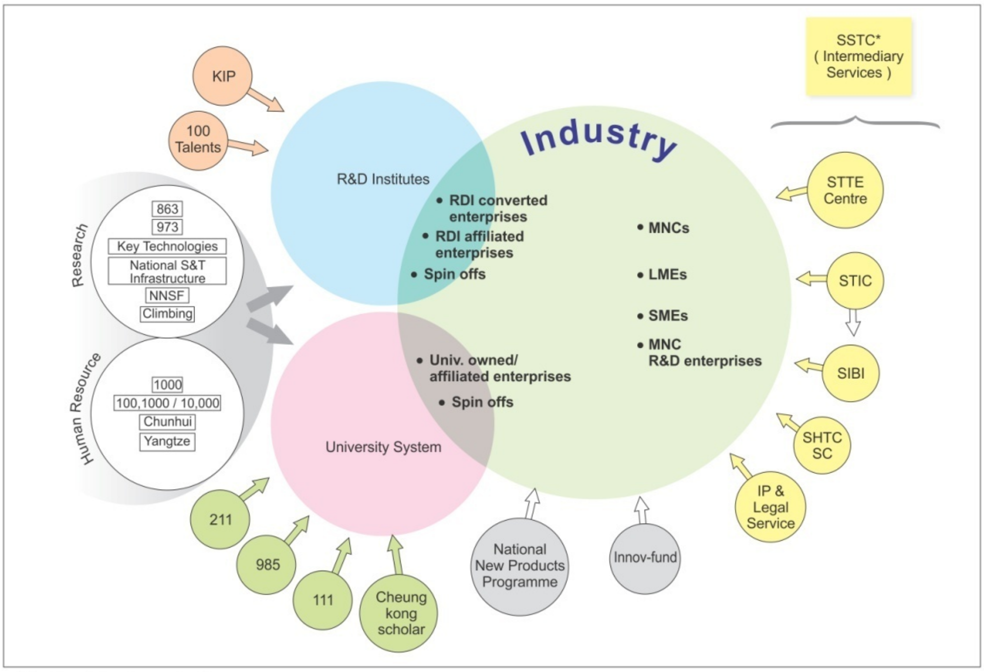
The emergence of innovation systems in China has been a part of an organized drive, facilitated by both the centre and the local governments (Hu, 2007). A total of 53 states level Science & Technology Industrial Parks (STIPs) were set up under the Torch Programme emphasizing on high-tech industrialization of China. These have been assisted by both central and state governments through the provision of physical infrastructure, provision of services, and preferential policies such as tax exemptions. Many of these STIPs have high tech innovation centres which keep the STIPs dynamic and sustainable. These have achieved high growth rates and have emerged as vibrant clusters by creating industrial aggregation advantages. Statistics suggest an accommodation of 45,828 tenant companies with 5.74 million employees in the parks till 2006, contributing 9% of the total of industrial value added and 5% of the national GDP and a third of the country's R&D expenditure (Hu, 2007).

These parks reflect dominance of priority sectors such as IT, electronics, pharma/biotech, energy, environment, etc. are seen, which have been projected as key areas designated for promotion in China. The creation of S&T Parks/University Parks/Incubators has facilitated the creation of an ecosystem in China that is conducive to nurturing innovation. Their contribution to industrial output has gone up from 2% to nearly one third (Hu, 2007). This accompanied by the structural reorganization of the university system and public research institutes and creation of intermediary structures such as innovation centres, productivity promotion centres, technology transfer centres, venture capital firms, legal services, etc., for supporting commercialization has helped in increasing dynamism in the parks, which though not comparable to that of Silicon Valley, has still resulted in creating an ecosystem that leverages collaborations. China has enabled its key organizations in academia and government research institutions through a process of gradual transformation to create knowledge and encouraged the creation of production centres from them to offset the limitation of lack of demand from the industry and facilitate the application of knowledge. The varieties of enterprises that have emerged in these clusters are spin offs, affiliated enterprises to universities and research institutes. Some of these have been established by scientists and researchers with privileged access to state programmes on basic research, high technology, and commercialization. These parks also house leading MNCs. Availability of physical infrastructure has contributed to the vibrancy of these parks with the availability of funding in state directed programmes along the entire value chain. The focus on select sectors and technologies within the national programmes encouraged competition for funding and therefore channelling of research efforts in state directed programmes. The success of S&T/University/Industrial parks lies in providing inter-connections amongst the programmes that focus on high technology, commercialization. The ability to bring together R&D resource residing in CAS, top universities, leading Chinese firms, MNCs and their R&D centres, the availability of talent in the huge geographical structures has facilitated manufacturing and industrial development.

A case of Shanghai S&T Park has been discussed here to depict the interconnections amongst the innovation actors and support from the intermediary services Figure 12. Both GRIs and universities draw support from the national programmes for research (973, 863, key technologies, etc.) as well as human resource support (211, 985, 111, etc.). Both have also entered into commercial activities by floating spinoffs, owning commercial entities or the production centres formed by the conversion of research institutes. The support services subsequently have been created with the aim of aiding manufacturing and promoting innovation. For instance in the Shanghai Technology Park, the Shanghai Science and

Technology Commission (SSTC) is not only involved in formulating and implementing policies but it also acts as an administrator of service centres (technology transfer exchange centre, high-tech commercialization service centre, high-tech enterprise incubators) that aid in innovation. It administers the high profile S&T programmes. STTE is a technomart where technology transfer transactions take place. It plays a role in providing business services including feasibility studies, market research, technology transfer certifications, venture capital financing. A large number of domestic firms in these clusters have emerged either as spin-offs or in the form of affiliated enterprises which are owned by universities and research institutes. Firms created by research scientists and the university professors too have been established. The region is dominated by GRIs and universities and has a range of firms from MNCs to small and medium enterprises.

Figure 12. An illustration of the Innovation Support System in China



KIP - Knowledge Innovation Programme
NNSF - National Natural Science Foundation
RDI - R&D Institution

SSTC - Shanghai Science & Technology Commission
STTE - Shanghai Technology Transfer Exchange Centre
STIC - Shangh Technology Innovation Centre
SIBI - Shanghai International Business Incubators
SHTCSC - Shanghai High-tech Commercial Service Centre
*Constructed with the help from http://www.stte.sh.cn, http://www.incubator.sh.cn

Regional focus is the most important feature of S&T Parks in China, with the active participation of local governments. Municipalities have been instrumental in establishing service centres to facilitate technology transfer and commercialization of products and play active role in information exchange among innovation actors and also assisting in commercialization of products. Municipalities are active in governance and providing resources such as land and finances for developmental work.

Although not all S&T parks have exhibited dynamism but the most dynamic parks are those that have attracted lot of attention reflect a combination of research, manufacturing and support services. What is noteworthy is the fact that the initiatives of change have led to a qualitative improvement in the institutions involved on one hand and also enhanced linkages amongst the actors of innovation on the other. The reforms indicate attempts being made by the state to create a national capacity for developing research, innovation and human resource.

2.4. Organization and Management of R&D and Technology:

The emerging new technologies are multidisciplinary in nature. Their introduction requires high R&D investments, creation of new organizations, advanced skill sets, appropriate regulatory frameworks, vibrant ecosystems, new firms to absorb the new research results, so on and so forth. The Chinese case show that it has succeeded in bringing out necessary changes in their institutional structures to carry forward the new technology dynamism as we have seen in case of nanotechnology in China by creating new institutions towards the development of this technology. Attention is also paid to the creation of standards, risk analysis, assessment and management centres to encourage wider acceptance of technology. China has developed science parks, high industrial zones and university-industry joint research centres that are functional entities leading to joint technology development, technology transfer and co-operative partnerships. Identification of new skill requirements not only towards its supplying the skill sets but also towards appropriate faculties to create the skill sets has been duly recognized in China.

Nanotechnology as a field of priority in China, surfaced in the beginning of 1990s and the subsequent growth in the field can be attributed to defining the R&D areas, massive R&D investments, mobilising advanced skills through creation and repatriation, developing instruments critical for nanotechnology research, emphasis on creating new materials, creating nanotechnology parks, availability of funding along the entire chain of innovation, creating standards, appropriate machinery for risk governance, etc. A factor that provided fillip to nanotechnology in China has been development of capital intensive equipments required for nanotechnology research. China has targeted enhancement of the capacities of their ICT industry and advanced manufacturing industries through nanotechnology.

Thus creating new organizations for meeting the challenges of emerging technologies in research, academia and industry has been another very important factor in case of China. The process has included both demolishing the old structures and creating new ones. Identification of new skill requirements not only towards its supplying the skill sets but also towards appropriate faculties to create the skill sets has been duly recognized in China.

3. Summing up and Lessons drawn for India

China has slowly and systematically narrowed down the scientific gap with developed countries and also overtaken them in specific technology groups. What China has been able to achieve is not merely through increased R&D but also with a focus on manufacturing and through creating conditions that encouraged learning and leveraging. The success of China lies in creating a physical infrastructure which along with the necessary transformation in the knowledge residing actors has been successful in leveraging linkages amongst the actors of innovation. The much talked about Chinese policy on indigenous innovation, through IPR, standards or public procurement is nothing but an instrument of making indigenous efforts productive. The Chinese innovation plan displays the focus on specialization and target of achieving milestones with both a medium and long-term focus.

Now in terms of the lessons that can be learnt from this analysis, it is clear that China is a controlled and command economy and can be directed and governed. The causality of dynamism in China S&T pinpoints at targeted development and commensurate resource mobilization, continuously evolving policies with strict enforcement and implementable instruments, a will to acknowledge failures and efforts to correct them. Some of the cardinal principles are important which can be adopted by India. For instance, India too has shown impressive achievements when it has targeted and directed development in selected sectors such as space, atomic energy and defence related technological innovations but the performance falls below global levels of efficiency in the industrial sectors where firms have to face market dynamics. There is no dearth of policies, rather there is a plethora of policies, strategies and policy instruments but the implementation and regulation requires strengthening. The first and foremost issue in this regard is to complement economic policies with suitable innovation policies for building S&T capabilities for a sustainable industrial development similar to one attempted in China, Korea, Japan , so on and so forth. The changes in the S&T policies along with appropriate industrial policies should be accompanied by necessary changes in the policy for human resource. There is a need to strengthen the co-ordination among these in terms of planning and enforcement. Some of the issues that require focussed attention are the following;

3.1. India trails behind China in its spending on R&D. India's expenditure on R&D as a percentage of GDP stood at 0.9% in 2011. In contrast, the same in the case of China during the same period stood at 1.83 %. While the industry dominates R&D in case of China with more than 70 % share, the government continues to be the major spender of R&D in India with around 3/^{4th} of R&D expenditure. Higher R&D investments coupled with focussed and target-centric approach has enabled the Chinese S&T rise.

3.2. Adequate systemic reforms are required in India to transform the education system in general at and higher education system in particular. India does not have a single university in top 200 global universities, even though Indian faculty enriches universities the world over. India has increased the number of IITs but faculty remains a key problem. Although some of the newly created IITs are making attempts to upscale their infrastructure, offer better remuneration and research opportunities, create better housing facilities, and reach out to PhDs and post doctorates, there is a need to address this at a larger scale. There is a shortage of PhDs in the engineering and software/IT sector, where there is a vast gap in the requirements and availability of PhDs. It would be useful to draw some lessons from China which has tackled this through a number of university upgradation and modernization programmes.

3.3. In India, it is extremely important to re-invigorate research institutions that have been created in a wide number of areas. There is a need for major structural and organizational changes to enhance their effectiveness and competitiveness on one hand; and creating well resourced newer institutions. The need for complementing the existing skill sets in research institutions with newer skills cannot be underestimated. Repatriation of foreign trained Indians has not been strategized in a manner that can help India augment its skill shortages, be it in academia or research institutions. Although there are some indications of repatriation in industries, these are not parts of a broader policy paradigm.

3.4. The infrastructure for innovation in India needs to be strengthened. There is a domination of technology generation organizations but these are not supported by adequate organizations to support and promote innovation. The local level support reflects a total dearth and participation of local governments are in terms of implementation of central schemes and mobilization of resources. Although a number of initiatives have been taken in the last two decades but these do not match the initiatives undertaken in China and Korea. For instance, in India the participation of state governments in developmental projects is mainly in terms of the implementation of central schemes and mobilization of resources. It would be crucial to involve local governments in providing inputs on research and intermediary facilities and hold them responsible with greater stakes. Introduction of result oriented accountability rather than financial accountability with continuous structural changes can render more meaningful results. In India, local and regional governments do not have major control except when involved as stakeholders. In contrast, in China, local governments have played a significant role in providing infrastructure and resources such as free land, training of manpower, and support services.

3.5. India needs to strengthen the organization and management of R&D. The planning for R&D most often pertains to disbursement of funds to existing institutions with existing manpower which quite often is not even really geared to look beyond compartmentalized disciplines in S&T. The focus is still R&D and its subsequent application towards industrial development is not the mainstay of policies in general.

3.6. The strategy for India should therefore target mega programmes, built around sectors where India has built manufacturing strengths and to consolidate them with R&D. There are sectors which have shown tremendous growth potential such as software/IT, pharmaceuticals, biotechnology, automotives, textiles, etc. These sectors can enable India to achieve global competencies. For instance, Indian software development skills are utilized by foreign global firms for high value added activities but a strategy that can hone Indian strengths for high value added activities by Indian firms is needed. In the pharmaceutical/biotech sector, India has manufacturing strengths and R&D skills residing in firms, research institutions and academia. The need is to look for a niche where India can set global benchmarks supported by R&D. For establishing India on a global map, it is important for the highest growing sectors to be given adequate attention for R&D. It would be important to establish India at least in a few areas where front-runner countries are engaged in R&D, in order to become competitive in the long run. Non-technological means of sustaining innovation alone will not be sufficient. It becomes all the more necessary to direct research as the government is still the major spender for R&D, and thus investments should go to sectors where industry has shown some manufacturing strengths. Though enhancing innovative capacity across a whole range of sectors, institutions and regions may not be feasible; it is possible to strengthen them selectively through ruthless restructuring- the way it is done in China. Resource mobilisation can be channelized in accordance with targets by reorienting academia, research institutions, and industry to consolidate the ecosystem of innovation.

Given the fact that India has made impressive achievements in sectors which were targeted; and there are systemic problems confronting India's innovation and higher education system; it becomes imperative to have a target-centric strategic vision that is built on existing strengths, along with the transformation of innovation and higher education system.

Although many initiatives have been taken in India to boost innovation, the outcomes can become more visible with following measures that affect the process of building S&T capabilities;

- ✓ Strengthening the strategic focus and target-centric approach in the industrial sector
- ✓ Optimal investments and timely implementation
- ✓ Strengthening links amongst R&D, innovation, and production systems. The focussed and targeted R&D for innovation paradigm and regional research
- ✓ Commensurate structural and functional changes in the organizations involved in S&T and innovation including the infrastructure for innovation.
- ✓ Streamlining organization and management of R&D in the emerging technologies like biotechnology, nanotechnology requiring strong R&D and production synchronization.

- ✓ Vigorous measures related to human resource generation and augmentation.
- ✓ Development of efficient geographical clusters.
- ✓

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