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China's Reformed Science and Technology System: An Overview and Assessment[1]

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ABSTRACT *Science and technology (S&T) systems are interconnected with economic systems. After China began to make its economic system more market-oriented in 1979, reforms to its S&T system became urgent. China's major breakthrough in reforming its S&T system occurred in 1985. This paper provides data on China's changing S&T sector, outlines the processes of its reform and China's changing sources of funding for R&D. China's evolving technology market is given particular attention and some of its pitfalls are discussed.*

Keywords: China, economic reforms, patents, research and development, science and technology policy, technology markets.

Introduction

The Chinese economy has changed remarkably since China began its market reforms and opening up to the outside world in the late 1970s. Therefore, in line with the observation of Suttmeier that 'while science policy is intended to shape research and innovation activities in the interest of societal change, particular science policies are the products of socio-political and economic forces',[2] one would also expect China's science and technology system to show considerable transformation. This paper shows that China's science and technology (S&T) system has significantly altered to reflect changes in China's economic management, but has done so with a lag. China's S&T system has become much more market-oriented, even though vestiges of China's command-and-control economic era still remain. Past institutional arrangements cannot be swept away quickly. The evolution of institutions displays path-dependence as a rule and this is evident in the development of China's S&T system.

The importance of S&T as a vehicle for achieving China's economic development and national goals was recognised by the Chinese Communist Party when it came to power in 1949. It moved rapidly to set up institutions to foster S&T in China, first by establishing the Chinese Academy of Sciences. The evolution of

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China's S&T system between 1949 and 1971 is outlined in Suttmeier and by Baum.[3] Suttmeier observes that Chinese leaders in the period 1949–78 placed much emphasis on expanding S&T output as a stepping stone to China's modernisation and development,[4] but the main goal of China's S&T in this period was to support China's centrally-determined goals and its planned economy. However, beginning in the late 1970s, China's planned economy started to be transformed into a market one. Hence, its pre-1978 S&T arrangements increasingly became less appropriate to China's needs and began to be reformed in the manner outlined by the International Development Research Centre (IRDC) and the State Science and Technology Commission (SSTC).[5] Changes were needed to China's S&T system so that it would serve an economy becoming more market-oriented and outward-looking.

So there was no basic disagreement of Chinese leaders in the period between 1949 and 1978 with the views expressed by some Western scholars that an appropriate science and technology framework is a critical factor in modern economic development.[6] Furthermore, this view did not change after 1978. What did change was the opinion of China's leaders about the mechanisms that would be propitious in fostering China's economic development. After 1978, market-oriented, decentralised economic mechanisms became increasingly favoured by China's leaders as a means to achieve China's economic development, and centralised top-down ones tended to fall into disfavour. The problems that China faced with science and technology when it commenced its economic reforms were similar to those of many former communist countries. The R&D efforts of those countries were undertaken in centralised institutions, financed and operated by government in a centrally planned economy.[7] Let us consider these problems generally before considering China's specific situation and its reforms of its science and technology system.

Several economists argue that the centrally planned system in the former communist countries was relatively ineffective at promoting innovation. Central priorities governed the items and quantities of commodities to be produced and determined their sources of supply. Consumer demands, input prices, and market competition inroads played no role in these socialist systems. Thus, the impetus toward production and, even more, toward product innovation was not as compelling as in competitive market economies.[8] Some of the principal reasons for this were: (1) bureaucratic structures that managed science and technology development and resulted in immobility of scientists and engineers;[9] (2) at the firm or institute level, there was little incentive for managers to improve product designs, quality or efficiency beyond what was demanded by planning authorities; and (3) the stumbling block for the system was not a lack of R&D funding or scientific capability. The S&T system's greatest weakness was poor linkage between research and production; for example, factories without engineering facilities and R&D institutes that lacked production engineering capability or pilot production plants.[10]

Gomulka points out that because of these weaknesses, the contribution of new innovations in centrally planned economies was negligible, despite expenditure in these countries being large and equal to at least a quarter of world R&D expenditure.[11] The structure, linkage and operating efficiency of R&D systems in these countries were badly in need of reform. Their national innovation systems were clearly inadequate,[12] but empirical studies record that changing these systems was difficult and slow because of institutional inertia and the interdependence of social systems.[13] Moreover, there was a need for informal as well as formal changes in institutions. There was a need to reconstruct linkages between research organisations, universities and manufacturers, improve R&D infrastructure, establish finance agencies for R&D, and promote dissemination of technology.[14] In addition, with opening up to the outside world, China also needed to integrate its import of science and technology into its S&T system, taking into account interconnections such as those mentioned by Radovesic and Tisdell.[15]

Rapid, 'Big Bang' transitional policies in Russia, based on neoclassical economics, ignored or downplayed the existence of the preceding pervasive nature of the state. The policy dismantled the old system without appreciating the strong connection between state ownership and the social obligations of the enterprise, and the need to take time to foster new social obligations and institutional arrangements. Thus, the consequences of this policy were generally negative.[16] Rapid privatisation and marketisation under the policy did not work as well as expected in Russia and some Eastern European countries. The consequences of this were that S&T funding was considerably reduced; large numbers of research projects were cancelled and the technological capabilities of Russia and some Eastern European countries were weakened in their transition. China did not follow this path.

China's economic reforms under the leadership of Deng Xiaoping proceeded more gradually. While China's general economic reforms began in 1979, reforms to its science and technology system did not get underway until 1985, when the *Decision on the Reform of the Science and Technology Management System* of March 1985 was made.[17] These reforms were also market-oriented, and gradual or evolutionary rather than sudden and large.[18] This paper examines, in turn, relevant comparative data on the development of China's S&T sector, the process involved in reforming China's S&T system, and changes in the pattern of funding of China's S&T research. Then it considers the nature of China's evolving technology market, China's establishment of a patent system, and its efforts to create closer ties between technology suppliers and users. This is followed by an overall evaluation of China's reformed S&T system and concluding comments.

Comparative Data on the Development of China's S&T Sector

China's science and technology base was very weak when the People's Republic of China was established in 1949.[19] Construction of its 'modernised' science and technology system was then initiated and developed, based on the Soviet model, but little progress was made until the commencement of China's large-scale industrialisation in the mid-1950s. For new technology, the economy relied largely on the adoption of foreign technology transferred from the Soviet Union and Eastern European countries.

In the early 1950s, China's scientific and technological personnel amounted to fewer than 50,000 and there were almost no suitable research facilities available. Nevertheless, after two and half decades of communist development, China's S&T efforts showed progress. In 1978, there were 1.37 million personnel engaged in S&T work. Subsequently, the number increased steadily, reaching 3.22 million in 2002 of which scientists and engineers (S/E) accounted for 2.17 million persons (see Table 1). R&D personnel numbers rose from 781,000 in 1986 to 1,035,000 in 2002.

Since 2001, China has had the largest number of R&D personnel and researchers in the world. It overtook Russia, the USA and Japan in 2001. But in terms of researchers per million persons, China's figure was five times lower than that of

Table 1. Numbers of China's S&T and R&D personnel (000s)

	Total personnel engaged in S&T activities	Of which scientists and engineers	Total R&D personnel	Of which scientists and engineers	S/E engaged in R&D per 1000 labour force
1949	50	–	–	–	–
1978	1,369	–	–	–	–
1985	–	–	576	–	–
1986	–	–	781	320	–
1987	–	–	713	341	–
1988	2,094	1,085	753	3,602	–
1989	2,099	1,150	763	376	–
1990	2,099	1,182	757	389	–
1991	2,219	1,248	776	395	–
1992	2,207	1,277	707	388	–
1993	2,374	1,297	682	383	–
1994	2,437	1,347	644	374	–
1995	2,476	1,353	626	368	–
1996	2,903	1,688	804	548	7.9
1997	2,886	1,668	831	589	8.3
1998	2,815	1,490	755	486	6.8
1999	2,906	1,595	822	531	6.7
2000	3,223	2,046	922	698	9.8
2001	3,141	2,071	956	743	10.1
2002	3,222	2,172	1,035	811	10.8

Note: – data not available.
Source: *Statistical Yearbook of China* and *Statistical Yearbook of China on Science and Technology and Science and Technology Indicators* for relevant years.

Japan, 3.1 times lower than that of the USA, and 1.5 times lower than that of both Singapore and South Korea in 1995 (see Table 2), although well ahead of India and Malaysia.

Using another indicator, R&D personnel per 10,000 of the labour force, China's status was even lower, accounting for less than 10% of that of developed economies and 20% of that of early NICs, such as South Korea at about 1995. This gap slightly narrowed by 2002, but is still quite large compared with developed countries and early NICs. Thus, China's average S&T and R&D personnel intensities were low in the late-1990s and at the beginning of the twenty-first century.

The main problems for China's S&T and R&D development in its pre-reform era were a chronic shortage of funds, a low ratio of technical personnel in its population and its labour force, a distorted R&D personnel distribution and poor linkages between research and production.[20] Thus, China's technological capacity was low, and it experienced high technology transfer costs and difficulties in obtaining research results from abroad. All these weaknesses seriously hindered China's effort, not only in developing domestic technology, but also in the efficient utilisation of foreign technology. As a result, improved technology contributed very little to China's economic development during the pre-reform era.

Table 3 indicates that China's total nominal R&D expenditure increased more than nine fold between 1990 and 2002, and its intensity approximately doubled in relation to its GDP. In total value terms in 1995, China's R&D expenditure was 5%

Table 2. R&D personnel in selected countries: numbers and intensity

	Researchers per million inhabitants			R&D personnel per 10,000 in the labour force	
	1981	**1990**	**1995**	**1995**	**2001**
Canada	1,573	2,301	2,719	–	–
Australia	1,661	2,408	3,185	–	–
USA	2,973	3,675	3,676	–	–
Japan	3,934	5,395	5,368	125 (1997)	132
Germany	1,596	3,029	2,831	116	121
Netherlands	2,084	2,693	2,202	–	–
Norway	1,830	2,880	3,664	–	–
Italy	921	1,366	1,318	–	–
UK	2,254	2,319	2,504	95 (1993)	–
Russia	–	6,697	3,503	136 (1996)	143
Poland	2,479	1,083	1,307	–	–
Hungary	2,081	1,694	1,027	–	–
S. Korea	536	1,645	2,235	63 (1997)	75
Malaysia	182	88	93	–	–
Singapore	485	1,426	2,316	–	–
China	–	967	895	11 (1998)	14 (2002)
India	131	151	149	–	–

Note: – data are not available.
Source: http://www.sts.org.cn/stsi_2/stsdata/data2004/debk26.html; China's figures were calculated using data from *Statistical Yearbook of China* in relevant years.

Table 3. China's R&D expenditure (by value and as percentage of GDP)

	R&D expenditure yuan 100 million	**R&D/GDP %**
1985	48.1	0.58
1986	51.0	0.54
1987	56.7	0.51
1988	60.1	0.56
1989	112.3	0.70
1990	125.4	0.71
1991	142.3	0.72
1992	169.0	0.70
1993	196.0	0.62
1994	222.2	0.50
1995	348.7	0.60
1996	404.5	0.60
1997	481.5	0.64
1998	551.1	0.69
1999	678.9	0.83
2000	895.7	1.00
2001	1,042.5	1.09
2002	1,287.6	1.23

Source: *Statistical Yearbook of China* and *Statistical Yearbook of China on Science and Technology.*

Table 4. International comparison of R&D expenditure per capita in selected countries, 1981–2000 ($US)

	1981	1985	1990	1995	1997	2000
Japan	230	327	715	1,176	–	–
USA	317	483	608	688	720	–
Germany	212	241	554	651	592	–
Norway	177	251	409 (1989)	559	–	–
Netherlands	200	203	406	511	–	–
Canada	150	202	308	302	312	–
Singapore	17	–	215	287	–	–
S. Korea	11	35	109	269	–	–
Italy	60	90	262	197	204	–
Hungary	53	49	53	26	–	–
Malaysia	–	12 (1988)	–	12 (1994)	–	–
China	–	3 (1988)	2	3	5	9
India	2	2	3	2	–	–

Note: – data are not available.
Source: UNESCO and International Financial Statistics of IMF.

of the level of the USA, 6.3% of that of Japan, 16.4% of that of Germany, similar to that of the Netherlands, Canada and South Korea, double that of Taiwan and 2.5 times that of India. In 1995, Japan had the highest R&D per capita expenditure ($1,176), followed by the United States ($688), Germany ($651) and West European countries (see Table 4). The recent whole range of data is not available, but the Chinese data suggest that the figure for 2000 was $9 per head. China's figure was far behind those for developed countries and much lower than that of Asian NICs. No doubt, a fundamental reason for the low level of China's per capita R&D funding is China's low level of per capita income.

However, Tables 3 and 4 may underestimate China's S&T and R&D expenditure because they were calculated using exchange rates based on traded commodities. LDCs, especially in previously planned economies such as China, trade mainly in primary and low value added products. For LDCs, real purchasing power parity rates should be larger than the figures calculated according to the nominal exchange rates used in Tables 3 and 4. Nevertheless, the figures given in the tables do highlight major R&D funding gaps between the developed and developing countries.

The Process of Reforming China's S&T System

China's economic reforms started in agriculture, then moved to industry, foreign trade and other areas. Reform in China's science and technology system dates from the mid-1980s and includes all aspects of S&T (institute, management, S&T personnel and funding).[21] One of China's important reforms of its S&T system was a change in funding procedures so that research and trial production funds were split into three separate categories: (1) applied and basic research; (2) trial production; and (3) technological back-up activities. In the first category, funds are distributed to research units through contracts. In the second category, funds are distributed directly to end-users, who then contract out trial production projects to units under the relevant industrial ministry and who thus have control over the implementation of the project. In the third category, funds are used to develop technological standardisation, information services and are distributed directly to research units by the relevant industrial departments. Consequently, the distribution of R&D became more demand-driven than formerly. Although significant change did not occur in China's S&T system until 1985, there was growing consensus from early 1981 that China's S&T should be developed mainly to accelerate economic development;[22] research on production techniques should be strengthened, and the production sector should participate more in research, and use results more extensively.[23]

As a prelude to the crucial *Decision on the Reform of the Science and Technology Management System* of the State Science and Technology Commission (SSTC), the State Council in 1983 established the Science and Technology Leading Group to canvass the views of major stakeholders and set guidelines for S&T development. In formulating its policy decision, SSTC basically followed the guidelines developed by the State Council. The decision of the SSTC of March 1985 reaffirmed the fundamental importance of S&T for China's continuing economic development, but changed the way it is managed. It stated that the funding system would be reformed, greater use would be made of the technology market, and there would be less reliance on 'purely administrative means in science and technology management, with the state undertaking too much and exercising too rigid a control'.[24] Furthermore, much more attention would be given to commercialisation of technological achievements and to greater use of technology markets. In addition, it was made clear that there would be greater emphasis on encouraging partnerships between research, educational and designing institutions on the one hand, and production units on the other and on strengthening the enterprises' capability for technology absorption and development.[25] Devolution of decision-making in S&T was to be encouraged. It emphasised that 'opening to the outside world and establishing contact with other countries is a basic and long-term policy in China's scientific and technological development'.[26] This decision recognised that the separation of technology generation (mainly by public research institutes) and utilisation (mainly by enterprises) in China had seriously hindered technology transfer, diffusion and spillover, and made transfer costs extremely high. According to Yu, about 85% of all research results were not utilised by enterprises.[27] Only 15% of these had been used in production to any extent; of these, only 5% were commercially successful.

To strengthen the human resources of businesses, the Chinese Government has adopted measures to encourage, stimulate and promote the transfer of S&T personnel from research institutes to enterprises. The Government also changed the operational function of research, encouraging some institutes to merge with enterprises and to link their work directly with production. Research institutes were required to link their research efforts more closely to market requirements and to receive feedback from customers, enabling them to adjust the direction of their research. There was also greater emphasis on in-house S&T effort by enterprises.

These reforms have resulted in significant changes in the distribution of R&D personnel in China by institutional affiliation. The technical human resources in enterprises were relatively limited in the pre-reform era in terms of quantity and quality, but since the mid-1980s the pattern has started to change. In 1990, research institutes employed 280,000 R&D staff, accounting for 45.3% of national R&D personnel while enterprises employed 154,000 (24.9% of personnel) (see Table 5). By 1999, the number of R&D personnel in institutes had

Table 5. Distribution of R&D personnel in China by institutional affiliation 1990–99

	Research institute (000s)	Enterprise (000s)	University (000s)	Research institute (%)	Enterprise (%)	University (%)
1990	280.0	154.0	128.0	45.3	24.9	20.7
1995	206.1	260.2	139.2	31.0	39.1	20.9
1999	234.0	351.0	176.0	28.5	42.7	21.4

Source: *Statistical Yearbook of China* and *China Science and Technology Indicator.*

declined to 234,000 (28.5% of total personnel), while S&T personnel in enterprises doubled to 351,000 to account for 42.7% of the total. S&T personnel and R&D personnel in universities increased slightly, but there was little change in percentage terms.

The distribution of China's scientists and engineers (S/E) showed a similar changing trend. The number of enterprise S/E tripled from 56,500 (13.9% of total S/E) in 1990 to 171,900 (32.4%) in 1999 while the number of institute personnel fell from 205,000 (50.3%) to 166,800 (31.4%) (see Table 6). The quality of S&T and S/E personnel in enterprises also improved. Previously the best-qualified S/E were willing to work in public research institutes only because these provided better research facilities, and the Government could pay higher salaries and living subsidies than were available working for business enterprises. After China's reforms, funding for institutes was reduced, or disappeared altogether, because of the reduction of government appropriations. Other sources of funds for research institutes also became more limited. At the same time, production, sales revenue and income of business enterprises increased considerably. Enterprises were now willing and able to pay higher salaries and provide research opportunities to R&D personnel and S/E engaged in S&T development of new products as the market became more technically demanding. Consequently, increased movement of high quality S&T and S/E personnel into business enterprises occurred. This significantly strengthened China's human technical resources in industry, and played an important role in generating domestic technology. At the same time, it has also greatly improved the ability of China's businesses to utilise imported technology and has strengthened the international competitiveness of China's businesses.

Table 6. Distribution of scientists and engineers engaged in R&D (1990–99) in China by institutional affiliations

	Research institute (000s)	Enterprise (000s)	University (000s)	Research institute (%)	Enterprise (%)	University (%)
1990	205.0	56.5	118.2	50.3	13.9	29.0
1995	157.8	103.8	132	37.3	24.6	31.2
1999	166.8	171.9	168.4	31.4	32.4	31.7

Source: *Statistical Yearbook of China* and *China Science and Technology Indicator.*

Sources of Funding for China's S&T Research—Changing Patterns and International Comparisons

Policy measures involving deregulation and decentralisation of the economy, adopted as part of China's market-oriented reforms, have reduced the Government's financial resources. Limited government resources now have to be shared among defence, social and public affairs. This partially explains the Government's dilemma: emphasis on science and technology is seen as a primary productive force, yet fewer public financial resources were available to distribute to this sector. Also, China's leaders became increasingly aware of the inefficiencies in China's S&T system. The funding pattern of science and technology in selected nations indicates that in most developed countries and in some early NICs, most funding for R&D effort was obtained from business enterprises. In China, contrary to this pattern, the Government was the main funding source.

Before China's economic reforms commenced, government appropriations, as in other centrally planned economies, provided virtually the entire funding for China's R&D. Under that system, some basic sciences were developed, but the linkage between R&D and end-users was very weak. Additionally, the transformation rate of R&D results to production was very sluggish and high costs were involved. The proposals for S&T reform included:

- diversifying of sources of funding away from sole dependence on the Government towards the business sector;
- undertaking paid commercial research;
- introducing research performance as a criterion for allocating funds; and
- encouraging borrowing from the banking sector.

Following SSTC's *Decision* of March 1985, the major funding reform regulations were promulgated in early 1986. Funds for post-laboratory development work, the trial production of new products, and key research projects were put under the joint management of the Ministry of Finance and the SSTC, and it was stipulated that the rate of increase of these state allocations would be greater than the rate of increase of state revenues. Contracts were now to be drawn up between successful bidders and the government department in charge of a project. The banking sector was drawn into the new system for the first time by being given responsibility for supervising fund disbursement and repayment on the completion of projects.

In April 1986, the State Council introduced a policy to promote the new R&D system. It encouraged research units to develop further their academic work and to co-operate closely with other research units, enterprises and institutes. Each research unit now has the right to keep any income earned, subject to the requirement of completing any research project required by the state. The units also were relatively independent with the authority to choose their own staff and research projects.[28] In recent years, absolute direct funding from Government has considerably increased, but its ratio to total S&T funds has decreased. Government appropriations fell from 50.8% in 1988 to 25.1% in 2000, while self-raised funds of research bodies increased from 42.7% in 1989 to 55.7% in 2000 (see Table 7). Commercial bank loans for S&T are still relatively rare in China. However, the funding pattern has changed to a considerable extent. S&T non-government funds (self-raised funds + bank loans + others) amounted to 22.9 billion yuan (49.2%) in 1989 and 177.5 billion yuan (74.9%) in 2000.

Table 7. Funding for S&T research (100 million yuan) 1988–2000, China

	1988	1989	1990	1992	1994	1996	1998	1999	2000
S&T funding	282.5	343.5	403.3	556.1	718.5	1,043.2	1,289.8	1,460.6	2,370.0
–government	143.4	114.4	124.1	149.4	204.4	272.0	353.8	473.0	594.8
–enterprises self–raised funds		146.7	174.4	240.4	288.7	434.2	655.1	745.9	1,319.5
–loans		40.9	49.0	80.7	108.9	149.8	171.0	123.0	194.9
–other		41.5	55.7	85.1	116.4				
S&T funding (%)	100	100	100	100	100	100	100	100	100
–government	50.8	33.3	30.8	26.9	28.5	26.1	27.4	32.4	25.1
–enterprises self–raised funds		42.7	43.3	43.2	40.2	41.6	50.8	51.1	55.7
–loans		11.9	12.2	14.5	15.2	14.4	13.3	8.4	8.2
–other		12.1	13.8	15.3	16.2				

Source: 1988 data from *China Statistical Yearbook on Science and Technology*, 1994; 1989–91 data from *China Statistical Yearbook*, 1989–2000; data from *China Statistical Yearbook*, 1992–2002.

Some production-related and development-oriented R&D institutes have become increasingly competent at funding much of their own operating expenses and have become almost financially independent. However, those R&D institutes carrying out basic research are, of necessity, still highly dependent on government assistance. Nevertheless, Chinese government funding of R&D decreased from 50.8% in 1985 to 27.1% in 2002, while R&D funding from enterprise rose to 61.2% (see Figure 1). In order to make China's R&D and R&D institutions more market-driven, the Chinese Government acted swiftly in the period 1987–92 by:

- substantially reducing the institutions' core-budget appropriations from Government (in some cases, especially in the provinces, this reduction was to zero);
- making government-contract funds, allocated by competition, an important vehicle for promoting technological development; and
- providing incentives for enterprises to invest in R&D at an increased rate.

This market discipline has had the positive effect of allowing creative institutions to expand their incomes and activities and to have a substantially increased impact on the economy.[29] It has, moreover, resulted in some research units engaging in production in order to survive or capitalise on their R&D. The reforms have been beneficial to institutions able to appropriate economic benefits from their R&D, but have disadvantaged those institutions that encounter 'market failures' in their sale of R&D. An example of change is the way in which the Chinese Academy of Sciences (CAS) is funded. Once it was entirely funded from the national government budget. However, by the mid-1990s, CAS's income was composed of the following items:

- 20% from budget allocation from national Government;
- 30% from contracts with national ministries;
- 30% from contracts with enterprises; and
- 20% from contracts with provincial and municipal governments.

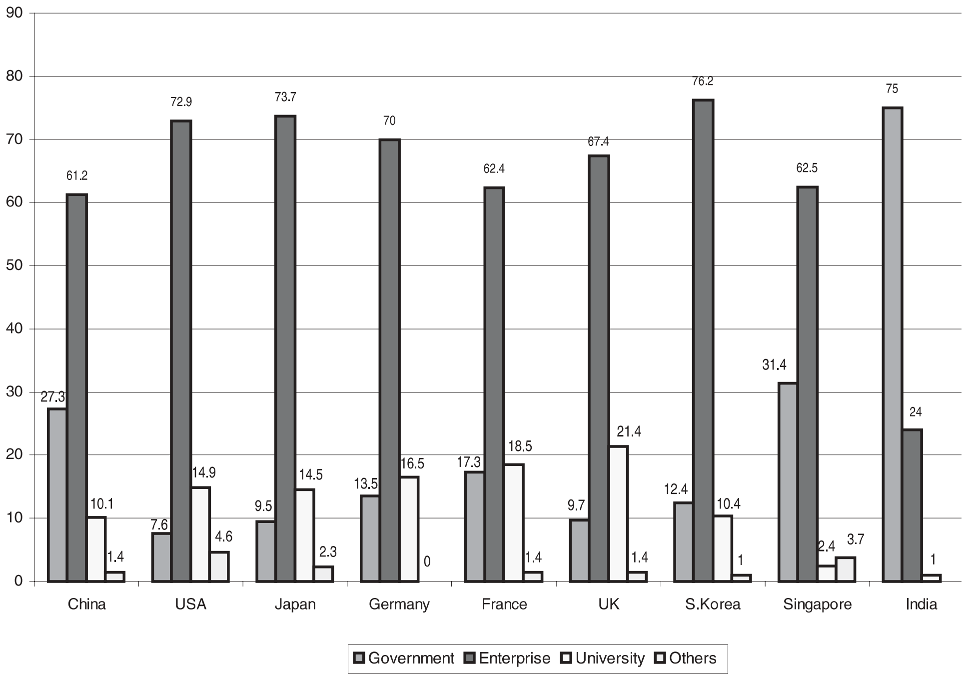

Figure 1. Sources of R&D funding for selected nations 2002.

It was also considering a long-term reduction in its staff from 90,000 to 50,000.[30] By the mid-1990s, CAS was facing 'market' pressures comparable to those faced by scientific bodies in some Western countries, such as the CSIRO (Commonwealth Scientific and Industrial Organisation) in Australia.

China's Evolving Technology Market

Under the pre-reform system, R&D results had no exchange value and were normally transferred from one research unit to another, or to the production factory, by the relevant administrative bureau at zero cost to the recipient. Technology was therefore a 'free good'. Consequently, there was neither incentive for innovation nor efficient transfer or diffusion between research institutes and the R&D users. Following the support for market-directed reforms and the SSTC *Decision* of 1985, there were moves to treat research results as marketable commodities, and the view that the revenue received could be used to provide incentives for further research became common. The practical steps for this commercial transition in technology started in the mid-1980s and are still ongoing. The establishment of a unified open technology market has been seen as a significant shift in China's S&T system, helping to break vertical and horizontal institutional barriers and accelerate technology transfer and diffusion.[31]

The departments administering S&T activities now have greater responsibilities to see that funds are better used and managed. Various R&D projects are funded in different ways and sources of funding have been expanded. Funds provided for some research projects now require repayment. Attempts have been made to remove the barriers between departments and regions, introduce competition into

Table 8. Technology transactions in the domestic market 1991–2002, China

	Number of projects	Value (yuan 10,000)	Value yuan per project
1985	9,932	230,000	23,150
1986	87,084	2,060,000	23,655
1987	131,617	3,352,130	25,469
1988	265,017	7,248,810	27,352
1989	262,161	8,146,390	31,074
1990	206,748	7,509,690	36,323
1991	208,098	9,480,540	45,558
1992	226,460	14,561,820	64,302
1993	245,967	20,755,400	84,383
1994	222,356	22,886,960	102,929
1995	221,182	26,834,450	121,323
1996	226,962	30,020,450	132,271
1997	250,500	35,137,130	140,268
1998	281,782	43,582,270	154,667
1999	264,523	52,341,260	197,870
2000	241,008	65,075,080	270,012
2001	229,702	78,300,000	340,876
2002	237,093	88,417,110	372,921

Sources: *Statistical Yearbook of China on Science and Technology* in relevant years and unpublished data from the Research Centre of the Ministry of Science and Technology.

the research system, and focus funding support on those who can best carry out the required work.

According to available data, China's trade in technology has grown very rapidly since the mid-1980s. In 1985, it accounted for 230 million yuan, increasing to 8,146 million yuan in 1989. There was further expansion in the 1990s. After more than one and a half decades of development, the value of the annual technology trade reached 88.4 billion yuan (see Table 8) in 2000. The number of technology transactions increased from 9,932 in 1985 to 237,043 in 2002.

Following its expansion, the nature of the Chinese technology market has changed greatly, especially in terms of its structure. In the early and middle 1980s, most buyers in this market were small rural enterprises that were not part of the state-owned system and had no way of obtaining 'free technology goods'. The major type of trade with those customers involved service arrangements to improve their outmoded production facilities. Most of the projects were small, and involved relatively unsophisticated technologies. About 77% of all contracts were of this type, with an average value of less than 20,000 yuan.[32]

From Table 8, it appears that the number of transactions in China's technology market increased several fold between 1985 and 2002. The value per contract in nominal terms has also risen steadily. Table 9 indicates that, in 1990, research institutes were the main providers in this trade in terms of the value of transactions, with enterprises ranked third. However, by 2002, enterprises accounted for more than 40% of the domestic technology trade and dominated supply. Hence, the trade became more closely connected with business enterprises and institutions involved in economic production. Enterprises may have an advantage over research institutes in the S&T market, the items they transfer may be more appropriate to commercial requirements, and more mature than those developed

Table 9. Sellers in domestic technology trade 1990–2002

	Number of contracts				**Value of contract (yuan)**			
	1990		**2002**		**1990**		**2002**	
	Projects	**%**	**Projects**	**%**	**000s**	**%**	**000s**	**%**
Research institutes	59,235	30.9	52,060	22.0	2,681,840	36.5	1,870.8	21.2
Universities	13,475	7.0	31,257	13.2	661,040	9.0	726.4	8.2
Enterprises	31,563	16.5	57,480	24.2	1,442,790	19.7	3,585.9	40.6
Technology trade companies	61,841	32.3	67,555	28.5	1,515,610	20.6	1,387.6	15.7
Private companies	6,403	3.3	4,826	2.0	132,560	1.8	74.6	0.8
Others	18,923	9.9	23,915	10.1	906,480	12.3	1,196.4	13.5
Total	191,440	100	237,093	100	7,340,320	100	8,841.7	100

Source: *China Statistical Yearbook on Science and Technology* in relevant years; 1999 data from http://www.sts.org.cn/stsi_2nbsjj/DATA99/Abt18_1.hmml.

by research units. Enterprises may also have more flexibility in funding than many research institutes.

While enterprises account for a significant amount of domestic technology trade purchases, their relative importance has decreased in recent years (see Table 10). This may indicate that more enterprises are engaging in in-house supply of their technology needs as is common for larger firms in higher income countries. It is also noticeable that it is particularly the case that large and medium firms have shown relatively the greatest decline as purchasers in the domestic technology trade. This probably indicates that the Chinese Government's aim of ensuring that technology development is more closely linked to enterprises than to public bodies is being met.

Table 10. Buyers in China's domestic technology trade, 1991–2002 (% of value)

	1991	**1995**	**1999**	**2002**
	%	**%**	**%**	**%**
Research institutes	7.6	4.9	–	21.2
Government	9.6	9.8	–	8.2
Enterprises	63.9	63.3	76.1	40.6
Technology trade companies	2.8	3.9	–	15.7
Private & others	0.5	1.3	–	14.4
Total	100	100	100	100

Source: *China Statistical Yearbook on Science and Technology*; 1999 data from http://www.sts.org.cn/stsi_2nbsjj/DATA99/Abt18_1.hmml.

China's Establishment of a Patent System

Patents are one of the most extensively discussed topics in the theoretical literature on innovation, and opinions differ about the economic benefits of patent systems. According to Beije, the patent system provides a valuable compromise between private and public interests in R&D and innovation.[33] From the private point of view, individual firms are stimulated to undertake R&D when they can appropriate the profits from successful innovation projects. Therefore, they should be favourably disposed towards strong protection for intellectual property rights. From the public's perspective, however, full disclosure and availability of the R&D results of all firms is often seen as most desirable.[34]

In R&D investment, there are two main uncertainties. One is the uncertainty of solving the technological problems faced; the other is concern with the possibility of imitation by competitors. A patent offers legal protection to an innovator against imitation. A patent, therefore, reduces market uncertainty, thereby increasing incentives for R&D and innovation firms. As a result, R&D investment may rise. Governments must seek a balance between the stimulating effect on R&D of a temporary monopoly position for the innovative firm and the disadvantage of actually establishing a monopoly for a single firm.

China's centrally planned economic system did not have a patent system. There was a lack of incentive for local innovation. Furthermore, extensive reverse engineering of foreign technology occurred without permission and this caused technical and legal problems. Following market reforms and commercialisation, the Chinese Government started to establish a patent system. This has become the cornerstone of science and technology development in China, and has enabled China to participate in the world's intellectual property market. In 1983, China enacted its patent law. This was the first step in establishing a legal basis for ownership of intellectual property. It signed the Paris International Property Rights Treaty in 1984. This was followed by laws on technology contracts, the first of which came into force in 1987. However, the law was framed in very general terms and did little to clarify the rights and responsibilities of parties to the contract. China's patent law was strengthened in 1992. Copyright law was also gradually implemented. China acceded to the Berne Convention in 1993.

The rapid increase in the number of patents granted reflects the change in policy. In 1985, only 138 patents were granted and, of these, just 40 were for inventions, with the balance being for utility/applied and design patents. The number of patents granted in 2002 totalled 132,399, including 21,473 invention patents (see Table 11). By 2001, China ranked 10th in the world in terms of invention patents granted (see Table 12). Given the fact that China's patent system became operational only in 1985, growth in patenting has been rapid.

China's patent structure is similar to that of other low-income NICs. The percentage of invention patents is relatively small with the majority of patents being utility model and design patents. This pattern indicates that China's innovative capability (especially in high technology areas) is still limited and its patents mostly relate to the absorption and adaptation of imported new technology. The World Bank has doubted whether China can enforce its intellectual property rights legislation.[35] Whether such concern was justified is difficult to say. In any case, China established an Intellectual Property Rights Court in 1994 to help enforce its legislation.[36]

Table 11. Patents granted in China by types 1985–2002

	Total	Inventions[a]		Utility model		Designs	
	Project	**Project**	**%**	**Project**	**%**	**Project**	**%**
1985	138	40	29.0	60	43.5	38	27.5
1986	3,024	56	1.9	2,530	83.7	438	14.5
1987	6,811	422	6.2	5,768	84.7	621	9.1
1988	11,947	1,025	8.6	10,191	85.3	731	6.1
1989	17,129	2,303	13.4	13,508	78.9	1,318	7.7
1990	22,588	3,838	17.0	16,952	75.0	1,798	8.0
1991	24,616	4,122	16.7	17,327	70.4	3,167	12.9
1992	31,475	3,966	12.6	24,060	52.8	3,449	11.0
1993	62,127	3,883	6.3	32,819	75.8	6,595	10.6
1994	43,297	3,883	9.0	32,819	67.8	6,595	15.2
1995	45,064	3,393	7.5	30,471	67.6	11,200	24.9
1996	43,780	2,976	6.8	27,171	62.1	13,633	31.1
1998	67,889	4,733	7.0	33,902	49.9	29,254	43.1
1999	100,156	7,637	7.6	56,366	56.3	36,151	36.1
2000	105,345	12,683	12.0	54,743	52.0	37,919	36.0
2001	114,251	16,296	14.3	54,349	47.6	43,596	38.2
2002	132,399	21,473	16.2	57,484	43.4	53,442	40.4

Notes: [a]**Inventions** refer to new technical proposals for the products or methods or their modification. **Utility models** refer to proposals for the shape or structure of the product or the combination of both. **Designs** refer to aesthetics, specifically new designs for the shape, pattern and colour of product, or their combination (*China Statistical Yearbook*, 2000, pp. 709–10). Because the data sources in Tables 11 and 12 are different, so there is a slight variance in the figures.

Source: *China Statistics Yearbook*, *Statistical Yearbook of China on Science and Technology* and *China Science and Technology Indicators*.

Creating Closer Ties between Technology Suppliers and Users

In most of the developed economies, continuing innovation is an essential factor in sustained economic growth at the firm, sectoral and national levels, and mechanisms for promoting innovations are well integrated.[37] Compared with these close and organic relationships, China's technological links between research institutes and enterprises, universities and enterprises, and between enterprises and other enterprises have previously been weak and fragmentary. This made domestic and international technology transfer very inefficient in the pre-reform era. Even within the same ministry, traditional vertical transfer results largely

Table 12. Invention patents granted in selected countries, 2001

	China	USA	Japan	Germany	France	UK	S. Korea	Italy	Netherlands
Domestic	5,395	87,606	109,375	19,242	11,010	3,975	21,833	882	2,956
Foreign	10,901	78,432	12,367	28,965	31,953	35,674	12,842	24,248	17,668
Total	16,296	166,038	121,742	48,207	42,963	39,649	34,675	25,130	20,624
Rank	10	1	2	3	4	5	6	7	8

Source: World Intellectual Property Organization (WIPO), *Industrial Property Statistics,* 2001.

depended on top-down administrative apparatus rather than on direct interaction between the units concerned.

The Chinese Government has introduced a number of measures (several of which have already been discussed) in an effort to improve links between research and production. Some of these additional measures are:

1. Promoting co-operation between research institutes and enterprises that have achieved some success in the past, under special conditions. State plans for developing key products and important technical innovation programmes all require intra- or inter-sectoral co-operation between the research and the production units organised by the relevant state organisations. Such co-operation, however, is mainly encouraged for sectorally important projects involving technology innovation, transfer, utilisation, assimilation and further refinement.
2. Stimulating the establishment of closer links between the R&D and production sectors by adoption of the so-called 'contract system': the Government granted research institutes greater autonomy to encourage them to develop their own research projects and permitted them to keep any profit in order to improve staff welfare and research facilities. While this was a useful way to make the research sector more responsive to the technical needs of production, overall the total volume of contract work was relatively small in the 1980s. A lot of it was consulting for small factories and most transferred technology was low value and 'one-off'. However, by the 1990s, these types of arrangements grew considerably. The majority of research institutes now depend on funds from their own research projects rather than on government finances.
3. Establishing technology alliances such as 'research/production combines' (R/P). These combines include objective alliances, organisational alliances and technological alliances. An objective alliance is where a research unit becomes a constituent part of a large corporation to form a research-based production unit. Alternatively, a large research institute integrates with an enterprise to form a trial production–research unit. The second organisational type of R/P entity is a research institute with some manufacturing capabilities that develops, produces and markets its own products (such as when an R&D unit links up with an engineering company to participate in a large civil engineering project). A technological alliance comprises those research institutes with technology development centres for specific industrial sectors. They focus on supplying technology for small/medium enterprises, or for small R&D units merged to form an R&D centre.

An Evaluation of China's Reformed S&T System

Despite the initial progress achieved, problems remain in China's S&T system and some new ones have also emerged.

1. The 'contract system' adopted in S&T has led to some negative short-term behaviour; for example, an emphasis on cash flow rather than on research or fundamental commercialisation of research results. The pressure on research units to generate their own income has created a tendency to ignore state-assigned projects in favour of independently contracted projects with other companies, especially private or collective ones.[38] The institutes receive most of their income from sales of their own innovative new products rather than from

Table 13. Structure of obtaining and utilising research results 1997 in innovations—Chinese sample of enterprises

	Number	%
1. Self–developed, produced and sold	1,969	30.1
2. External research, self–produced and sold	763	11.7
3. Produced by innovation firm	1,372	21.0
4. Developed and utilised through the co–operation of institute and firm	1,313	20.1
5. External transfer with payment	1,118	17.1
6. Total	6,535	100
7. Firms having long–term technological co–operation with research institutes	952	14.6

Source: Ministry of Science and Technology.

the commercial sale of R&D results. The latter is very difficult in China's technology market and domestically generated technology is always underpriced. The economic benefits of many R&D units are, in fact, linked to production outcomes rather than to R&D achievements.

2. Compared with earlier figures, the utilisation ratio of China's research results has improved, but external transfer/diffusion is still limited. Results of a sample survey (Table 13) indicate that 51.1% of research results (1+3) were self-developed, produced and sold or were adopted by the innovators themselves to ensure a temporary monopoly. Joint research and production accounted for 20.1%; external transfer 17.1% and other external resources 11.7%. This suggests that China's environment for external technology diffusion is not favourable and existing transfer mechanisms are not effective. However, it is also true that science and technology markets can work very imperfectly in Western economies, or are absent in some cases because of market failures.[39] Much R&D is conducted in-house by companies rather than contracted out.
3. Some research, especially basic research, appears to have been neglected despite efforts made to encourage it. This is understandable because market failure is especially marked in relation to basic research.[40] At a broader level, the measures designed to substitute independently sourced income for state grants in practice often penalise the more successful research units. In many areas of the economy, 'soft budget constraints' still operate in the S&T system. For example, the repayment of funds provided through a state organisation is sometimes possible via low interest loans. Banks are usually mere conduits for funds and the agents for local or central organisations rather than independent parties lending funds through set evaluation procedures.
4. The tendency for research units to become much more involved in their own manufacturing activities has had both positive and negative results. The pressure to become financially independent has resulted in some units becoming *de facto* production units. This is especially true of income derived from technology transfer. Of the 144 transfer projects surveyed in 1994, transfer fees did not cover research costs in over 50% of the cases.[41] This trend may damage R&D capabilities as it has forced the research institutes to operate their own manufacturing facilities. There is, however, an obvious role for them in producing

and manufacturing trial products embodying advanced technology. Research resources tend to become tied to production and research units and, as such, the unit rarely has the capacity to achieve economies of scale. The diffusion of new technology is retarded as research units try to protect their market position and competitive advantage by retaining sole possession of their new technology.

5. There are also continuing problems about the desirable balance between administrative intervention, market forces and the need for further adjustment. In addition, the lack of skilled labour and well-regulated capital markets is seen to have a significant constraining effect on the development of the technology market. One problem is that newly developed technology is often 'immature', needing further work before the product/process can be put into production. The weak link is seen to be a lack of intermediate, experimental or pilot plant facilities. Hence, the Government's encouragement to research units to link-up with production units. A second problem is the very uneven distribution of technology trade throughout the country. Several issues relating to production appear to be the major limiting factor in the expansion of commercialised technology trade. Until the late 1980s, China's booming demand for producer and consumer goods reduced pressure on enterprises to develop new products. However, since the early 1990s, competitive pressure has increased and the market has become much more technically demanding.
6. The existing contract S&T system concentrates on the short term, and desire for quick results. Hence, basic research work also appears to have been hit by funding reforms, despite government commitments to increase investment in basic research as a proportion of total expenditure.

Despite such difficulties, after less than two decades of significant reform in China's S&T system, considerable progress has been made. China's S&T and R&D personnel numbers have increased, a more efficient distribution pattern of resources has emerged, funding sources have been diversified, its volume of R&D output has considerably increased, and R&D results have been more efficiently utilised. However, China's average R&D outlay from the personnel and financial perspective is still lower than in developed countries, and compared to the early Asian NICs. In recent years, rapid overall economic growth has been due largely to economic reform, capital accumulation (from domestic saving and foreign borrowing), labour (released from the rural area), and the inflow of foreign technology, with some contribution from indigenous technology. Indigenous technology has not been the main source of economic growth, but China's S&T efforts have probably been very important in complementing the successful transfer of foreign technologies.

Concluding Comments

There is interdependence between change in major components of social systems.[42] For example, a change in the economic sub-system can be expected to alter a society's S&T sub-system, with some further feedback influencing its economic sub-system. Such change is evident in China's transition to a market economy. Beginning in 1978, China decided to change gradually from a centrally planned economic system to a more market-led one. At first, China's economic reforms proceeded without any significant change in its S&T system. However, as these economic reforms progressed, it became clear to Chinese leaders that

China's S&T system (which was tailored to the philosophy and requirements of a centrally planned economy) would need to be reformed so that it would be more compatible with a market-led economy, and more effective in serving the needs of such an economy.

Actually, the Chinese Government acted swiftly; in 1983, the State Council set-up a committee to consider reforms to China's S&T system and act as a catalyst for its change. This was followed by the policy decision of the State Science and Technology Commission in early 1985 to institute changes to China's S&T system to make it much more market-based than previously. This resulted in significant transformation of the S&T system within a period of about seven years, even though evolution of this system still continues. At the same time as China has increased its reliance on market-oriented funding of its S&T activities, it also strengthened its recognition and enforcement of intellectual property rights, an important ingredient of a market-dominated S&T system.

Given the extent of these reforms, China now faces challenges similar to those faced by many Western countries when deciding on appropriate science and technology policies. Market failures do occur in relation to the development of science and technology, and these can be quite serious in some areas.[43] Scientific and technological progress in these areas cannot be left to the market, or even mainly to the market. Administrative intervention is called for. How to do that well is a challenging issue involving many of the types of problems raised, for example, by Williamson and encountered in most market-oriented economies.[44] Care now needs to be exercised so that China does not become obsessed with the effectiveness of market power. According the Gu, such an obsession in China may have already resulted in some 'simplistic policy formulations that amount to no more than relying upon the expansion of "free-market". This has already considerably weakened the effectiveness of policies for the R&D system'.[45] An ideal S&T system for promoting development is difficult, maybe impossible, to achieve. It needs, however, to complement the economic system. Nevertheless, an ideal S&T system is not one that is purely market-driven. Achieving an appropriate balance between market and administrative methods for managing S&T systems remains a major problem in most economies, and China's is no exception.

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