4. Chidambaram, R., *Curr. Sci.*, 1995, 69, 12–14.
5. Bhabha, H. J., An invited lecture, International Council of Scientific Unions, Bombay, 7 January 1966.
6. Wali, Kameshwar, C., *CHANDRA – A Biography of S. Chandrasekhar*, Viking Penguin India, 1991, p. 246.

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Academia–industry symbiosis: The new norm of science in socialist China

V. P. Kharbanda

With globalization and international competition, university–industry symbiosis has gained importance, particularly in China. Since the initiation of reforms of the science and technology system, it has tried to re-establish its higher education system and the research base in terms of institutional infrastructure and manpower. One of the significant moves has been to link its R&D institutions as well as higher education system to meet its economic and social needs. Industry and the academia are collaborating in more diverse ways for technological innovations in an ideological environment, which was, in the recent past, definitely adverse to private entrepreneurship and profit motives. However, it still lacks the capacity to translate indigenous innovations in terms of economic gains on a scale to compete in the globalized world. Industry mainly depends on import of technologies for its survival. R&D capabilities of the firms need to be strengthened to fully exploit the indigenous knowledge base. In this scenario, the author surveys the efforts made by the Chinese to overcome the problem of linking the knowledge base with industry and proposes some measures which could be useful for both India and China, to face the onslaught of multinational giants in these countries.

DURING the recent years, the emergence of entrepreneurial science and the resulting university–industry symbiosis has proved to be of immense significance for achieving international technological competitiveness in the developed countries[1]. One explanation for the emergence of entrepreneurial science is that academic scientists, such as the founders of biotechnology firms in the late 1970s and early 1980s suddenly awakened to the financial opportunities emanating from their research. Implicit in this explanation is the notion that there were recent scientific advances in molecular biology, polymers, material sciences and information technologies that could be quickly developed as a source of profit. It may be seen that this cognitive condition exists only in a small number of research fields and scientific disciplines. But recent developments suggest that such a cognitive shape appears in more and more scientific fields. For example, linguistics, for a long time a purely curiosity-oriented basic research field, suddenly became part of the emerging trans-disciplinary area of cognitive sciences which have strong links to computer and software industry[2]. Thus, the emergence of new high technology knowledge-intensive areas, especially micro-electronics, computer and information processing, biotechnology, new materials, etc. has accentuated the linkages between knowledge-generating institutions and the industry. This has also led to legitimization of science as a source of new high technologies. Industry harvests the potentials of fundamental as well as applied research pursued in universities. The

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professor becomes deeply involved in helping a set of strategic research direction of the company rather than merely handing over a technology. On the other hand, universities benefit from the industry in terms of, (i) selection of research programmes of vital significance to the society at large; (ii) selection of teaching material/ courses in accordance with the needs of industry; and (iii) financial resources required to pursue them. Following globalization of trade during the 1990s, this symbiosis has gained further importance in view of: (i) international technological competition; (ii) increased cost of research; and (iii) decreasing time lag in research and application. Under the circumstances the universities are undergoing a 'second revolution' incorporating economic and social development as part of their mission. The first academic revolution, taking off in the late nineteenth century in the US, made research an academic function in addition to the traditional task of teaching. This revolution is by no means finished. In most advanced segments of the world-wide university system, a second revolution has taken off, where an entrepreneurial university integrates economic development into it as an academic function along with teaching and research. It is this capitalization of knowledge that is at the heart of a new mission for the university linking it to the users of knowledge in more effective ways. In this scenario, the national governments, particularly in developing countries, have an added role to play to provide an appropriate environment and conditions under which academic institutions and the industrial sector can fully realize their potentials and capabilities[3]. In this concern, China with its characteristic social system, is no exception.

Since the late 1980s China has been pursuing science and technology policy reforms and is experimenting with diverse forms and methods for strengthening this symbiotic relationship. In the recent past, Chinese institutions of higher education had been severely affected by the political events, which made them to work in isolation from the industry[4]. The present policies in China, particularly after the initiation of 'Reforms in the Science and Technology System since 1985, are oriented towards rectifying such a situation. How are these linkages being strengthened? What are the different forms and methods adopted by the Chinese government? What lessons can be drawn? What measures could be useful, to face the onslaught of multinational giants. Focusing on these questions, the present paper is divided into three parts. Part I throws light on the updated research base in China; Part II reviews the existing linkages and problems; and Part III deals with policy options to improve the linkages and conclusions.

The research base

After liberation in 1949, the Chinese government, at the initiation of the First Five-Year Plan (FYP) (1953–1957), made a nation-wide reorganization of the higher education system under the scheme 'Readjustment of Colleges and Departments' (Yuanxi tiaozheng), essentially on regional basis. After this reorganization, most provinces had one university and their own colleges of engineering, agriculture, medicine and teacher training. During this period the Chinese system of higher education was heavily influenced by the Soviet system. The Chinese Academy of Sciences (CAS) was formally established on 1 November 1949, merging research institutes of the former Academia Sinica (1928) and the Peking Academy (1929). CAS quickly developed, from only 14 research institutes with 224 researchers in 1949 to a network of 47 research institutes with 2977 researchers (including 448 senior ones) in 1955. The Chinese Academies of Medical, Agricultural and Geological Sciences were established in 1956, 1957 and 1959 respectively, drawing a number of leading scientists from universities. The de-emphasis on university research relative to the centralized academies closely followed the Soviet pattern and inevitably gave rise to complaints and even protests from university professors. Their voices were strongly echoed in a number of national conferences on higher education convened in the fifties. In September 1953, a National Conference on Comprehensive University Education proposed that universities should also be the institutions for research. Following this conference, strong impetus was given to the development of research in universities[5].

However, the next two decades witnessed havoc with educational institutions, except in the brief period of 1960–1964, primarily to meet political objectives. In 1958, the country entered the great leap forward (GLF) phase, which was characterized by mass movements in every field from academic research to industrial production. The number of institutions of higher education increased swiftly from 229 in 1957 to 1289 in 1960, with intake of students increasing from 105,581 in 1957 to 323,161 in 1960. Obviously, such high rate of growth was too hectic to be sustainable[6]. During the Reorientation Period (1960–1964), the State Science and Technology Commission (SSTC) drew up a programme for scientific and technological development (1963–1972) which listed 374 key R&D programmes, including 41 basic research programmes. By the end of August 1964, 184 institutions of higher education were involved in about 70% of the research programmes. But this did not last long. The Cultural Revolution (CR) (1966–1976) seriously disrupted the functioning of and inflicted heavy losses on institutions of higher education[7]. After the downfall of the Gang of Four on 29 July 1977, Deng indicated that the Ministry of Education (MOE) must encourage a number of key universities which should be both centers of education and centers of research. Since then, higher educational institutions have been given autonomy in respect of enrolment, establishment of organization, appointments and removals, fund utilization, professional title appraisals, salary distribution and international cooperation. The government has shifted from direct administrative control of institutes of higher education to macro-management through legislation and policy guidance[8].

In 1993, there were 1065 universities or colleges, of which 34 were under State Education Commission, 670 under Provincial authorities and 361 under ministries/ departments and commissions. In these institutions, during 1993, there were a total of 2.536 million undergraduates, of which 263,000 graduated with 2.6% in natural sciences, 22.3% in engineering sciences, 5.7% in medicine, 2.3% in agronomics and 0.6% in forestry. During the same year, some 29,000 received post graduation. There were 588 colleges and research units to confer master's degree and 248 for doctoral degrees.

At present, China's R&D base consists of about 72,167 R&D units which include research institutes in CAS (123), units attached to various government departments (4996), institutions of higher education and their affiliated R&D units (2616), technological development units of medium and large industrial enterprises (9432), and technological units run by collectives and individuals (55,000). Basic research is mainly carried out by CAS and key universities. During the reforms since 1985, about 155 national laboratories, jointly managed by CAS institutes and the universities, and some open laboratories under CAS have been set up to carry out research in some newly emerging areas and train outstanding S&T personnel. Research units in medicine, agriculture and industry conduct some mission-oriented basic research, but their R&D work mainly concerns subjects with potential applications. R&D units attached to industrial enterprises mainly serve the technological development of their enterprises, while R&D units run by the collectives and individuals focus on short-term projects that can give quick profits. However, most of the research units are very small in terms of R&D funding as well as R&D personnel. In the country, about 65% of R&D manpower and 68% of R&D funding is concentrated in just 11% research units under the State, attached to CAS and higher education research institutions. Some 70% of the research units have less than 20 personnel. Most of these are collective and private institutions. Although these have shown rapid growth during the last 10 years, their contribution to R&D is insignificant. R&D efforts by the industrial enterprises are also not very significant. Research units under the enterprises spend only 22.7% of the total R&D funds and engage only 27.5% of the total R&D manpower[9]. Thus, although there are not many institutes belonging to CAS and the State Council, they are the major actors of R&D and enjoy major share of funds and personnel resources and act as the backbone for R&D.

National Natural Science Foundation of China (NSFC) founded in 1986 has the prime responsibility to direct, coordinate and finance basic research in the main and part of applied research; and to identify and train talented persons. It has six science departments and several functional agencies, which cover all disciplines of natural sciences, including mathematical and physical sciences, chemical sciences, life sciences, material sciences, engineering, information and management sciences. NSFC receives and processes R&D project applications from the whole country. Regional foundations have also been set up by the State's departments and local governments. Till now, 28 science foundations have been set up in 26 provinces.

NSFC has contributed a lot towards stabilizing high level science and technology workers for the country. A series of policies and measures have been drawn up to support the young scientists' research. Some special funds have been set up to encourage and assist young scientists in their work, such as the Fund for Young Scientists, the Special Fund for Middle-aged and Young Talents, and the Science Fund for Outstanding Young Scientists. In 1986, only 1.3% scientists below 35 headed the NSFC supported research programmes. In 1994, this increased to 26.9%. In 1986, the Foundation received a fund of 80 million yuan ($ 9.5 million), which reached 500 million in 1995. The fund to support regional foundations has reached 200 million yuan ($ 25 million). It also receives funds from various societies and scientists from both home and abroad.

Apart from this, beginning from 1985, about 928 Mobile Post-Doctoral Research Stations (MPRS) had been established by 1995 in 212 universities and 69 CAS research institutes with a view to providing young doctorate recipients with opportunities of research, increasing their mobility and helping them to find the most suitable places to settle down for permanent employment[10].

In 1996, there were a total of 19.13 million S&T workers (including technicians); among these 1.48 million were scientists and engineers. Of these, 917,000 were R&D personnel – 65.0% in State-owned R&D units and institutions of higher education and 26.2% in industrial enterprises.

The level of funding has gradually grown from 20 m RMB yuan in 1963 to 44 m RMB yuan in 1966, but it became negligible during the period of CR (1966–1976). In the aftermath of CR, the funding was restored to 40 million in 1979 (ref. 11). After this, R&D funds have increased steadily from 7.40 billion yuan in 1987 to 36.82 billion yuan (US $ 4.44 billion) in 1997 (ref. 12). However, category-wise, expenditure on basic research has continuously declined from 12.47% in 1986 to 7.3% in 1990 to 6.7% in 1995 (Table 1). Like in India, government continues to be the major source (70%) for expenditure on R&D. As percentage of GNP, there was a decrease from 0.72% in 1991 to 0.50% in 1994 and was maintained at this level in 1997, which indicates that increase in R&D inputs was falling behind the rate of development of the Chinese economy and its rapid growth in GNP (Table 2). However, it is hoped that by the end of this century, the expenditure on R&D as % of GNP may increase to 1.5% and the proportion of funding to basic research may be of the order of 10–20% of the total expenditure on R&D by the State.

Existing university–industry linkages

In China, up to 1985, close academia–industry interactions were almost nonexistent[13]. The S&T reforms initiated in 1985 were directed to intensify such a relationship. During the reform period, a number of mechanisms have been evolved to effectively link academia with the industry. There has been significant progress in linking research institutes with production, which has facilitated efficient technology transfer through various measures. Over the years, the following approaches have been adopted:

Contract research

In 1985 alone, 7469 technology transfer contracts were signed by academic institutions with industrial or other recipients. Classified by category of recipients, large- and medium-sized state-owned enterprises accounted for 47.9%, small state-owned enterprises for 29%, collective enterprises for 7.4%, village and township enterprises for 9.6% and other entities for 6.1% (ref. 14). Statistics reveal that about 80,000 S&T research projects are being conducted in China's more than 1000 institutes of higher learning. An investigation of 17 colleges and universities in Beijing, Shanghai, Jiangsu and Hubei shows that during 1991–1992, more than 5000 inventions by college students have been put to use. These are reported to have been received well by the industrial circles[15].

Teaching-research-production (T-R-P)

For university–industry cooperation, a number of T-R-P Associations have been formed. These associations help in facilitating transfer of technology for new products and processes developed by the academic institutions to small and medium size or village and township enterprises, as they lack R&D capability. University cooperation with large and medium size enterprises is also growing steadily in order to: (i) update their technologies; and (ii) assimilate the newly introduced foreign technologies.

A number of universities in China are shifting to manufacturing to finance their research and educational programmes. For example, Beijing University has established a number of companies[16], e.g. The Bei Da New Technology Company; The Bei Da Fang Zheng Co.; and Bei Da Weimin Bioengineering Co. According to reports, per capita R&D expenditure by these university-run enterprises was about[17] US $ 850 in 1995, which is much higher than the average per capita expenditure on R&D in China.

The success of these college-run enterprises setup by the universities is evident from the fact that some of them have been listed among the country's top 100 high tech enterprises. These are Beijing University's Founder Group, Xi'an Jiaotong University's Kaiyuan Group, Qinghua University's Ziguang Group, and Fudan University's Fuhua Group[18].

School-based R&D centres

Several school-based R&D centers have been set up jointly by the enterprises and the academic institutions. For example, the Ministry of Petroleum and the General Petrochemical Corporation have set up seven such centres in close cooperation with nine academic institutions. Salient features of these centers are as follows: (i) Liberal investment from industries combined with the existing facilities of academic institutions is very cost-effective in organizing R&D activities; (ii) it is easier to have a well conceived research programme; and (iii) it is possible to realize better integration of basic research, development, design and production[19]. Some 67 R&D Centres for Engineering Technology were established by 1993 by the State for improving R&D for engineering technologies and strengthening the connection between

Table 1. Share of national S&T expenditure by type of work in China

Type	(Per cent) 1986	1990	1995
Basic research	12.4	7.3	6.7
Applied research	57.7	28.5	30.5
Experimental development	24.6	64.2	62.8
Other activities	5.3	–	–

Source: Various issues of *Beijing Review*, *China Daily* and *China State Science and Technology Newsletter*.

Table 2. Total expenditure on R&D in China

	Billion yuan	Billion US $	Per cent of GNP
1980	5.332	3.58	1.5
1985	8.383	2.85	–
1987	7.4	1.99	0.65
1990	12.543	2.65	0.71
1991	14.230	2.85	0.71
1992	16.9	3.13	0.70
1993	19.6	3.06	0.62
1994	22.2	2.60	0.50
1995	28.6	3.45	0.50
1996	33.2	4.00	0.50
1997	36.8	4.44	0.50

Sources: Various issues of *Beijing Review*, *China Daily* and *China State Science and Technology Newsletter*.

academic institutions and the enterprises and promoting transfer of research results to enterprises.

High technology development zones (HTDZ)

These HTDZs (similar to S&T Parks in developed countries) are being promoted through Torch Programme (TP) initiated by SSTC in August 1988, with the objective to develop new and high-tech products in close co-operation with universities and CAS research institutes[20]. TP helps in commercialization of high tech and new technologies resulting from '863 Programme' and 'National Key Technologies Programme'. The Beijing New Technology Industrial Development Zone, founded in 1988, was the first of its kind in China. So far, it boasts of more than 2000 new and high tech enterprises employing 50,000 people. In 1992, it realized trade income of 16 billion yuan and industrial output of 5 billion yuan.

By 1992, fifty two such national level zones had been established. These house about 12,900 high/new tech enterprises. About 1000 of them are affiliated with the educational sector. At present, China has 120 HTDZs at different levels. These zones have been developed with different specialties. For example, the 'Shenyang Zone' features integration of machinery and electronics, while the 'Nanning Zone' focuses on the development of agro-biotechnology. 'Daqing Zone' established in 1992, places high priority on promotion and development of oil and petrochemical equipment and refined chemical technology. This zone enjoys cooperation from Qing Hua University, Beijing, to develop low temperature nuclear heating systems to cope with severe winters. It has also linked itself with Microorganism Research Institute of CAS in respect of a key project which relates to direct pouring of micro-organisms into the strata for raising oil recovery by 30%.

The first Torch belt was set up in 1991 in the Yangtze river belt with the approval of SSTC. In 1992, it undertook 120 TP projects. Projects listed in the TP are entitled to secure funds from the State budget or preferential loans from banks for start ups. Funding by the State increased from 750 m yuan in 1990 to 1.6 billion yuan in 1992. It is estimated that through the implementation of the TP, the total industrial output value may increase from 15 billion yuan in 1992 to 250 billion yuan by the end of the century. Out of the total of 12,000 projects, one third are export-oriented[21]. The major technologies being developed in these zones relate to new materials, biotechnology, electronics, information, integration of machinery and electronics, efficient new energy sources, energy and environmental protection technology. Some high technologies, such as those in the fields of fibre optic communications and electronic information have grown into major industries in Wuhan, Hubei and Beijing HTDZs[22].

The TP had as its major thrust the development of new technology enterprises (NTEs) which basically spin off from R&D institutions. This is supported by preferential tax treatment in the zones, special loans to finance new enterprises in fields such as biotechnology high energy physics, lasers, microelectronics, materials, computers and information technology, mechatronics, and ocean engineering. Various forms of consortium among R&D and academic institutions and enterprises of various sizes, are being encouraged. Multiple sources of funds have been opened up such as governmental 'leading funds', bank loans and foreign capital, in order to broaden the resources for commercialization of technology. Thus, a network of financing NTEs has been developed under the umbrella of decentralization with three investors, viz. R&D institutions, banks and Zones. While R&D institution mainly provide Venture Capital for the initiation of NTEs, the banks provide fund for expansion of NTEs and Zones provide investments mainly for the development of the infrastructure.

About 1000 of NTEs, out of the total of 13,700, are affiliated with the educational sector. Most NTEs are located in urban areas with concentrations of R&D institutes and universities aiming at exploiting the potential of the available S&T expertise. For example, Beijing and Shenyang have the highest concentration of NTEs (Table 3). The success of these NTEs has been widely accepted in China as they bridge the gap by creating innovative and autonomous NTEs[23].

High/new technologies pioneer service centres (PSCs)

These PSCs (also known as incubators) have been established in high tech zones to transfer scientific research results to production. The first such Center was founded in Wuhan in Central China in 1987. Since then, more than 70 incubators have been established in various provinces and cities. These centres provide scientific workers a place to turn scientific results into technical applications. These thus act as 'incubators' for research institutes and enterprises. Firms and research institutes need only to pay low rents to develop their products. These products are exempted from tax for two years. It is

Table 3. Cities with zones for NTEs in China

Zone	NTEs (*n*)	Turnover (billion CNY)	Employment (*n*)
Beijing	4000 (1995)	7 (1995)	29000 (1991)
Shanghai	28 (1991)	0.7 (1991)	18700 (1991)
Shengyang	600 (1991)	0.36 (1991)	5800 (1991)
Anshan	> 150 (1995)	0.7 (1995)	
Guangzhou	185 (1991)	1.44 (1991)	2600 (1991)
Xi'an	200 (1995)	2.5 (1995)	

Source: ref. 37.

claimed that 'Pioneer Service Centers' in various provinces and cities have become an important part of the Torch Programme to the extent that the Shanghai Scientific and Technical Innovation Center has set up a 'Pioneer village' where all institutions of higher education and research are entitled to enjoy preferential policies granted by the State. Services such as industrial and commercial registration for enterprises, housing lease and facilities for loan are available[24].

Joint exhibitions

Another important form of linkage is holding of joint exhibitions by the academia and the industry. One such exhibition was co-sponsored by the Central Committee of the Chinese Communist Youth League, the All China Student Federation and the 'Si da' Technology Development Center – a non-governmental corporation in Beijing. The 470 items on display were selected from 5000 inventions submitted by 600 Chinese colleges to a national contest for student inventions in various fields like machinery, electronics, chemicals, computer sciences and telecommunications. Nearly 1000 industrial units entered into negotiations for technology transfers. Of the prize entries, eight were put up for auction. For example, the ultra fine magnetic production technology invented by Gu Hongchen and two other students from East China Chemical Engineering College earned the top bid of more than 2 m yuan and was bought by Shanghai Printing Ink Factory. According to experts, bio-adhesives developed by students at Jilin University are at par with advanced international standards. Organizers of the exhibition felt that institutions should track markets and economic development and adjust curriculum accordingly[25].

To promote such relationships, China has established its first University–Industry Cooperation Committee to accelerate the translation of scientific research results into commercial products. In this direction, Law on Transformation of S&T Achievements is also proposed to be enacted[26].

Critical appraisal and constraints

The centrally planned economies, before the initiation of the reforms have been basically characterized by the separation of the R&D institutions and the universities from their potential users. Their R&D capabilities were established in centralized institutions, and financed and operated by the governments. A 'linear' or 'pipeline' innovation model was adopted with a market push approach and a one way flow from basic research to applied research to product development. While this model had been quite successful in the US[27], this has not met with much success in most of the developing countries including India and China. While in India it was supplanted by an import substitution model during the 1960s and 1970s, which was only partially successful, in China the model operated in an ideological environment where technology was considered as a public good which contradicted the economics of innovation. Since 1985 the planned economy instruments have been radically modified. The funds granted to R&D institutions by the State have been drastically cut. The old social contract with promised funds from the State has been modified to a new social contract, where the State supports science partially, and allows the market to dominate. This has forced the R&D institutes to link their R&D activities with the industry and sell themselves in the market. The ideological shift from egalitarian science where technology was considered as public good to entrepreneurial science with profit motive, where technology is considered as private good has been tremendous. This is primarily the result of the open policy, where China had to face international competition, and due to the fact that a closed system is adverse to innovation. The concept of scientist entrepreneur is well placed in the Chinese context, although still under experimentation. The exploitation of knowledge for profit motive is well placed and accepted in the socialism with Chinese characteristics to the extent that proletariat science is replaced with capitalist science in the Chinese context.

However, because of various reasons, R&D institutes have proved to be bad sellers, which they argue is due to low demand from users and the inadequacy of legal protection for intellectual property. The market reforms introduced are not sufficient, and require institutional restructuring because old institutions were developed to fit within the old economic regime[28]. The above-mentioned efforts do indicate that conditions are being created to have an efficient link between knowledge generating institutions and the industry in China. But, several problems still persist.

The first problem is the lack of coordination between educational training and industrial demands. When making plans to accept students, schools consider only funds and faculty resources instead of social demand. Further, the educational system remains backward in many ways. Specialties that are not associated with social development are given undue weightage. For example, colleges in Beijing now admit about 200 students per year to study Chinese medicine. However, the actual annual demand is only about 50 (ref. 29).

The second problem is that of mobility. According to the present regulations concerning personnel, academic institutions cannot freely employ additional personnel for R&D without permission of the planning and personnel department. Lack of mobility of R&D personnel is still a great handicap. Jobs are still assigned by the State instead of encouraging graduates to find jobs by themselves[30].

The third problem is that of extremely low investments by industry in R&D. While the present reforms have made scientific research institutions to invest in applied R&D, insufficient enterprise reforms to make them invest in R&D inhibit efficient transfer of technologies. Further, the interface of technology transfer is still tilted towards R&D institutions, which is one of the reasons for insufficient transfer of technology to enterprises. This calls for more R&D investments by the industry, which would make them participate at an early stage of the perception of projects. One-sided reforms of the scientific institutions have already led them to pursue short-term R&D activities. According to a survey, the projects have already become smaller and scattered. This may result in continuous degeneration of the comprehensive capabilities of technology supply and competitiveness[31]. To cite one example, in the past decade, China has put billions of yuan into '863 Programme' and till date has achieved about 1,398 research achievements in biotechnology, space, information, lasers, automation, energy and materials. But the problem remains of how to transfer the results into successful products; a major part of research remains in the hands of researchers. This is mainly due to the fact that the scientists and technicians are unfamiliar with the work of transfer of results into goods[32]. Weak linkage between research institutions and the industry is also obvious from the fact that negative balance of hi-tech imports and exports has been continuously increasing over the years. It reached 11.23 billion US $ in 1993 as compared to only 4.47 billion US $ in 1987 (Table 4). This shows that not enough efforts are being put in for absorption, adaptation and further innovation on the imported technologies. Statistics indicate that only 20% of high technologies developed in China find applications in industry and according to Ma Hong, a famous economist in China, it is still lower[33]. Linkage with knowledge base is an essential requirement to manufacture 'knowledge intensive products' and to narrow down the technological gaps and reduce negative balance in technology trade.

An overview of the efforts made in China in creating formal mechanisms to strengthen linkages between the academia and the industry indicate the following:

- China is still in transitional phase to explore and experiment with new forms of academia–industry collaborations in order to exploit the knowledge base to economic needs and to face international competition. The goal of this transition phase is to build upon existing resources so as to create niches of technological innovations.
- Chinese efforts in establishing such linkages, which began only in mid-eighties, have been considerable. Government support to promote such linkages has been more diverse in the form of HTDZs, formation of NTEs and spin off enterprises from universities and R&D institutions, R&D centers, technology incubators, university enterprises and promotion of scientist entrepreneurs.
- Development of High Tech Zones (known as S&T Parks in western term) has been much faster compared to India, although both the countries started almost at the same time (during mid-eighties). India's STEP scheme (similar to S&T parks) has had very sluggish and discouraging pace of development compared to its Chinese counterpart.
- It still faces acute problems of successful transfer of technologies from academic research institutions to industry which cannot be neglected in the present scenario of international competition. There are four reasons for this:

  (i) Technologies developed by academic institutions do not match the interest of the enterprises, as the latter are not involved at an early stage of initiation of the project;

  (ii) Technologies developed by the research institutions are not tested for commercial applications because of lack of funds;

  (iii) Insufficient funding by the enterprises either for in-house R&D or to the academic research institutions to execute the projects. With the present level of R&D funding by the industry, compared to that in advanced countries, it may not sustain the international competition effectively in the long-term scenario.

  (iv) Funds devoted to R&D are too scattered, with the result that critical investments for R&D have not matured into commercial applications.

Table 4. Imports and exports of hi-tech products (1987–1993)

	(Million US $)						
	1987	1988	1989	1990	1991	1992	1993
Total	6309	9418	8701	9653	12316	14708	20585
Exports	918	1286	1848	2686	2877	3996	4676
Imports	5391	8132	6853	6967	439	10712	15909
Balance	–4474	–6846	–5005	–4281	–6562	–6716	–11233
Ratio in total goods, I&E (%)	7.6	9.2	7.8	8.4	9.1	8.9	10.5

Source: ref. 17.

Policy options for improvement

A number of studies have revealed that the performance of enterprises is far superior to that of similar 'Off Park' enterprises. Employment generation is fast, besides increased industrial output and exports[34]. Further, it provides a high class infrastructure and environment in the vicinity of educational institutes, where qualified scientists and engineers interact and grow professionally in a dynamic way. It is not enough now to provide engineers and technologists, but it is equally essential to offer them an environment where they can grow academically and professionally and not migrate. It is fully realized that without building up such capabilities for technological innovation, it is next to impossible to survive in the present-day globalized competitive world. This capability can be built up only if one exploits the knowledge base to the fullest extent and consequently builds up proper linkages between the academia (the generator of knowledge), the industry (the potential users) and the financial institutions to provide the necessary venture capital. Further, these linkages can survive only in a conducive environment with suitable government policies, rules and regulations. According to Etzkowitz, a spiral model of innovation is required to capture the evolution of multiple linkages at different stages of the capitalization of knowledge. This is achieved when academia, industry and the government interact in a complex way in the form of a 'Triple Helix'[35]. During the late nineteenth century the concept of basic research culminated in the linear model of innovation – a one-way flow from fundamental to applied research and to product development. In this present situation of complex relations between academia and the industry, this Linear model or pipeline model does not work well and is currently being supplanted by the 'Feedback' model (Figure 1) as proposed by Niwa[36] where knowledge-generating institutions and the market place interact in a multiple way in a symbiotic form with the government playing a catalytic role to induce technological innovations. This capitalization of knowledge has replaced 'communalism' as a norm of science, and has arisen not only from the practice of industrial science and the emergence of an entrepreneurial dynamism within the academia for new and high technologies, but also from the external influence like the government policies which act as a catalyst to forge this symbiotic relationship. This is significantly exemplified by the Chinese experiment with the New Industrial Enterprises and the emergence of the entrepreneurial scientist. The result of this is that the proletariat scientist is slowly transforming itself into an entrepreneurial scientist, where profit motive plays a dominant role. The norm of science is changing fast from egalitarian mode to capitalist mode to face international competition.

While China has built up sufficient infrastructure for generation of knowledge base, they still lack sufficient linkages to generate technological innovations to compete in the international market. While the ongoing market reforms, coupled with open policy, have accelerated the flow of import of technologies, it has not as yet been able to bring academia and the industry closer to build up indigenous technologically innovative base. This is where the Japanese model succeeded. This means that reforms at organization/institutional level are needed urgently as also pointed out by Gu Shulin. This calls for intensive government actions and conducive policies to promote industry to invest in R&D through contract, sponsored, or joint projects/programmes, building up of consortia and establish effective linkages with academic institutions. It is well recognized that the governments alone cannot bear the total burden of financing higher education as well as research. This is what is exemplified by the advanced countries where industrial R&D expenditure is 70–75% of the total expenditure on R&D; the government spends the rest 20–25%. In China, it is just the reverse. Further, some of the multinational corporations in advanced countries spend about 5 billion US $ per annum on R&D which is more than the total expenditure incurred by China. Further, till recently, on an average, Chinese industries have been investing only up to 1% of their sales turnover on R&D programmes compared to 7–10% in advanced countries. In Japan, 80% of the budget for R&D of each university is made available by the industry. In such a scenario, it may be very difficult for the Chinese firms to compete in the international market unless some concrete and selective steps are taken. This is also true for most of the other developing countries. Being short of financial and expert manpower resources, the developing country firms, in order to compete, apart from mobilizing additional resources, have to pool resources and select high

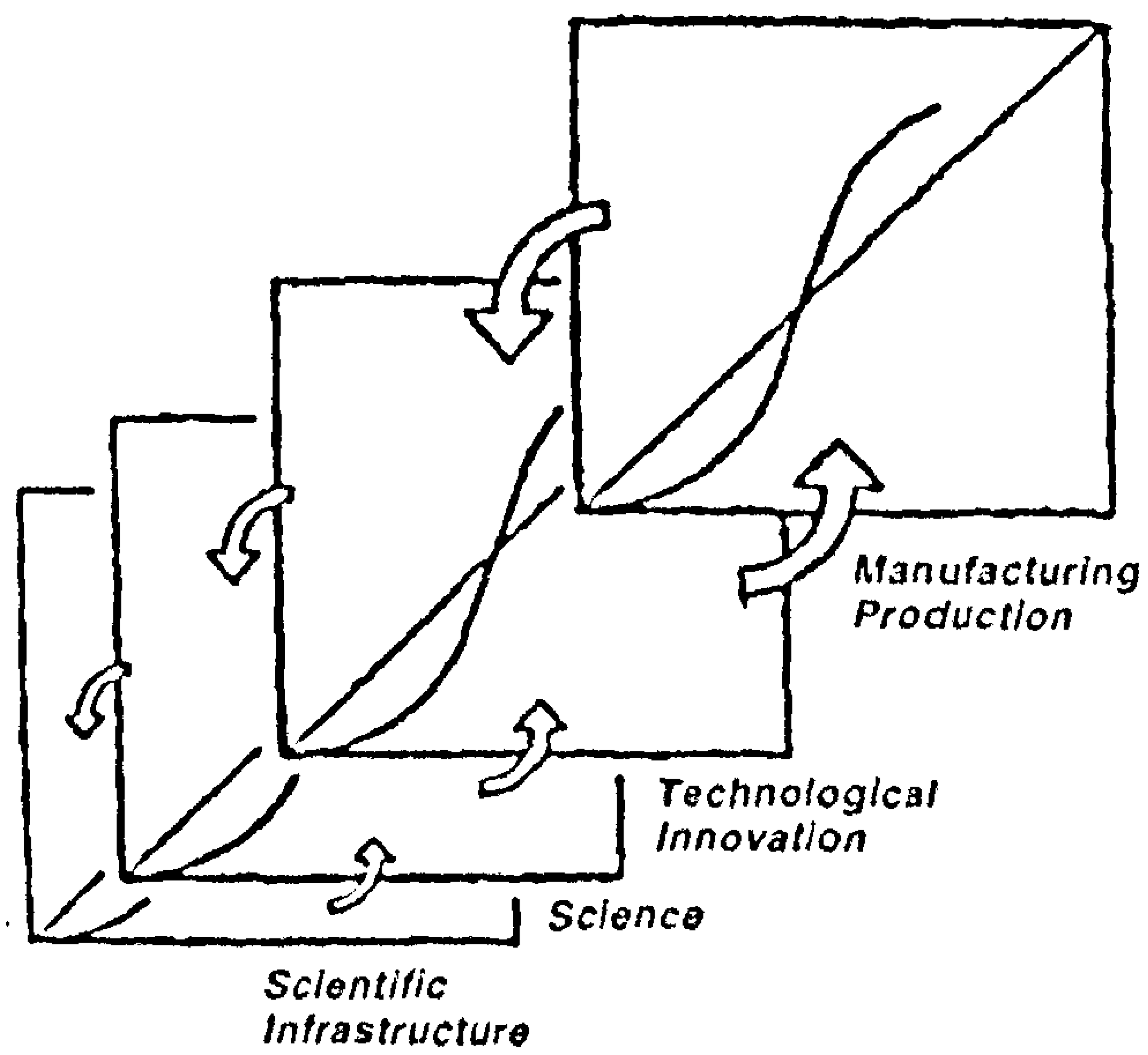

Figure 1. Dynamics of Science and Technology development cycle – The 'Feedback' model. Source: See ref. 36.

priority areas of their competitive advantage mainly through networking.

Conclusions

With the new phase of liberalization, globalization and privatization, industries in the developing countries face a stiff competition with large multinational giants. It is well recognized that only knowledge-based industries can be successful in the present scenario of global competition. It is thus necessary that the research projects undertaken by R&D institutions must meet the societal demand apart from keeping abreast of new knowledge generated. Research institutions, industry, financial institutions and the government must work together to be really effective in the present scenario. Market reforms have definitely contributed to establish intermediate institutions such as NTEs and Spin-off Enterprises, for transfer of technology. However, building up indigenous technological capability is a pre-requisite for absorption and adaptation of imported technologies and for further innovations. With the squeeze in the government financial support, the industries must come forward to extend financial help to research programmes of the universities and promote teaching/training/exchange programmes to solve their problems at an early stage. There is need to establish National Innovation Systems by creating regional Techno-economic Networks where the academia has an enhanced role to play, and the norms of science changed to capitalize on the knowledge base in the best possible manner. 'Socialism with Chinese Characteristics' is already on the road to exploit the new norm of science primarily through entrepreneurial scientist.

1. Papadakis, M., *Technovation*, 1995, **15**, 569–583.
2. Etzkowitz, H., *Res. Policy*, 1998, **27**(8), 823–833.
3. Kharbanda, V. P., *J. Sci. Ind. Res.*, 1993, **52**, 585–594.
4. Kharbanda, V. P. and Qureshi, M. A., *Science, Technology and Economic Development in China*, Navrang Publishers, New Delhi, 1987, 206p.
5. Huang Shiqi, Paper presented at the International Seminar on Current Policies for Higher Education Reforms, Beijing, held 21–25 June 1988, p. 7.
6. *Ibid*, p. 9.
7. For details of disruption of higher education and research during CR see Kharbanda, V. P. and Qureshi, M. A., 1987, *opcit*.
8. Cui, Lili, *Beijing Rev.*, 1993, **36**, 13–18.
9. Fang Xin, Paper presented at the Workshop on Science and Technology Development Strategies in India and China, Organized jointly by NISTADS, and Central-South University of Technology, Changsha, China, at New Delhi held 25–26 September 1995, p. 13.
10. *China Sci. Technol. Newslett.*, 1995, **63**, 4.
11. Huang, Shiqi, *opcit*, 1988, p. 17.
12. *China Daily Bussiness Weekly*, 8–14 March 1998, p. 5.
13. Gu Shulin, A Review of Reform Policy for the S&T System in China. From paid Transactions for Technology to Organizational Restructuring, The United Nations University/Institute for New Technology Working Paper No. 17, The Netherlands, 1995, p.16.
14. Huang, Shiqi, *opcit*, 1988, p. 18.
15. Scientific inventions by college students, *Beijing Rev.*, 1993, **36**, 21–23.
16. Cui, Lili, *Beijing Rev.*, 1993, **36**, 19–22.
17. *China Sci. Technol. Newsletter*, 1995, **63**, 3–4.
18. *China Daily*, 1996, 30 October, p. 4.
19. Huang, Shiqi, *opcit*, 1988, p. 21.
20. These HTDZs are essentially Science and Technology Parks (STPs) and is an industrial complex, close to the place of learning like universities, colleges or polytechnics or research laboratory having formal or informal links. It is designed to encourage formation of knowledge-based industries in a high quality and competitive environment. It has a management function for transfer of technology and business skills to enterprises on site; aims to reduce the time gap between scientific invention and its commercial application. The first STP was established in Stanford University, USA around 1950. However, the STP movement picked up only in late 1980s. At present there are 200 parks in the USA, 52 in UK, 86 in Germany, 27 technopolis in Japan, and 120 high-tech zones in China. In UK the 52 parks have come together to form a Science Park Association. (Naik, B. M., Technology park and its relevance to India, *University News*, 7 November 1994, p. 65).
21. Wei, Liming, *Beijing Rev.*, 1993, **36**, 18–23.
22. *Beijing Rev.*, 1994, **37**, 7.
23. Gu, Shulin, *opcit*, 1995, p. 37.
24. Wei, Liming, *opcit*, 1993, pp. 18–23.
25. Scientific inventions by college students, *opcit*, pp. 21–23.
26. University, enterprises establish committee, *China Sci. Technol. Newslett.*, 15 October 1995, p. 4.
27. Vovakova, B., *Minerva*, 1998, **36**(3), 210.
28. Gu, Shulin, *opcit*, 1995, p. 61.
29. Zhou, Bian, College graduates facing market challenge, 1993, *opcit*, p. 27.
30. Zhou, Bian, *ibid*, p. 28.
31. Jia, Xinmin, *Study on the Interface of Technology Transfer in Transition Economy*, Chinese Academy of Sciences, Beijing, 1995, p. 73.
32. *China Daily*, 18 April 1996, p. 4.
33. Xiao, Lu, Technology can revive state firms, *China Daily Bussiness Weekly*, 28 July–3 August 1996, p. 1.
34. Naik, B. M., *Univ. News*, 7 November 1994, p. 65.
35. Etzkowitz, H. and Leydesdorff, L., *Minerva*, 1998, **36**(3), 205.
36. Niwa, F., Tomizawa, H. and Hirahara, F., The Proceedings of NISTEP the Third International Conference on Science and Technology Policy Research, 23–24 Mita Press, Tokyo, 1993.
37. *A Decade of Reform – Science and Technology Policy in China*, International Development Research Centre, 1997.

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