

NIS Transformation and Recombination Learning in China

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This paper applies the notion of national innovation systems (NIS) to analyze the market reform of China's NIS in the 1980s and 1990s. It focuses on two issues. Firstly it probes the interaction between policy-making and reform practice that leads to the transformation of a huge sized government-run industrial technology R&D system, becomes it fitting to the changed macro-economic conditions. Secondly, it analyzes underlining learning mechanisms, as we call it re-combination learning, that assisted the NIS transformation and a rapid pace of economic growth during the transition. This paper demonstrates the analytical power of the NIS approach in the developing country circumstance of China.

Section 1 “Universal Science and Specific Institutions” illuminates the importance of institutions and outlines the unique institutional structure of China's NIS developed prior to the market reform. Section 2 “Innovation Systems, NIS Transformation, and Learning” elaborates analytical concepts and tools for the paper. Section 3 “Transformation of NIS in China—Why Did a Gradual Process Work?” addresses the policy process responsible for the proceeding of the reform. Section 4 “Recombination Learning and Technological Trajectories” analyzes the learning process associated with the system's transformation. Section 5 evaluates the NIS Transformation in China.

1. UNIVERSAL SCIENCE AND SPECIFIC INSTITUTIONS

Scientific knowledge is universally valid. From the very beginning Chinese scholars and officials have never been feeling about modern science as “allied”. An external observer Joseph Needham noticed an interesting story (Needham 1969:13 note 1). In the 1640s when Jesuit commissioners brought in scientific books from Europe, a debate broke through in Peking (Beijing) as whether the newly introduced were primarily “western” or primarily “new”. The Jesuit commissioners wanted to accent on “western” to attach the prestige of science to the religion they propagated, while the Chinese refused and in 1669 Emperor Khang-Hsi (Kang-Xi) finally decided in favor of “new”. Professor Needham, with the episode, was arguing that Europe contributed to the progress of universally valid “world science” but not to something which is “European” or “Western”.

Not allied the modern science through, China could make substantial progress in both modern science and technology and economic development only since the 1950s, regardless that Chinese students had been sent abroad for modern science as early as in the second half of the 19th century, and scientific and engineering education had thereafter soon been introduced. Why then science and scientific talents alone could not benefit China in more than a half-century? One of the reasons was the lack of (or ill-developed) necessary institutions that support the generation, dissemination and application of knowledge for the purpose of economic and social value.

Institutions imply formal organizations and informal norms, habits, and attitudes (North 1990) that have deep roots in history (e.g. Zysman 1994) and tradition, hence socially or nation “*specific*”. For developing countries, a necessary step forward is the construction of institutions. Since the 1950s China underwent the process of institutionalization for modern science and technology and production under a centrally planned regime.

The Pre-reform Institutions in China. By 1980 when market reform started, there were more than 4000 research institutes affiliated to administration bodies higher than the “county” level (including central, provincial, and regional/city governments), together with additional some 3000 institutes at the county level. This was resulted from the enormous investment in science and technology (Table 1), mobilized under central planning, 323 thousand R&D scientists and engineers worked in these institutes. The rate of R&D investment reached at the level of 1-2% GDP in most of the years in the planning time, a record never achieved by other developing countries at similar income levels.¹

1 In comparison, United States, Japan and Soviet Union had 650, 625, and 1373 thousand in the same year, respectively (National Statistics Bureau 1990: 191, 492, 494, 495).

TABLE 1 CHINA'S INVESTMENT IN R&D

Year	Percentage of R&D Expenditure Based on National Income	Year	Percentage of R&D Expenditure Based on GDP
1953	0.1	1978	1.5 (1.8 of national income)
1954	0.2	1979	1.5
1955	0.3	1980	1.5
1956	0.6	1981	1.3
1957	0.6	1982	1.3
1958	1.0	1983	1.4
1959	1.6	1984	1.4
1960	2.8	1985	1.2
1961	2.0	1986	1.3
1962	1.5	1987	1.0
1963	1.9	1988	0.8
1964	2.1	1989	0.8
1965	2.0	1990	0.8
1966	1.6	1991	0.8
1967	1.0	1992	0.7
1968	1.0	1993	0.7
1969	1.5	1994	0.7
1970	1.6	1995	0.6
1971	1.8	1996	0.6
1972	1.7	1997	0.6
1973	1.5	1998	0.7
1974	1.5	1999	0.8
1975	1.6	2000	1.0
1976	1.6	2001	1.1
1977	1.6		
1978	1.8 (1.5 of GDP)		

SOURCES: CHINA STATISTICAL YEARBOOK ON SCIENCE AND TECHNOLOGY VARIOUS ISSUES; NATIONAL STATISTICS BUREAU 1990: 207, AND [HTTP://WWW.STS.ORG.CN/KJNEW/MAINTITLE/MAINTITLE.HTM](http://www.sts.org.cn/kjnew/maintitle/maintitle.htm)

The centrally planned regime endowed particular mechanisms to join together R&D and the application of R&D results. All the R&D institutes, except for Chinese Academy of Sciences (which was assigned to be as the national top organization for comprehensive natural and engineering science), were organized under the jurisdiction of respective ministries or bureaus. The machinery R&D system for example (Figure 2) (Gu 1999a: 151-176) had 199 research institutes at the central ministry level,² of which the Ministry Department of Science and Technology administered 8 which were assigned for manufacturing (processing) technologies. And the Ministry Bureaus specialized in particular groups of product, such as machine tools and other tools, chemical and petroleum refinery equipment,

2 This is based on the author's interviews. Details of the structure changed from time to time in the planning time, while the overall picture was valid until the second half of the 1980s.

energy generation equipment, mining equipment, and so on, managed the majority rest, who were also specialized in the same categories of product technology. Research tasks of the institutes, and needed resources, were decided and allocated by respective Department or Bureaus; these Department or Bureaus coordinated as well between R&D and production, since production enterprises were also subordinates to them and with similar specialization. Additionally, 493 R&D institutes evolved at the regional levels, supportive to local machinery production under the coordination by local governments. Accordingly, system's *compatibility*, one of the qualities that institutional settings bear for a smooth operation was matched well. Specialization upon product category, totalized central coordination, and the separation of firms for innovative activities were common features in the former centrally planned economies (Hanson and Pavitt 1987; Granick 1967).

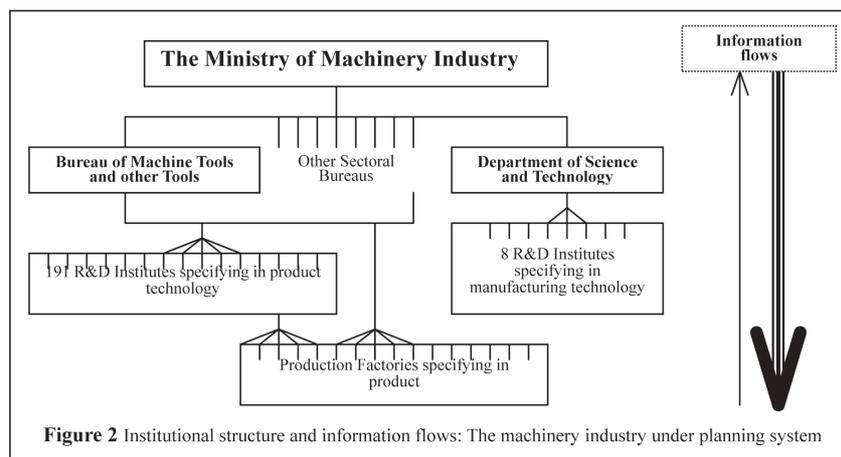
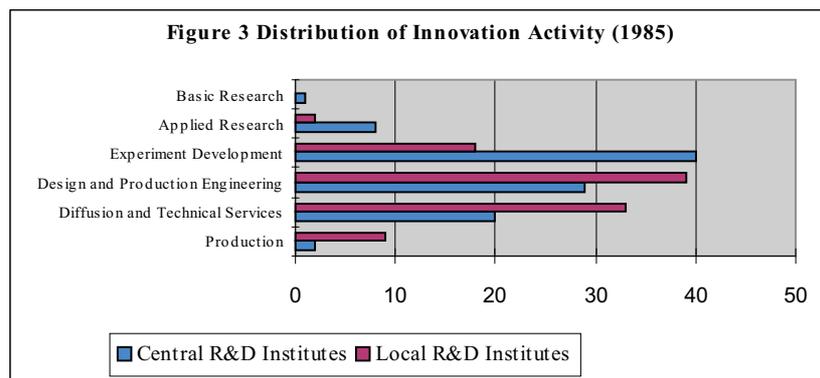


Figure 2 Institutional structure and information flows: The machinery industry under planning system

Meanwhile, the system had the basic weakness that firms in it did not independently engage in innovation process as far as industrial technology is concerned.³ They did almost non R&D; but mainly in test, standards and quality control, only associated with minor design for maintaining production upon the technology diffused from R&D institutes. This is in sharp contrast to the institutions in advanced market economies where private firms are the key player. Incentives set forth in the system were not much to innovation but to quantitative expansion of mature technology (Kornai 1980). Information flows were mainly vertically channeled (Figure 2), it blocked the necessary interactions between producers and users of technology (von Hippel 1994; Kline and Rosenberg 1986; Lundvall 1988). As a consequence, the machinery industry (Gu 1999a: 127-135) was apt at “general purpose” machinery, incapable of the technology specifically fulfilling a particular machining task with precision and at low cost. The machinery industry, being an “innovation center” for the economy as whole (Rosenberg 1963), did spread only inferior production means for various sectors. This was responsible not only for the low international competitiveness of the sector itself, but also for the low development performance of the Chinese economy as a whole. Hence in terms of *effectiveness*, the centrally planned institutional settings made the record of very low degree.

3 In objectives term, the S&T system in China had R&D activity for industrial development that accounted for 33% according to 1987 data on expenditure, that for defense 21%; for energy, agriculture, medicine & public health each about 7-8%. Source: China Science and Technology Indicator 1988: 58.

An inescapable institutional derivation from the centrally planned institutional structure is that R&D institutes were involved in many “down-stream” works (Figure 3).⁴ The 1985 data show that on average centrally affiliated R&D institutes engaged mainly in “experiment development” and “design and production engineering”; or, half of their works were not internationally standard “R&D”.⁵ The locally affiliated R&D institutes went down further, engaged mainly in “design and production engineering” and “diffusion and technical services”, or, roughly 80 % of their activities were not R&D. This proposes that the majority of industrial technology R&D institutes in China would tend to become themselves production firms afterwards in market reform. The characteristic transformation of R&D system in China hence should be considered as offering a reference less relevant to those systems like that in India and Brazil where R&D were more upstream or academic activities-oriented, and scientists and engineers had more elite-like social positions.



SOURCE: WHITE PAPER NO. 1: 238

2. INNOVATION SYSTEMS, NIS TRANSFORMATION, AND LEARNING

Apparently in order to understand and manage innovation and development, it is necessary to go beyond merely science and technology. Innovation Systems (IS) is such an analytical tool. Central to the IS conception is the recognition of the importance of institutions, and the interaction between technology and institutions (Freeman 1987; Lundvall (ed.) 1992; Nelson (ed.) 1993; Edquist (ed.) 1997). IS (OECD 1999) imply the “...set of distinct institutions which jointly and individually contribute to the development and diffusion of new technologies and which provide the framework (upon) which governments form and implement policies to influence the innovation process. As such it is a system of interconnected institutions to create, store and transfer the knowledge, skills and artefacts which define new technologies.” “From this perspective, the innovative performance of an economy depends not only on how the individual institutions (e.g. firms, research institutes, universities) perform in isolation, but on “how they interact with each other as elements of collective system of knowledge creation and use, and on their interplay with social institutions (such as values, norms, legal frameworks)”.

4 To put an innovation into place, not only design and R&D, but also production engineering and other production spot-related adjustments are needed. When design and R&D were organized separately from production enterprises, some down-stream works have to be carried out also separately from production enterprises with much low efficiency.

5 R&D embraces “basic research”, “applied research” and “experimental development”. “Design”, “production engineering” and other activities such as training and marketing are activities necessary for innovation, but not R&D. (ref. to Frascati Manual and Oslo Manual).

A Framework for Investigating the Quality and Characteristics of an Innovation System. Innovation systems, as so defined, gives guidance to the formulation of criteria for IS evaluation. Firstly, a national IS embraces a set of distinct institutions and their interactions. R&D system alone is not an innovation system, for firms is the major player in the generation and application of economically valued knowledge. On the other hand, firms alone do not make up an innovation system either, for firms cannot innovate in isolation. The major components of an innovation system should include (refer to, e.g., OECD 1999; OECD: Oslo Manual) a) the innovation “dynamo” of firms, b) the science and engineering base usually public R&D, c) the supporting and bridging institutions which link up firms and channel knowledge flows, and d) the macro economic, political, social and cultural conditions in which innovation takes place. This conceptualisation looks into functional match or mismatch of innovation system, and the pattern and intensity of incentives and information flows, sees them as major determinants for the efficiency of the system (Edquist (ed.) 1997). The conception also concerns about links of a national IS with international pools of scientific and technological knowledge (Mowery and Oxley 1995) as an important quality of, especially, a developing innovation system.

Having introduced the construction of National IS, we will in this paper use the following scheme to evaluate the NIS transformation in China in the 1980s and 1990s. It briefly assesses several sensitive parameters to show what the transformation has led to.

1 *Openness* to international exchange of technology and knowledge for the vitality of NIS;

2 *Incentive* that is the NIS-embedded towards innovation and learning

3 *Clustering and user-producer interaction*, Porter (Porter: 1990) also maintains that competitive advantage of a nation is associated not only with individual firms, but also and more importantly, with clustering of firms;

4 *Supporting and coordinative institutions*. Knowledge flows diffuse through supporting institutions, and supporting and coordinative institutions have been dramatically changed during the reform;

5 *Strength of science and engineering base*.

Learning and Competence Building. In the knowledge-based economy, the most important factor for economic growth is knowledge, and the most important process is learning (Lundvall (ed.) 1992: 1). Learning is essential for change, and competence building is one of the results from learning. Not only advanced economies, which are confronted with accelerating paces of change, but also developing and transition economies, which have to cope with comprehensive and profound ‘historical transition’ (Fei and Ranis 1997) in both institutions and technological mastery, need to learn. Development without learning and competence upgrading will inescapably fall into a disastrous “low equilibrium trap”. However learning by advanced economies and by developing economies may be somehow different in character (Gu 1999b): developing economies rely more on absorption and imitation of external sourced technology; and meanwhile, patterns of institutional change more diverse.

Analysis of learning mechanisms, from the NIS perspective, addresses questions such as: What are *sources of knowledge* for the learning? What are the *institutional basis* and environment conditions that stand behind the learning? What *competences* are resulted from the learning? What is the sequence/process in which the system in examination moves up the *competence or comparative advantage ladder*? By so doing we would get some details that hopefully enriches our understanding about the work of the China’s NIS in its transformation.

We have just briefed the NIS of China in the planning time with the machinery industry as example. In that time, sources of knowledge for innovation came from limited sample machine

imports, upon which the government-run R&D institutes, separately organized from production firms, did imitation with minor modifications. The institutional basis was a totally vertically integrated planning system. Result from the learning was quantitative expansion of mature and general-purpose technology with some exceptions (which were the few radical innovations conducted under the planning body's direct coordination). Competence accumulation was concentrated in the R&D institutes, mainly in design and testing, and to a less extent, R&D capabilities. With production being expanded to a large scale, the NIS of China accumulated also production engineering and production management skills. All the capabilities and skills accumulated lacked some critical elements, related to the mastery of quality, productivity, and reliability. This was a kind of imitation learning under the directives of central planning. We will explore in Section 4 what characterizes the learning of China's NIS in the reform time, which we title as "recombination learning".

Some, but not many, studies on learning mechanisms that underpin the successful catching up of Asian NIEs (Newly Industrializing Economies) have been well circulated. Based on Hobday 1995; Amsden 1989, Wade 1990; Kim 1997, among others, we sum up the commonality of their learning mechanisms as "export-oriented enhanced learning" (Gu 1999b). They all developed extraordinarily (unusual in developing countries) high human resources and kept extraordinarily proactive development strategy and policy at both the government and firm levels. With this as internal source, they were able to absorb intense inflows of knowledge, in association with high level of investment. They were all "export-oriented", that from the learning point of view offered learning incentives and learning opportunities, in case where their domestic markets were too small to provide the space for enhanced exercise of learning and innovation. They, upon little accumulation of modern science and technology and industry, took the learning ladder mainly of a linear-like one. We will compare the recombination learning in transitional China with the Asian NIE's learning.

Policy Institutions and Policy Process for NIS Transformation. In line with IS, one of the most outstanding findings in international comparison is that innovation systems are country-specific (OECD 1999; Nelson (ed.) 1993; Nelson 1996). Specifics to country are not only in specialized patterns of science and engineering base, in advantageous areas of innovation and international trade, but also in policy institutions and measures and supporting institutions. These are features of an "evolutionary" process in which, as far as institutional restructuring is focally concerned as we do in this paper, policy institutions and the complex and dynamic interaction between policy initiatives and the response of the system to the initiatives cast distinct development and transformation paths. To understand system's transformation, most important is to review policy institutions and the process in which policies evolve with the work of the system in transition. In this way we discuss the transformation of China's innovation system accentuated on the question as how a gradual process worked in China in the 1980s and 1990s—we specify that a gradual process of reform offered the space for adjustment and refinement of both policies and the management of R&D institutes, it was responsible for the unprecedented reform proceeding in a relatively smooth manner.

Stiglitz, in address on *An Agenda for the New Development Economics* (2001) commented that "...there is no well developed theory upon which policy makers wishing to have a nuanced, gradual transition can base their prescription." The transformation of NIS in China is indeed a good example of exploring about gradual transition.

3. TRANSFORMATION OF NIS IN CHINA—WHY DID A GRADUAL PROCESS WORK?

Policies and Process. The cornerstone event for NIS transformation was the 1985 Decision on Science and Technology System Management Reform (thereafter simply Decision) by the Central Committee of Communist Party of China. Beforehand, market reform for agriculture and rural economy had started in the end of the 1970s, and reform for industrial sectors begun in 1984. In the circumstances when demand, supply and coordination factors were changing, reform for S&T system was indispensable. Accordingly, the target of the S&T system reform was removing direct governmental indicatives to turn the R&D institutes into “organic” linkages with production. The then Premier Minister Mr. Zhao Ziyang put it as the following:

The current science and technology institution in our country has evolved over the years under special historical situations. The advantages embodied in this system manifested themselves in concerted efforts to tackle major scientific and technological projects, with great success. However, there is growing evidence to show that the system can no longer accommodate the situation in the four modernizations programme, which depends heavily on scientific and technological progress. One of the glaring drawbacks of this system is the disconnection of science and technology from production, a problem which is a source of great concern for all of us....

By their very nature, there is an organic linkage between scientific research and production. For this linkage a horizontal, regular, many-leveled and many-sided channel should be provided. The management system as practiced until now has actually clogged this direct linkage, so that research institutes were only responsible to the leading departments above, in a vertical relationship, with no channels for interaction with the society as a whole or for providing consultancy services to production units. This is the root cause of the inability of our scientific research to meet our production needs over the years.... This state of affairs can hardly be altered if we confine ourselves to the beaten track. The way out lies in a reform (Zhao Ziyang 1985).

A two-pronged policy means was designed. On the one hand, “technology market” was established (Decision: Section III) to be as the distributive institution for R&D outputs; and an excellence based mechanism set forth (Decision: Section II) for the allocation of public R&D funds. In cope with the competitive measures, various kinds of autonomy, in terms of personnel, research project, and acceptance and use of contractual fees, were assigned to R&D institutes (Decision: Section VII) for their independent management in response to opportunities arisen at the market place. On the other hand, fixed operation fees from the government were decided to reduce (Decision: Sections I and II). It was expected that by push and pull, the previously public funded R&D institutes would move to serve for their clients via horizontal, regular and multiple linkages. Notable is that the Decision recognized the diversity of R&D institutes in their functionality. It distinguished them into “technology development type”, “basic research type”, and “public welfare and infrastructure services type”. The reduction of public funds was mainly applied to the technology development type in a gradually way to complete it in a time span of five years. Consequently by 1991, the 2,000 plus, out of the 4,000 in total, technology development institutes had had their public “operation fees” entirely or partly cut⁶. Shortly speaking, it is not an overstatement that the reform focuses on marketization of the state-owned industrial technology R&D institutions.

6 Roughly the sum of the reduction accounted to slightly less than RMB 1 billion (or USD 200 m), or about one tenth of the overall government S&T budget in 1985.

Interesting is the policy process through which solutions for horizontal, regular and multiple linkages were gradually enriched, replenished and consolidated (Gu 1999a: Part I). The *technology market* solution, central in the initial design, was soon recognized as not adequate. Both buyers and sellers felt difficult in transaction at the market: the users were not capable of absorbing transferred technology; the market was too small to secure R&D institutes with enough earnings; and more seriously, the uncertainty in use value of technology made it uneasy to write and implement the contract. As a response, in 1987 reform policy began to promote *merger of R&D institutes* into existing enterprises or enterprise groups. This policy was only partially applicable at the start. Huge gaps between the merging parties, coming from culture and administrative affiliation relations, were hard to be filled up immediately. In the next year 1988 reform policy took in the practice originally created by scientists and engineers, lunched the Torch Programme to encourage *spin-off enterprises*—called as NTEs (New Technology Enterprises), from existing R&D institutes and universities. R&D institutes, universities, S&T persons, and local governments responded to this initiative actively. Local governments contributed to investment in New and High-Tech Industry Zones as the supporting institutions to NTEs. As I have argued elsewhere (Gu 1996; Gu 1999a: Part II) that Torch Programme helped for restructuring of the ICT industry in China, made it ready for widespread applications of the powerful means of information and communications technology. By the end of the 1980s, reform policy furthered to embrace *transformation of R&D institutes* on a whole institute basis, which was in effect a legitimization of actual progress, apparent to many industrial R&D institutes from their adaptations during a number of years. A study (Gu1999a: Part III) shows that in the machinery industry these institutes became either providers of engineering services in manufacturing or product or plant engineering, or producers of relatively new or sophisticated products, according to their previous specialization and market opportunities. In this way by early the 1990s solutions for transformation enlarged as multiple and practical as possible, all the mentioned approaches played a part.

Up to the end of the 1990s, the reform came to a conclusion. In 1999 an official decision declared to clarify the character of the previously government-run R&D institutes upon what they really be from the transformation. By 2001,⁷ as a stage result, some 1,200 institutes, mostly of technology development type, have re-registered their business type. Of them more than 300 were *merger* cases, these institutes have canceled their independent position, became a part of an enterprise; 600 plus have changed to be *profitable firms* in themselves; and a few have entered into a university. Careful observers might have found out that in 2000 the proportion of R&D performed by “enterprises” leaped up abruptly (see line 3, Table 4) largely because of this. Table 4 also depicts the scope of *technology market* and *spin-offs*, both grew steadily over time (lines 1 and 2), illustrating the complementary effects of various transformation approaches.

7 See: http://www.sts.org.cn/report_3/documents/2002/0207.htm

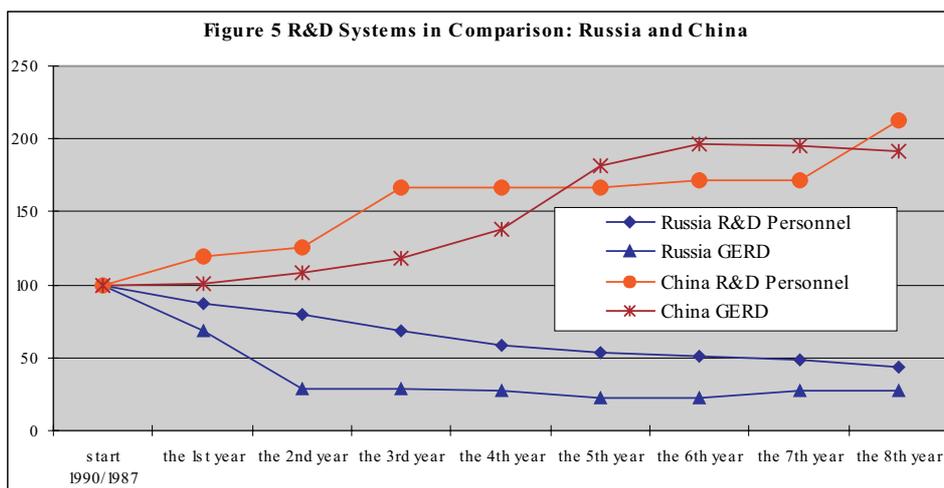
TABLE 4 THE MULTIPLE APPROACHES TO NIS TRANSFORMATION £" ALL THE MEASURES AT CURRENT PRICE£©

	1985	1990	1995	2000
(1) Technology Market				
Contract fees (RMB Billion)	2.30	7.51	26.83	26.83
(2) Sin-offs				
Number of NTEs	-	1,690	12,937	20,796
Annual turnover (RMB Billion)	-	5.94	151.2	920.9
Export (USD Billion)	-	0.69 (RMB Billion)	1.55	13.81
(3) Domestic R&D expenditure (RMB Billion)				
in which Enterprises (%)	6.74 (1987)	12.54	34.87	89.57
Independent R&D institutes (%)	29.3	n.a.	43.7	60.0
Universities (%)	54.7	n.a.	42.1	28.8
	15.9	n.a.	12.1	8.6
(4) Import of capital goods (USD Billion)				
	16.24	16.85	52.64	69.45 (1999)
(5) FDI (USD Billion)				
	1.96	3.49	37.52	40.72

SOURCES: CHINA STATISTICAL YEAR BOOK ON SCIENCE AND TECHNOLOGY VARIOUS ISSUES; [HTTP://WWW.MOST.GOV.CN](http://www.most.gov.cn); [HTTP://WWW.STATS.GOV.CN/ND\\$//ZGNJ/2000/Q05C.HTM](http://www.stats.gov.cn/nds/zgnj/2000/q05c.htm) [HTTP://WWW.MOFTEC.GOV.CN/ARTICLE/200303/20030300072333_1.XML](http://www.moftec.gov.cn/article/200303/20030300072333_1.xml); [HTTP://WWW.STS.ORG.CN/REPORT_3/DOCUMENTS/2002/0220.HTM](http://www.sts.org.cn/report_3/documents/2002/0220.htm); [HTTP://WWW.STS.ORG.CN/REPORT_3/DOCUMENTS/2002/02HDB01.HTM](http://www.sts.org.cn/report_3/documents/2002/02HDB01.htm)

Why Did a Gradual Process Work in China?—A Comparison with Russia. Let's first see (Figure 5) what a gradual process led to as in the case of China in comparison to that an abrupt or "shock" therapy led to as in the case of Russia. Figure 5 shows overall capacity of the two R&D systems in terms of R&D personnel and GERD (General Expenditure for R&D). From a start year onwards (1990 for Russia and 1987 for China—data for 1985 not available), the two systems moved to different ways. A gradual process brings about both growth space and restructuring feasibility, although in the first years China was not able to grow with a fast pace (see Table 1). However an abrupt shock seems stifling both growth and restructuring.

Why so? An explanation from the NIS and evolutionary perspective concerns the complex and dynamic nature intrinsically in association with change. A reform initiative actually launches a social innovation. Like an entrepreneur who engages in technological innovation, a reform initiator will be likewise in face of a great deal of uncertainty in the work of the social system (Metcalf and Georghiou 1998), incurred by "unintended" responses (Aoki 1996). A gradual process opens the feasibility for both policy maker and system members to adapt. Hence the policy makers of China modified themselves upon the applicability of policy means, in which some unexpected responses were incorporated into official policy package. The system members have to adapt too. The R&D institutes (Gu 1999a: Part III) worked hard to re-organized institute's resources and re-create external relations in a piecemeal manner, and the gradual adaptation eventually altered the R&D institutes themselves by nature. In short, a gradual process permits the creation of knowledge and information upon experimentation (Rosenberg and Birdzell 1986) as necessary input into complicated "fitting" and "re-fitting" at various levels of the system, absolutely indispensable for reducing uncertainty involved in complex system transformation.



SOURCES: RADOSEVIC 2003 (FOR RUSSIA); [HTTP://WWW.STS.ORG.CN/KJNEW/MAINTITLE/MAINMOD.ASP?MAINQ=2&SUBQ=2](http://www.sts.org.cn/kjnew/maintitle/mainmod.asp?mainq=2&subq=2)
[HTTP://WWW.STATS.GOV.CN/ND SJ/ZGNJ/2000/101C.HTM](http://www.stats.gov.cn/nds/jzgnj/2000/101c.htm)

In order for a gradual reform to work some necessary conditions are needed. By drawing upon the experiences in China and Russia, a *first condition* concerns that policy-making is to be responsive, as has focally discussed in the above. A pragmatist tradition seems to be in favor of responsive policy-making, but there is no guarantee even with such tradition. Inertia of political institution once worked well and normalized would turn to be dull in responsiveness. A *second condition* requires political stability (Rodrik 1999) and a minimum level of social consensus. Political stability and social consensus serve as supporters to the macro-environment in which chaos remains organized and controlled, and adaptive learning carries out in a cumulative manner. Russia was unfortunately suffered from abrupt disturbances⁸. It was hardly possible to develop some agreed policies, no mention to continue adaptive efforts by policy maker and system's members. Debates were long held between the "preservation" strategy (*i.e.*, not to reform) and restructuring strategy (*i.e.* to transform the R&D system), lasted until the end of the 1990s (Randosevic 2003), with which survival reactions taken by R&D institutes could only be of random kind. This leads to *Condition 3*, the importance of strategic vision. Strategic vision now is a popular notion in business management. A strategic vision offers the guidance as to where the reform is to approach. In China the strategic vision has been clear, despite that policy details were initially imperfect; While in Russia in absence of such a vision, the voice of preservation strategy was once rather strong, however this voice is not realistic at all when the ground for preservation was no longer in existence.

⁸ They include the collapse of trade block with former European Planning Economies, the frequent alternation of political leadership, and finally but not least importantly, a set of shock therapy policy.

4. RECOMBINATION LEARNING AND TECHNOLOGICAL TRAJECTORIES

Recombination Learning in Economic Transition. “Recombination learning” is a summary of the learning in China that took place during market reform. It describes the mechanisms underlying the application-driven development in the major manufacture industries, most apparently the ICT and machinery industries (Gu 1999a: 308-310; Gu and Steinmueller 1996/2000), which were the investment priority in the planning period. In recombination learning,⁹ several parallel processes intertwined to assist and reinforce each other: (1) the stimulation of market reform and trade liberalization that produced new incentives and induced the reallocation of innovative capabilities; (2) the re-organization of previously accumulated capabilities in production, design, testing and R&D in novel and productive ways to meet the challenges of market reform and trade liberalization; (3) the intensive learning devoted to identifying and filling major gaps in the capabilities inherited from the previous system; and (4) the efforts aimed at institutional restructuring that support these developments. Table 6 depicts such learning in the PC and machinery industries in comparison with more traditional industries exemplified by textile, in terms of technological gaps, means for filling the gaps, accumulated capabilities and institutional restructuring.

TABLE 6: RECOMBINATION LEARNING IN CHINA

Example Sector	PC	Machinery	Textile
Technological gaps	—Product Architecture	—Design engineering —Production Engineering	—Design —International marketing
Means of filling the gaps	—Application and sales of advanced products	—Technology licensing	—OEM Export-production
Accumulated capabilities	—Design —Testing —R&D —Production	—Design —Testing —Production	—Production
Institutional restructuring	—Spin-offs	—Transformation of R&D institutes —Transformation of state enterprises	—Export-production Zones —Joint-ventures —Local Small startups

Look at Personal Computer (PC) versus machinery first. The two are both modern industries with certain degree of sophistication. The PC technology is highly internationally migratory across country borders upon “open architecture”, and the machinery technology more localized (e.g. OECD 1996). Besides the machinery industry was more developed in China, institutions for R&D and production were systematically established, while the PC industry was new in the 1980s, related talents were dispersed in universities and military electronics R&D. Gaps for PC were in product architecture, with which the Chinese producers were not familiar before opening to international trade. The Chinese

9 Although similar expression like ‘technological combination’ or ‘technological fusion’ (Kodama: 1990) are often used by scholars who work on technological innovation, our term “recombination” has much more to do with extensive institutional innovation simultaneously at macro- and micro levels. Besides, innovative recombination involves active effort in selectively accessing international sources of technology to fill gaps in previous accumulations, which is particularly significant when an economy turns to change its routines in both internal operation and international relations. Surely, a common sense behind the combination-kind expression is that learning is an accumulative process and an abrupt stoppage of accumulation would discard accumulated intangible assets of knowledge and competence into ruin

got to know it firstly and mainly via the access to imported PC machines, which embody the architecture knowledge. A number of spin-off companies (see above) began to start their business in the early 1980s with selling and after-sales-services of computers made in United States; They thereafter turned to be able to incorporate Chinese Character Processing Techniques into the architecture upon the skills in design, testing and R&D. The huge demand for their services and techniques consolidated their competitive strengths; by the second half of the 1990s domestic brands became dominated at domestic market. In contrast, the gaps for machinery technology can be considered in design and production engineering. Because although long experienced the industry lacked some elements responsible for quality and efficiency. It learned systematically since the reform the techniques such as feasibility analysis, unit design, reliability design, finite design and CAD, systems engineering, and standardization. In the meanwhile transformation of R&D institutes and state enterprises provided the institutional basis conducive to the learning; it turned the related institutions more responsible to competitive pressure and market signals.

Recombination learning assisted a “path shifting” of technological trajectories, a process that is indispensable in association with the transition of an economy.¹⁰ Re-combination learning enabled China in preserving and re-deploying technological assets built up in the planning time. In the 1990s China entered the phase of widespread benefiting from the revolutionary IT technology; and resumed a certain level of domestic supply of capital goods: in the machinery industry the rate of domestic supply is at 60-70 % by the end of the 1990s, declined from the unnecessary height of 95% prior to the reform (Shi and Shang 2000). The significance of such preservation and re-deployment is manifested in comparison with Argentina and Brazil where the machinery industry previously developed disappeared to a large degree in the 1990s restructuring,¹¹ and with Russia where the capacity in IT technology was largely destroyed in economic transition.

The story about traditional industries like textile is slightly different. These are industries long depressed in the centrally planned era. The surge of them was attributable to a mix of factors: the chance of reallocation of international production from Hong Kong and Taiwan to South China that brought about fashionable design and international marketing skills, the huge demand at the domestic market that was hindered before and has been in rapid expansion since reform along with the increase in income level; the responsive policies including that for the creation of export-production zones, that for joint-ventures which often involved with capital and management of overseas Chinese, and that for local small startups in coastal areas many of them engaged in OEM production. Domestic accumulation was mainly in manufacturing experiences, which were widely disseminated around the country under the thrusts (in 1958-1960 and 1970-1975) for local initiatives to industrial development in the planning economy time. Backed up by appropriate institutional restructuring and certain level of manufacturing experiences, China became highly integrated in the global value chain, supplying for both the international and domestic markets (Gereffi 1999; de Buckle 2001).

10 Problem-solving and skill-accumulation take place in a certain direction, showing a “trajectory” of technological development; this is because of selectiveness of technological change and positive feedback loops of information and knowledge. Technological trajectory is institution-shaped. Through re-combination learning, the IT technologies in China turn to embark on the application-driven and international standards compatible, from those before the reform which were military purpose oriented and internationally incomparable in architecture. The machinery technology changed trajectories from those that were general machining-function oriented towards more responsible to user specifics and machining functional specifics. (Gu 1999a, Chapter 18; Gu and Steinmueller 1996/2000)

11 Personal discussion with Dr. Ludovico Arlcota, UNU/INTECH and Maastricht Management School.

What Characterizes Recombination Learning in China? —A Comparison with Asian NIEs—Comparing with South Korea and Taiwan, distinctness of the Chinese approach is apparent. In addition to associated radical institutional restructuring, recombination learning in China started at middle-low (respectively for different cases), but not the lowest, stages of skills and competences as the Hobday (1995) scheme. Higher staged skills like design and R&D were incorporated in the learning soon once it started; while in the same time lower-staged skills such as quality manufacturing which were missing previously have to be acquired and exercised simultaneously (hence, “re-combination”). In comparison, learning in Korea and Taiwan took a more linear-like approach, step-by-step from the less complicated such as assembly to the more sophisticated such as design, R&D and product innovation. In terms of targeting market, Chinese enterprises served for both domestic and international markets in the process of transformation;¹² unlike in Korea and Taiwan where learning was heavily for entry in the international market. Not surprisingly the level of accumulated technological assets and the size of domestic market were the causes of the distinctions. This shows that workable learning models can be many but not exclusively one. Nevertheless, the ability of product innovation seems important that a latecomer learner has eventually to master it. Product innovation creates an either radical or incremental “new trajectory” of technology; it strengthens the power in earning “innovation rent” and activates the dynamics to further learning (Scherer1992).

Concerning product innovation, South Korea and Taiwan present some characters which are differentiable to each other. Korea developed by the end of the 1990s international comparative advantages in large mechanical systems like automobile and ships and scale-processed components like semiconductor; while Taiwan has the advantages in small systems like computer motherboards and mice, image scanners, monitors, keyboards, simple CNC machine tools. This is basically because firm structures developed in them differ. The innovation system of Taiwan, upon small firms-dominated structure, had the tendency in selecting small systems or “niche” technologies, and developed distinctive (to Korea) policy priorities and supporting institutions fitted to their technology-institution framework (Gu 1999b). In this sense, learning models and development paths are differential even between the successful Asian “Tigers”.

Where, then, is China in the Korea-Taiwan dichotomy of technological specialization? The answer seems that it is not unfolded fully yet. China as whole has not moved to the stage of being able to create distinctively specialized competitiveness in the international market beyond labor-intensive manufactures. Re-combination learning was the learning that underpinned the relatively smooth re-deployment of accumulated intangible assets, or a kind of profound system’s transformation. On the basis of successful transformation, China has a long way to go before evolved out its distinctive international specialization of technology, which is considered the quality of a well developed or a mature modern NIS.

12 The PC and machinery industries of China were firstly in the 1980s for the domestic market and gradually in the late 1990s became able to export; and the textile industry was firstly largely for the international market and gradually expanded the supply for the domestic market.

5, AN EVALUATION OF NIS TRANSFORMATION IN CHINA

Figure 7 illuminates in the simplest way the NIS of China as it is before (part A) and after (part B) the transformation, upon the above discussion. We examine the transformation following the scheme earlier developed (Section 2). Table 8 sums up the marks from the evaluation.

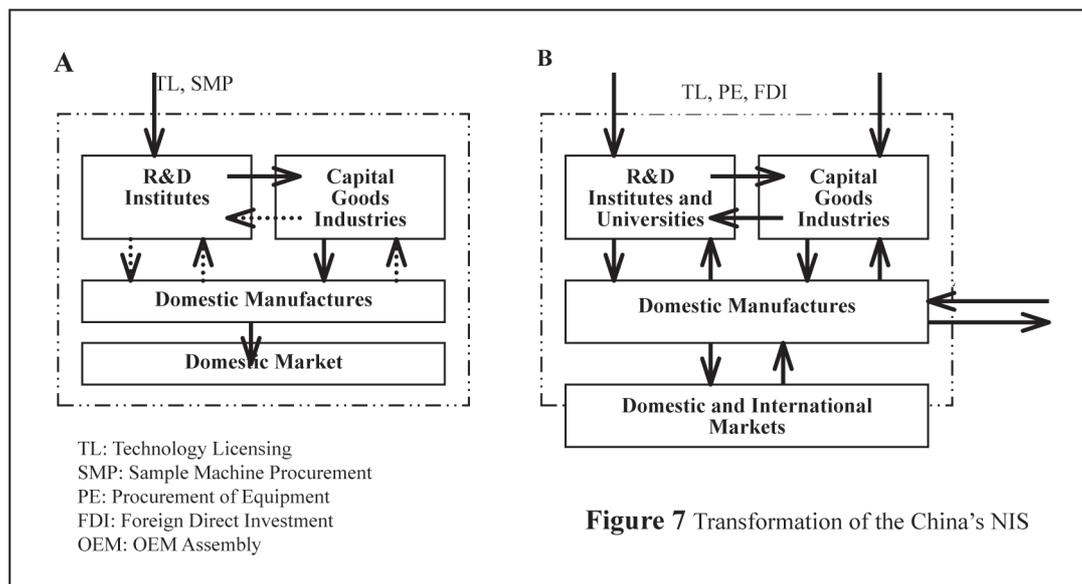


TABLE 8 EVALUATION OF NIS TRANSFORMATION

Quality Item	Evaluation
Openness	££££
Incentives	££££
Clustering	££
Supporting and Coordination Capacity	£££-
Science and Engineering Base	£££-

Both the first two items of Table 8, namely *openness* and *incentives*, earn a double plus mark. In terms of openness, improvement is great. Inflows of technology, in “embodied forms” such as capital goods procurement (line 4, Table 4), disembodied forms such as technology licensing, and FDI (foreign direct investment, line 5, Table 4) come in through multiple channels and of much higher intensity. The pre-reform system was primarily closed; only small windows kept open for incoming sample machines and urgently needs. The lessons are that a closed system is deemed to lose its vitality; such systems could hardly avoid the fate of becoming dull and inferior. Drawing upon internationally common pools of knowledge, and meanwhile developing specialized competitive strengths, is proved necessary especially for today than ever before. And, higher levels of incentives for innovation are intrinsically associated to market-based systems (Metcalf 1995). Market reform widened the scope and scale of people’s participation in innovation and learning, although obstacles remain from inappropriate intervention of government, from weak credibility and trust that raise transaction costs, and from a less developed IPR system that impedes knowledge creation activities, from which software industry is one of the most seriously suffered.

Clustering, as widely accepted crucial for development in face of global competition (UNIDO 2002), motivates dynamic learning, spreads common knowledge and good practice, and develops something called locally embedded and non-traded advantages (Cooke 1998). A single plus mark is made upon a general improvement in horizontal linkages. However, clustering or networking could not be intensified automatically without purposeful effort to establish sufficient supporting institutions and coordinative mechanisms (Saxenian 1996), to which the reform policies have so far not addressed seriously. Hence although a local dimension of S&T and innovation policy strengthened during the market reform, many regions of China lack of clustering or networking even with firms agglomeration (Wang and Tong 2003).

The NIS perspective sheds a light on the importance of *supporting and coordination institutions* (or “technological infrastructure”). We give a plus and a minus mark to the item. Positively, market-mediated supporting and coordination functions have emerged via successful transformation of the old system—some R&D institutes turned to be providers of technological services; and via new institutional establishment for standards, quality control and product safety, which are necessary for the operation of market. Negatively, supporting and coordination functions particularly for small and medium firms have been relatively overlooked. Besides, supporting and coordination for the “public goods” areas like health care and agricultural technology were weakened during the market reform. The hit of SARS epidemic in 2003 spring revealed the weakness obviously. A combination of public and private provision of the functions is necessary, while this is a topic largely ignored until recently.

A *science and engineering base* is an important part of NIS. It embraces a set of science and technology institutions and embeds accumulated knowledge that maintains vital long-run potential of innovation. The scientific publication indicators (lines 2.1 to 2.3, Table 9) point out an improvement of the base, but still much inferior to science and engineering giants like United States, Japan and Germany. This earns a plus mark to this item. The improvement in science and engineering publications can be largely attributed to the improvement in international academic exchange.

TABLE 9 THE SCIENCE AND ENGINEERING BASE

	Year 1		Year 2	
	1987	2000	1999	2001
(1) R&D expenditure Billion (GDP%)	5.67 (1.0%)	89.6 (1.0%)		
(1.1) Basic Research %	7.7	5.2		
(1.2) Applied Research %	32.1	17.0		
(1.3) Experimental Development %	60.2	77.8		
(2.1) SCI International Rank	24	10 (India 13) (Russia 8)		
(2.2) ISTEP International Rank	14	8 (India 23) (Russia 7)		
(2.3) EI International Rank	10	3 (India 12) (Russia 9)		
(3) Patents, USPTO granted Number: China	41	266		
India	24	179		
Russia	67	239		
S. Korea	586	3,763		
Taiwan	1,252	6,544		

NOTES:

SCI: SCIENCE CITATION INDEX

ISTP: INDEX TO SCIENTIFIC AND TECHNICAL PROCEEDINGS

EI: ENGINEERING INDEX

USPTO: THE US PATENT AND TRADE MARK OFFICE

SOURCES: CHINA SCIENCE AND TECHNOLOGY INDICATOR 1988: 56

HTTP://WWW.STS.ORG.CN/KJNEW/MAINTITLE/MAINMOD.ASP?MAINQ=13&SUBQ=1; HTTP://WWW.STS.ORG.CN/REPORT_3/DOCUMENTS/2001/0113.HTM; HTTP://WWW.USPTO.GOV/WEB/OFFICES/AC/IDO/OEIP/TAF/REPORTS.HTM

There are problems and restrictions with the S&E base; we have to give a minus mark either. The patents granted in US (line 3, Table 9), used to be an indicator for relative innovativeness, shows that China is inferior to the successful Asian NIEs like South Korea and Taiwan by quantitative order. China increased export volumes dramatically, while internationally competitive advantages remain in labor-intensive goods.¹³ Recently the so-called “shortage of ideas for innovation” problem attracted the attention of media and scholars in China, that enterprises feel they don’t have “good innovation projects” to invest when competition pressure drives them to do more endogenous innovation, but not merely rely on technological imports.¹⁴

Why universities and R&D institutes could not help for innovation ideas or seeds? There might be several reasons intertwined together. Firstly Universities and public R&D institute in China might have gone too far away in keeping their knowledge “proprietary”, under the general policy push into the marketplace.¹⁵ Secondly, the NIS of China remains weak in “upstream” basic (only 5.2 % in 2000) and applied research, the major seedbeds for ideas, theories, and methods (lines 1.1 to 1.3, Table 9).

13 An UNCTAD study reports that “terms of trade” for China has been in deterioration in the 1990s; deterioration was worse for medium-tech and high-tech products than low-tech products. UNCTAD Discussion Paper No. 161 2002, at

14 See: <http://tech.enorth.com.cn/system/2001/04/29/000032182.shtml>

15 Marketization of science and technology has been a global trend in the 1990s. The negative impact is in damaging the “commons” of scientific knowledge, which serves as input in downstream innovation activities (see Dasgupta and David: 1994 among others)

¹⁶ Thirdly scientific communities of China are segmented, lacking exchange and cooperation, although it is now much more open to international counterparts. For example the scientists who work in epidemic disease in one place might know little about what their domestic colleagues do, maybe such knowledge is even less than what they know about their international colleagues. In addition, along with corruption that becomes pervasive in economic life academic disciplines seem getting worse.

Nevertheless, China was successful in transformation of a huge R&D system previously established in the planning time. The accumulated knowledge and skills were rather smoothly re-organized to be contributing factors in the transition period. It is a great success remarkable among the group of former centrally planned economies.

Up to the second half of the 1990s, symptoms increasingly manifested the fact that the space of development created by reforms and re-combination learning is about exhausted. And the accession to WTO aggregated one more element to the need that China to move into a new period of economic and NIS development. This was the background for the Decision by the Central Committee of Communist Party and the State Council, it declares for “enhancing technological innovation, developing high technologies and promoting commercial production of S&T achievements.”¹⁷ The WTO regulations ruled out the trade and industry policies that Korea and Taiwan took in the 1970s and 1980s, and elevated the costs for acquiring foreign technologies, both together were the major means for their learning, a learning that characteristically began with, and reinforced upon, repeated acquisition and “imitation” of externally sourced technology. China has to do more endogenous innovation soon than merely imitation, if China is to enter into a new period of development successfully in the new Millennium.

Favorable conditions include a certain level of technological capability, which has re-organized in the past decades, the large domestic market (once again), which embraces diverse demands/tastes some rather advanced some preliminary while many unique, and internationally the high mobility of knowledge and talents (globalizing production and knowledge systems). To promote interaction between technological capabilities and the demands/tastes emerging at the domestic market would nurture novel ideas for endogenous innovation, that would eventually make up an contribution to the international market and the wealth of human-being. This requires a lot of efforts rather different from what has been taken in the 1980s and 1990s, in development strategy and policy, business management, and NIS construction.

16 The cultural tradition of “organic naturalism” or empiricist attitude towards knowledge as earlier mentioned also played a part. Discussion on this issue is beyond the scope of the paper.

17 For the full document, refer to http://www.most.gov.cn/t_a3_zcfgytzgg_a.jsp

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