

# **NIS Transformation and Recombination Learning in China**

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This paper applies the notion of national innovation systems (NIS) to analyze the transformation 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 market reform time. 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 "Analytic framework: Innovation Systems, NIS Transformation, and Learning" elaborates analytical concepts and tools for the paper. Section 3 "NIS Transformation" addresses the policy process responsible for the success of the transformation. It explains the frequently asked question: Why Did a Gradual Process Work? Section 4 "Recombination Learning" analyzes the learning process associated with the system's transformation. This section makes as well a comparison of the learning in China in the examined period with that analyzed for South Korea and Taiwan. Section 5 evaluates the NIS Transformation in China. Finally a short section concludes this work.

## **1, Universal Science and Specific Institutions**

*An Episode.* Scientific knowledge is universally valid. From the very beginning Chinese scholars and officials have never felt about the 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) 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 to the modern science though, 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 19<sup>th</sup> century, scientific and engineering education had thereafter soon been introduced in universities, and Research and Development (R&D) establishments were started to organize in the 1920s to 1930s. 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 modernization.

Institutions imply formal organizations and informal ones like norms, habits, and attitudes (North 1990). Evolution and patterns of institutions have deep roots in history (e.g. Zysman 1994) and tradition. Institutions are therefore socially or nation “*specific*”. For developing countries, a necessary step forward for benefiting from modern science and technology is the development of institutions. China, after a long period of wars and social turmoil, could only since the 1950s be able to endure the process of institutionalization for modern science and technology and production in a nationwide scope, it was under a centrally planned regime.

***The Pre-reform Institutions in China.*** What were developed during the centrally planned time? We describe the pre-reform institutions in China for a clarification of the start point upon which the transformation takes place.

By 1980 China developed an R&D system of huge size. There were 4,690 research institutes, which were 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, a level that stands at the lowest of the nation's administration hierarchy while with an independent budget ("White Paper" No. 1: 232, 235). 323 thousand R&D scientists and engineers worked in these institutes. This was a result from the enormous investment in science and technology (Table 1) that the central planning mobilized in pursuit of self-reliance strategy of development. The rates of R&D investment reached to 1-2% GDP in many of the years, made a record that was never achieved by other developing countries at similar income levels.<sup>1</sup>

### **Table 1 is about here**

The centrally planned regime grounded particular mechanisms to linking up R&D activity and production. 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 (Figure 2) (Gu 1999a: 151-176), for example, had 199 research institutes at the central ministry level,<sup>2</sup> of which the Ministry Department of Science and Technology administered eight institutes, which were assigned for manufacturing (processing) technologies. And the Ministry Bureaus responsible for particular groups of product, such as machine tools and other tools, chemical and petroleum refinery equipment, energy generation equipment, mining equipment, and so on, managed the majority rest of the R&D institutes, who were also responsible for the same categories of product technology. Research tasks of the institutes, and needed resources, were decided and allocated by the respective Department or Bureaus; these Department and Bureaus took as well coordination functions over R&D and production activities, for, to them similarly specialized production enterprises were also subordinates. Additionally, 493 R&D institutes evolved at the regional levels, supportive to local machinery production under the coordination by local governments. Accordingly, the system was harmonized, or, it had a quality of *compatibility* necessary for it to work. Specialization upon product category, total planning coordination, and

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<sup>1</sup> India for example, had much lower percentage of R&D investment in the 1950-1970s. Comparing with advanced countries, the pool of R&D in China was not trivial as well, although it is inferior in terms of quality and population-average R&D investment. For example in comparison to the 323 thousand, United States, Japan and Soviet Union had 650, 625, and 1,373 thousand R&D scientists and engineers in 1980 respectively (National Statistics Bureau 1990: 191, 492, 494, 495).

<sup>2</sup> This is based on the author's interviews in the 1980s and 1990s. Details of the structure changed from time to time in the planning period, while the overall picture was valid until the second half of the 1980s.

the separation of firms from innovative activities were among the common features for the NIS in the former centrally planned economies (Hanson and Pavitt 1987; Granick 1967).

### **Figure 2 is abhere**

Strongly central planning coordinated though; that firms in it did not independently engage in innovation was one of desperate intrinsic weaknesses as far as advance of industrial technology is concerned. Firms did mainly manufacturing upon the technology designed by respective R&D institutes. This is in sharp contrast to the institutions in advanced market economies where private firms are the key player for product and process innovation.

One of the results from the peculiar pattern of division of labor is that R&D institutes developed in the planned régime were involved in many “down-stream” works (Figure 3).<sup>3</sup> 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”.<sup>4</sup> 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 gives a hint to the transformational tendencies of the institutes afterwards in market reform. Their expertise structure tends them to become production enterprises once a pressure from the government pushes them to redefine themselves. Such transformation of R&D institutes would be less possible for India and Brazil (ref. to Krishnan and Villaschi chapters in this special issue) where R&D institutions developed in the post-WWII time were relatively more “upstream” or academic activities-oriented, and scientists and engineers there had more elite-like social positions. One the other hand, one would expect to see some similarity in transformation in former centrally planned economies, such as in Russia. We will return to this issue in Section 3.

### **Figure 3 is about here**

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<sup>3</sup> To put an innovation into place, not only R&D, but also design, production engineering and other on-spot technical preparation are needed. When the introduction of new product and process is assigned to separately organized R&D institutes from firms, many these down-stream works have to be carried out also by R&D institutes. Before the reform, usually R&D personnel by working in firms carried these out.

<sup>4</sup> 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).

The organizational separation between innovation and production blocked the system from vital and intimate interactions between producers and users, which, as researches reveal (von Hippel 1994; Kline and Rosenberg 1986; Lundvall 1988), is one of the most important dynamics especially for sophisticated producer goods technology. Figure 2 depicts information flows in the centrally planned system, which was mainly vertically channeled. The machinery industry of China was (Gu 1999a: 127-135), in consequence, apt at “general purpose” machinery, incapable of the technologies specifically fulfilling a particular machining task with precision and at low cost which could only be developed in close producer-user communication and mutual trial and tuning. More seriously, the machinery industry, as important as an “innovation center” for the whole economy (Rosenberg 1963), led not only to the low international competitiveness of the sector itself, but also to the low development performance of the Chinese economy as a whole. Hence in terms of *effectiveness* of IS, the centrally planned institutional settings made a record of very low degree. The low efficiency that was well acknowledged by the 1970s was one of the motives for the launch of programmes for economic as well as R&D system reform.

A technical note: This paper focuses on the transformation of industrial technology R&D institutions. Industrial technology R&D constituted a significant part of the R&D system in China. The 1985 statistics shows that of the 4,690 above-county-level R&D institutes, about half were to be counted as for industrial technology.<sup>5</sup>

## **2, Analytical framework: Innovation Systems, Systems Transformation, and Learning**

*Innovation Systems.* In order to understand innovation and development and the experience of China during the market reform, it is necessary to go beyond merely science and technology. The approach of innovation Systems (IS) provides a useful framework. Central to IS is a systemic view of the importance of institutions, and the interaction between technology and institutions (Freeman 1987; Lundvall (ed.) 1992; Nelson (ed.) 1993; Edquist (ed.) 1997). Innovation systems imply:

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<sup>5</sup> Of the total 4,690 R&D units at the above-county-level, those in the categories of “industry”, “construction” and “transportation and posts and communications” were 1,882, 103 and 98 respectively, together being slightly less than half of the total. Of the total 231 thousand R&D scientists and engineers working in the R&D institutes at the same level, those who were in the three categories were 104, 5, and 8 thousand respectively, together being half of the total R&D manpower. Source: “White Paper No. 1: Table 1-2, on page 232.

“...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)”. (OECD 1999:24)

Innovation systems, 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 IS approach, we will in this paper use the following *evaluation scheme* to depict characteristics of China’s innovation system both before and after the reforms in the 1980s and 1990s. It briefly assesses several sensitive parameters to show, in our context, what changes have been led to it during the final two decades of the 20<sup>th</sup> century.

- \*1\* *Openness* to international exchange of technology and knowledge for the vitality of NIS;
- \*2\* *Incentive* that is 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*.

***Transformation of NIS, Policy Institutions and Policy Process.*** In a rapidly changing world, economic structure as well as innovation systems everywhere in the world have to succumb to change. This is particularly so for developing countries, for them the process of development is intrinsically a “historical transition” (Fei & Ranis 1997; Madisson 1991; Ohkawa and Rosovsky 1973; and Hayami 1997) that accompanies fundamental changes in patterns of division of labour and in mastery of modern technology. Transformations of production system and innovation system are the essence of development.

Essential though system’s transformation to development, study on it has been short in supply. Big questions have been holding concerned people: Why a shock therapy approach to economic and social transition did not work? How to manage fundamental transitions and transformations when indispensable? 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.”

It seems, as we believe, that the IS approach may offer conceptual as well as instrumental tools for approaching the issue of transformation.

The findings from NIS survey (OECD 1999; Nelson (ed.) 1993; Nelson 1996), as well as the theoretical underpinning of the IS approach reject a deterministic once-for-all initiative of systems transformation. The findings from NIS survey show that innovation systems are country-specific. Not only are patterns of science and engineering base and advantageous areas of international trade and so on specific to countries, but also policy institutions and policy measures

country-specific. From an “evolutionary” perspective (Metcalf 1995), policy institutions and the complex and dynamic interaction between policy initiatives and the response of the system cast distinct development and transformation paths. To understand system’s transformation, therefore, most important is not how perfect and beautiful the initial reform scheme is, but about the process: how the policy-making is responsive so as to make adaptive revision upon learning from the system in transformation. In this way we in Section 3 discuss the transformation of China’s innovation system. We explain how a gradual process worked in China in the 1980s and 1990s, specify in comparison with Russia what might be conditions for a gradual process to work, and how a gradual process of reform offer the space for both policy adjustment (policy learning) and growth.

***Learning models.*** When the focus of research turned to change and transformation, the most important process is learning (Lundvall (ed.) 1992; OECD 1996b). The adaptive policy as above discussed is a kind of learning, i.e. policy learning. Learning models here imply the process of technological mastery. Development if 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 different in character (Mowey 1995; Lall and Pietrobelli 2003; 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, 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 more radical, conducted as high priority under the direct planning 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, given that the quality, productivity, and reliability of the technologies developed in that time were inadequate (Gu 1999a Chapters 14 and 18). This was a kind of imitative learning under the directives of central planning. We will explore in Section 4 what characterizes the learning in the reform time, which we title as “recombination learning”.

Studies on learning models 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 as “export-oriented enhanced learning” (Gu 1999b). They all developed extraordinarily (unusual in developing countries) high human resources and kept extraordinarily proactive development strategy 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 the circumstances 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.

### ***3, NIS Transformation***

***Policies and the 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 in which 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, so that 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, which were achieved 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 cut<sup>6</sup>. Shortly speaking, the reform focuses on marketization of the state-owned industrial technology R&D institutions.

Interesting is the policy process through which solutions for horizontal, regular and multiple linkages were gradually created, enriched, 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 a 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, from differences in work culture and administrative affiliations, were hard to fill up immediately. In the next year 1988 reform policy, by taking in the practice originally created by individual scientists and engineers, launched 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. Scientists and engineers, often in support of their parent institutions, jumped into the sea of commercial application of their inventions and expertise. One of the results from spin-off initiatives is, as my collaborator and I have argued elsewhere (Gu 1996; Gu 1999a: Part II, Gu and Steinmueller 1996/2000) the birth of a “new” ICT (information and communications) industry, which made it ready for widespread applications of the powerful means of information and

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<sup>6</sup> 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.

communications technology. By the end of the 1980s, reform policy furthered to embrace *transformation of R&D institutes* on a whole institute basis. This was in effect a registration of actual evolution realized to many industrial R&D institutes. A study (Gu1999a: chapters 16 and 17) shows that in the machinery industry these institutes became either providers of engineering services in production or product or plant engineering, or producers of relatively new or sophisticated products, according to their previous specialization and market opportunities.

By means of this evolutionary process, solutions for transformation of R&D institutes created and consolidated as multiple and practical as possible. All the mentioned approaches to transformation 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,<sup>7</sup> as a stage of the clarification, 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.

#### **Table 4 is bout here**

*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

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<sup>7</sup> See: [http://www.sts.org.cn/report\\_3/documents/2002/0207.htm](http://www.sts.org.cn/report_3/documents/2002/0207.htm)

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: chapters 16 and 17) worked hard to reorganize institute’s internal resources and recreate external relations in a piecemeal manner in which they test out opportunity and feasibility. It was through such gradual adaptation that the R&D institutes eventually altered 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 that is unavoidably involved in complex system transformation.

### **Figure 5 is about here**

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 supporter to a macro-environment whose rules are basically predicable so that reform programme-stirred chaos remains an “organized” or “controlled” type. This is necessary for adaptive learning to carry out in a cumulative manner. Russia was

unfortunately suffered from abrupt disturbances too roughly<sup>8</sup>. It was hardly possible for Russia to develop some agreed policies, not to mention policy maker and system's members hardly able to make adaptive efforts towards an agreed target. Debates were long held between the proponents for the "preservation" strategy (*i.e.*, not to reform) and those for restructuring strategy (*i.e.* to transform the R&D system), lasted until the end of the 1990s (Randosevic 2003). In the interval R&D institutes could only attempt for survival randomly. This leads to *Condition 3*, the importance of strategic vision. Strategic vision now is a popular notion in business management. A strategic vision of policy-makers 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.

#### **4, "Recombination Learning"**

***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). These were industries developed as priority industries in the planning period. In recombination learning,<sup>9</sup> 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

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<sup>8</sup> 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.

<sup>9</sup> 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

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 and more traditional industries exemplified by textile, in terms of technological gaps, means for filling the gaps, accumulated capabilities and institutional restructuring.

### **Table 6 is about here**

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 1996a). Besides the machinery industry was better 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 got to know it firstly and mainly via the access to imported PC machines, which embody the architectural knowledge that has been proved at the marketplace. 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 local brands became dominated at the domestic market. In contrast, the gaps for machinery technology can be considered in design and production engineering. 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.

Re-combination learning enabled China in preserving and re-deploying specific technological

assets built up in the planning time. In effect, what was associated with it was a “path shifting” of technological trajectories.<sup>10</sup> Up to the 1990s China entered the phase of widespread applications of ICT; and resumed a certain level of domestic capacity in machinery capital goods. The rate of domestic supply in machinery 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 Russia where the capacity in IT technology was largely destroyed in economic transition.<sup>11</sup>

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; the responsive policies including that for the creation of export-production zones, that for FDI, 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 spreading manufacturing to provincials. 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).

***Compare Recombination Learning with Learning Experiences in Asian NIEs.*** In comparison with South Korea and Taiwan, distinctness of the Chinese approach is apparent. In addition to associated radical institutional restructuring, recombination learning in China started from middle stages of skills and competences as on the Hobday (1995) learning ladder scheme. Higher staged

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<sup>10</sup> 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 to an extent institutional structure shaped. Through re-combination learning, the IT technologies in China turn to embark on an trajectory characteristic of application-driven and international standards compatibility, from that before the reform which was 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)

<sup>11</sup> The importance of re-combination learning is apparent as well in comparison with Argentina and Brazil where the machinery industry previously developed declined to a large degree in the 1990s restructuring. Source: Personal discussion with Dr. Ludovico Arlotta, UNU/INTECH and Maastricht Management School.

skills like design and R&D were incorporated in the learning soon once it started; meanwhile 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;<sup>12</sup> 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 among causes for the distinctions. This shows that workable learning models can be many but not exclusively one.

Concerning specialized strengths of technology, South Korea and Taiwan demonstrate some characters, which are differentiable to each other. Korea developed by the end of the 1990s international comparative advantages in large 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, and 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 the case of Korea, upon its rather concentrated firm structure, shows a tendency just in the opposite: preferred for technologies with higher effects of scale economy (Gu 1999b).

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 significantly beyond labor-intensive manufactures. Re-combination learning was the learning that underpinned the re-deployment of accumulated intangible assets during economic transition. On the basis of successful transformation, China will have a long way to go before develop out its distinctive international specialization of technology, which is considered the quality of a well developed or a “mature” modern NIS.

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<sup>12</sup> 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, Evaluation of NIS Transformation***

According to the discussion made in the previous section, Figure 7 illuminates in a simplest way the NIS of China as it is before (part A) and after (part B) the transformation. It embraces (1) innovation actors—R&D institutes, capital goods industries they provide embodied technology as the means for user sectors, domestic end-product manufacturers; (2) inflows of technology—by means of technology licensing (TL), sample machine procurement (SMP), equipment procurement (PE), foreign direct investment (FDI), and original equipment manufacturing (OEM); and (3) interactive relationship between actors and with domestic and international markets. It gives a first impression as how significant the transformation has brought changes into the system. Following the evaluation scheme earlier developed (Section 2), we examine the transformation a bit more in detail. Table 8 sums up the marks from the evaluation.

### **Figure 7 and Table 8 are about here**

Both the first two items as shown Table 8, namely *openness* and *incentives*, earn a double plus mark. In terms of openness, improvement is immense. Inflows of technology, in “embodied forms” such as capital goods procurement (line 4, Table 4), disembodied forms such as technology licensing, and ownership-involved (FDI line 5, Table 4) come in through many 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 credit and low trust that raise transaction costs, and from a less developed IPR system that impedes knowledge creation activities.

*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 (Nelson 1992; 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 2000).

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 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 the 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 is about here**

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 international competitive advantages remain in labor-intensive goods.<sup>13</sup> 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, not merely rely on technological imports.<sup>14</sup>

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 towards keeping their knowledge “proprietary”, under the general policy push into the marketplace.<sup>15</sup> 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).<sup>16</sup> Thirdly scientific communities in China are segmented, lacking exchange and cooperation, although it is now much more open to international counterparts. In addition, academic disciplines seem to become worse these years.

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.

## **6, Conclusions**

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<sup>13</sup> 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 <http://www.unctad.org/Templates/Page.asp?intItemID=2101&lang=1>

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

<sup>15</sup> 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). In China although the reform programme distinguishes different types of R&D institutes, the thrust to the market place has nevertheless overwhelmingly strong. Universities and “basic research type” and “public welfare and infrastructure services type” R&D institutes were also under the influence of market-oriented reforms.

<sup>16</sup> Both before and after the reform, China carries out less basic research than many developed and developing countries. Being at low development state might be one of the reasons. Deep reasons might come from some scientific cultural tradition of “organic naturalism” or an empiricist attitude towards knowledge as Needham observed. Discussion on this issue is beyond the scope of the paper.

We exercised the innovation systems approach to China in its 1980s-1990s reform. The exercise demonstrates that the IS approach has explanatory power in analyzing a very comprehensive phenomenon of NIS transformation in China. The explanatory power stems from the systemic and evolutionary assumptions of IS; namely in the context of our analysis, the adaptive policy process, as well as the fitting and re-fitting responses (or, learning) by system's members to changed rules of game. A broad definition of innovation systems which the IS approach insists, is proved necessary. Indeed, it was the changed relationship between the industrial technology R&D institutes with their industrial users, but not the R&D system *per se*, that legitimated the reforms; the interactive process also shaped the path of the transformation

The exercise of the paper shows as well the policy diagnosis potential of IS approach, although this instrumental functionality is yet to be fully explored and implemented in policy practice. Gauged by the evaluation scheme derived from the IS concept, two out of the five variables, *i.e.* “supporting and coordination institutions” and “strength of S&E base” reveal problems of the China NIS which remained weak or even deteriorated during the transformation. The reform programmes might have taken a more balanced stance between market mediation and public provision of technological knowledge, and between direct commercial use of technological capacity and the use for supporting learning and upgrading especially at SMEs, if it had had the chance not merely to consult to market-centered theorems. The multi-institutional and multi-functional perspective of IS points to policy areas such as supporting and coordination institutions and the health of S&E base we emphasize here, which were not clearly highlighted in traditional science and technology policy perspective or in mainstream macro economics.

Up to the second half of the 1990s, symptoms increasingly manifested the fact that the 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.”<sup>17</sup> The WTO regulations ruled out the trade and industry policies that Korea and

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<sup>17</sup> For the full document, refer to [http://www.most.gov.cn/t\\_a3\\_zcfgytzeg\\_a.jsp](http://www.most.gov.cn/t_a3_zcfgytzeg_a.jsp)

Taiwan took in the 1970s and 1980s, and elevated the costs for acquiring foreign technologies. Both assisted the successful catch-up in Korea and Taiwan, which have the characteristic of imitation to innovation. China has to do substantial endogenous innovation sooner, 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, which embraces diverse demands/tastes some of which are rather advanced some preliminary while many unique; and internationally the high mobility of knowledge and talents—namely, globalizing production and knowledge systems. Upon the circumstances, intensifying innovative response to the demands/tastes emerging at the domestic market would nurture novel ideas for endogenous innovation that would eventually make up a contribution of China to the international market and the wealth of human being. This requires a new set of efforts rather different from what has been taken in the 1980s and 1990s, in terms of development strategy and policy, business management, and science and technology policy and NIS development.

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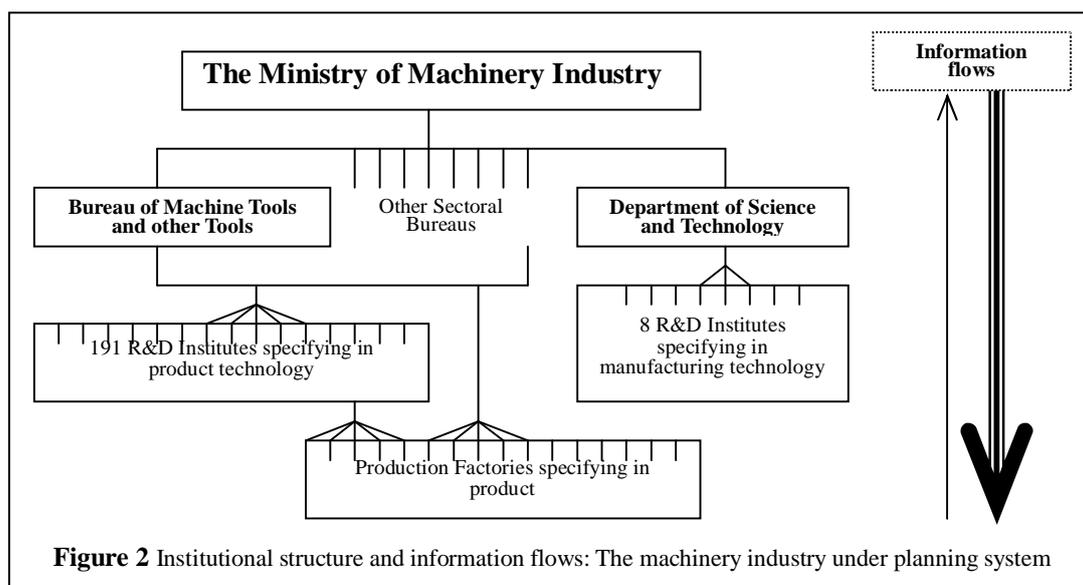
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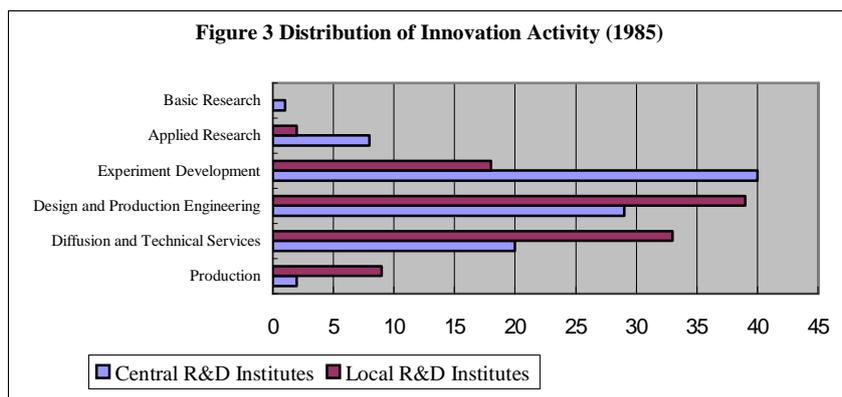
**Table 1 China's Investment in R&D**

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	2002	1.2
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>



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

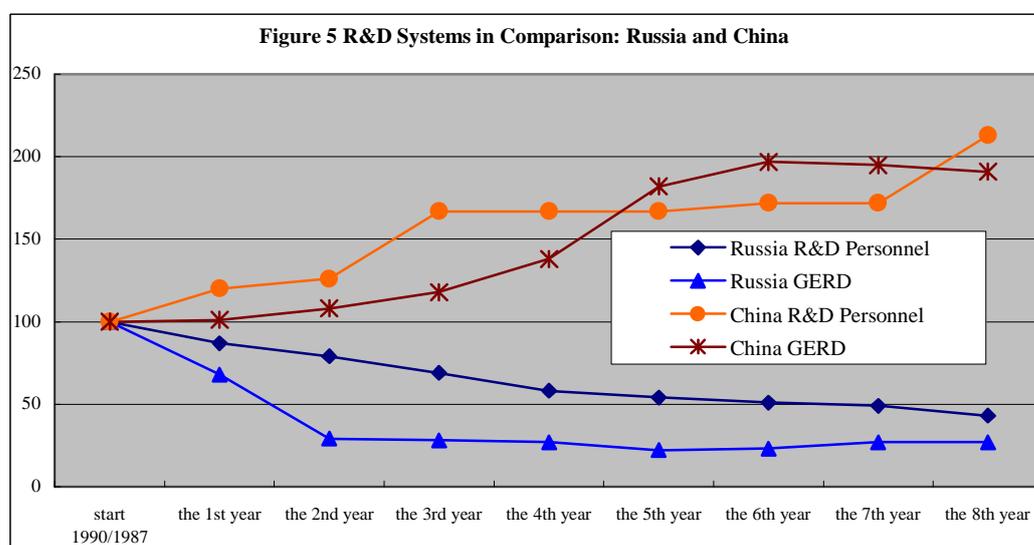


Source: "White Paper" No. 1: 238

Table 4 The Multiple Approaches to NIS Transformation (All the measures at current price)

	1985	1990	1995	2000
<b>(1) Technology Market</b>				
Contract fees (RMB Billion)	2.30	7.51	26.83	65.07
<b>(2) Spin-offs</b>				
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
<b>(3) Domestic R&amp;D expenditure (RMB Billion)</b>				
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
<b>(4) Import of capital goods (USD Billion)</b>				
	16.24	16.85	52.64	69.45 (1999)
<b>(5) FDI (USD Billion)</b>				
	1.96	3.49	37.52	40.72

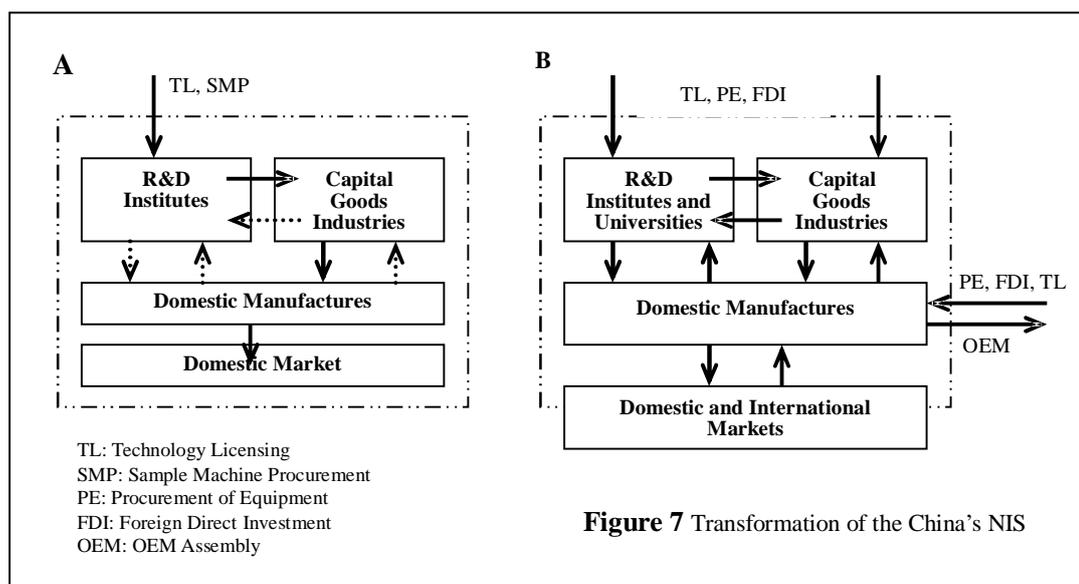
Sources: China Statistical Year Book on Science and Technology various issues; <http://www.most.gov.cn>;  
<http://www.stats.gov.cn/nds/zgnj/2000/Q05c.htm> [http://www.moftec.gov.cn/article/200303/20030300072333\\_1.xml](http://www.moftec.gov.cn/article/200303/20030300072333_1.xml);  
[http://www.sts.org.cn/REPORT\\_3/documents/2002/0220.htm](http://www.sts.org.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)



Sources: Radosevic 2003 (for Russia); Data for China is from  
<http://www.sts.org.cn/KJNEW/maintitle/MainMod.asp?Mainq=2&Subq=2>  
<http://www.stats.gov.cn/ndsj/zgnj/2000/I01c.htm>

**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



**Figure 7** Transformation of the China's NIS

**Table 8** Evaluation of NIS Transformation

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

**Table 9 The Science and Engineering Base**

	Year 1		Year 2	
(1) R&D expenditure Billion (GDP%)	1987	5.67 (1.0%)	2000	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	1987	24	1999	10 (India 13) (Russia 8)
(2.2) ISTP 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	1992	41	2001	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;>

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<http://www.uspto.gov/web/offices/ac/ido/oeip/taf/reports.htm>