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Complementary innovation systems for catching-up in China

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Abstract

This paper discusses what kind of national innovation system (NIS) is built up in China and whether the NIS is helpful for China to catch up. Our research methodology is based on the combination of new growth theory with the NIS theory and our involvement in OECD research project about Chinese NIS. We find that Chinese NIS is composed of two complementary systems, namely FDI-based innovation system and indigenous innovation system. Both systems are found to have a positive influence on attaining China's catching-up objective but indigenous innovation system seems not as influential as FDI-based innovation system for the moment. We suggest that Chinese NIS needs to be further shaped for improving the absorption and innovation capability of domestic firms and for strengthening university-enterprise-research institute interactions.

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1 Introduction

In the 1990s, the research about national innovation system (NIS) focused on advanced countries and newly industrialized countries either individually or collectively. Nowadays, the NIS research is shifted to some newly emerging countries, like China, Brazil, India and Mexico. One of the recent research questions of NIS is placed to discuss whether national innovation policies can play an important role in helping technologically-backward countries catch up with technologically-forward countries. In fact, a handful existing research literature has already discussed the issue but not centered on one specific country like China.

Freeman (1988) and Perez (1988) both stress the importance of public policies to identify the new techno-economic paradigm[3] for catching-up. They consider that supporting infrastructure (e.g. science and technology policies) and the capacity for institutional change at both macro and micro level, impacts on the integration of a country into the technological revolution and the alleviation of heavy dependency on foreign technology. However, they do not analyze how a specific country or a group of sample countries can implement a set of policy instruments in response to the paradigm for catching-up.

Radosevic (1997) focuses his research interest on the system of innovation in transitional countries, namely Eastern Europe. He describes the socialist system of

[3] The expression of 'techno-economic paradigm' implies a process of economic selection from the range of the technically feasible combinations of innovations ; and indeed it takes a relatively long time (a decade or more) for a new paradigm to crystallize and still longer for it to diffuse right through the system. This diffusion involves a complex interplay between technological, economic and political forces. The impulse to the development of a new techno-economic paradigm arises from the perceived constraints on the further development of productivity, profitability and markets within the hitherto existing dominant mode (Freeman, 1988, p.74).

innovation and shows the way to restructure the system of innovation. In the same vein, government policies (openness, regulations) are highlighted in his research. The research output of Radosevic provides a theoretical remedy to transitional countries including China. But for adopting his proposition, it is necessary to take specific-location, institution, social culture into consideration.

Kim and Nelson (2000) analyze in detail how firms in newly industrialized economies acquire technological capabilities and how public policies shape the process of technological progress. Their study indicates that if technologically backward and poor countries implement proper public policies to support innovation activities and domestic firms creatively learn from advanced innovators, it is possible for the later comers to create the economic miracle as newly industrialized countries did in 1980s. The focus of their research is placed on domestic firms and the impact of foreign direct investments (FDI) on national innovation capability is much less discussed.

Fagerberg and Godinho (2005) discuss the role of inward FDI to some successful catching-up economies, like Hong Kong and Singapore, and explain how Asian catch-up gets an access to foreign technology. They recognize the importance of firms in the catching-up process and identify four institutional instruments which need to be improved to meet the requirement of firms in developing countries. However, they do not explore the way how European and Asian catching-up economies implement these institutional instruments and examine the efficiency of these instruments.

Tylecote (2006) agrees with Fagerberg and Godinho's opinion in terms of tracing technology frontier but he explains explicitly what kind of NIS catching-up economies need. He argues that less developed countries need twin national innovational system: system with upper level to engage with advanced technology and develop industries which use it and a lower level to help to improve the economy's existing traditional technology. In order to improve the technological level of the whole nation, the development of intermediate technology is needed to bridge advanced technology and traditional technology. In other words, developing countries should build a middle-level of NIS to promote the diffusion of advanced technology resulting from the upper level toward the traditional technology resulting from the lower level. But he does not discuss whether the different levels of technology need to depend on imported technology or on indigenous innovation.

In short, the existing research results signal that it is possible for technologically backward countries, big or small, to become competitive and affluent nations in knowledge-based economies if these countries can coordinate science-industry relationships, shape appropriate institutional set-ups to support innovation activities and promote interactive learning. And the theoretical and practical experiences arising from the above research have encouraged some emerging countries to take actions to build up innovation-based society, like China, Brazil and India.

China, trying to transform from a manufacturing to innovation-based society, has implemented a wide range of institutional reforms to promote innovation. The concept of Chinese national innovation system (NIS) was originally introduced by the Chinese Academy of Sciences in 1998 to the central government. Many studies on the Chinese NIS focus on either China's S&T system reform (Fang 1999; US embassy 2002) or S&T programs (Bao *et al*., 2002; Chen, 2003; Suttermier *et al*., 2004; Huang *et al*., 2004; Yan, 2005; Bach *et al*., 2007). Very few researches emphasize the institutional and organizational changes of the Chinese NIS, expect Liu and White. Liu and White (2001) study China's NIS in a transitional context and discuss how organizations and distribution of fundamental activities[4] change in the innovation process before and during the transition period. However, they do not link these changes to China's catching-up objective.

Based on the above fruitful research findings, we center our analysis on what kind of national innovation system (NIS) is built up in China and whether the NIS is helpful for China to catch up. In our analysis, the meaning of 'catch-up' adopts Fagerberg and Godinho's (2005) understanding as the ability of a single country to narrow the gap in productivity and income vis-à-vis a leader country. To narrow the average income gap vis-à-vis developed countries, the new growth theory[5] emphasizes the role of science & technology, human capital and FDI in economic growth (Romer, 1986, 1987; Lucas, 1988) whereas the NIS theory highlights the importance of innovations in catching-up economies. Our paper combines the new growth theory with the NIS theory to conduct our discussion. Section 2 and section 3

[4] Fundamental activities: Liu and White (2001) identify five fundamental activities as the core of the NIS framework. These activities are composed of R&D, implementation, end-use, education and linkage.

[5] The new growth theory differs from the early post-Keynesian growth model which emphasizes savings and investment, and from the neoclassical models which highlight technical progress (Solow, 1957).

will analyze the build-up of China's NIS and its impact on attaining the nation's catching-up objective respectively. Finally, we draw a conclusion and provide some implications for policy makers.

2. FDI-based innovation system

Although the effect of FDI on economic growth of host countries is debatable (Ran *et al.*, 2007), many developing countries believe that the inward FDI is helpful to narrow their technological gap with developed countries, particularly witnessing the contribution of FDI to the rise of newly-industrialized economies. China is a practitioner of this view. Since the economic reform in 1978, China has implemented a package of institutional changes to attract FDI, expecting the spillover effects of FDI to facilitate technological progress of domestic firms. This section discusses how China takes actions to build up FDI-based innovation system and also examines the impact of the system on innovation promotion.

2.1 Institutional changes for building up FDI-based innovation system

Institutional changes designed and implemented by the Chinese government include open policies, IPR legislation, tax holiday policy and R&D infrastructure reconstruction to acquire and absorb imported technology. Imported technology embedded in FDI is viewed as a short cut way to improve China's competitiveness in the world market.

- **Open policy**

China's open policy to FDI follows a pragmatic approach. The geographic openness was firstly limited in four special economic zones (SEZs) as open economic areas in four coastal cities[6]. SEZs perform under a more liberal environment, isolated from the prevalent hierarchical system of order (Lerais *et al*., 2006). After receiving the government's positive appraisement, various derivatives of SEZs emerge as open areas to FDI[7], spatially distributed almost all over the country. The expansion of geographic openness is expected to spread FDI's externalities at a national level rather than a regional level.

The sectoral openness to FDI matches the "Foreign Investment Industrial Guidance Catalogue" in which industries foreign investors are encouraged, restricted and prohibited. In general, FDI are encouraged to flow in high-tech and friendly-environment industries, such as equipment manufacturing, new material, and energy-saving industries. Moreover, the WTO adhesion requires China to liberalize industry trade border. Since 2006, high value-added industries (e.g. telecommunication, banking and insurance) have been gradually open to foreign investors. Protected industries, i.e., automobiles, chemicals, and electronics, are not allowed to enjoy the tariff and non-tariff protection. More export-oriented products can enter domestic market (Jiang, 2002).

- **Legislation on IPRs**

Due to market diversity within or beyond the boundary of a country, innovators can benefit from a temporary monopoly income for a long time if their intellectual property rights (IPRs) are protected. Foreign firms, especially

[6] Four coastal cities: Xiamen, Zhuhai, Shantou and Shenzhen. Xiamen is in the Fujian province, the other three cities are in the Guangdong province.
[7] Derivatives of SEZs: 14 open coastal cities (1984), 54 economic & technical development zones (1984), 53 high technology development zones (also called S&T industrial parks, 1988). Details see Tseng, W., Zebregs, H., 2002 and Llerena, P., Tang, M.F., 2007.

multinational companies (MNCs), are recognized as a major source of technology and know-how channelling to developing countries. To sustain their profitability, foreign companies require the host country to build up and implement a legal system on IPRs protection. Countries without IPR policy would decrease the gains to an innovator. Sooner or later, competitors will be able to imitation, or invent around, or develop a better version of, the initial innovation (Nelson, 1987). Indeed, the destination of FDI is influenced by the legal framework and the rule of law in the recipient country (Report, 2003).

To attract FDI and also to motivate domestic innovators, China has made great progress in developing a comprehensive legal system on IPRs. Laws on IPRs range from Patent Law to Trademark Law, Copyright Law, Regulations for the Protection of Computer Software and so on. Although the protection of IPRs is criticized as not being effective, it signals that the infringement activities of IPRs are to be punished under the established legislative framework.

- **Tax holiday policy**

Since the 1980s, FDI have begun to enjoy excess national treatment in terms of tax. The central government outlines the tax polices and local governments to a certain extent are given autonomy to formulate their preferential treatment towards foreign investors. Governments at local levels center more on economic growth and revenue increase in their jurisdictions when attracting FDI, whilst the central government pays much attention to transferring technology and managerial skills from foreign firms (Shi, 2001). Up to the late of 1990s, preferential tax policy gives priority to foreign R&D centers so as to encourage foreign innovation in China. Although new enterprise income tax law of 2008 reunifies the differential tax rate between foreign enterprises and domestic enterprises, high-tech and energy-saving foreign firms can still benefit from preferential tax rate, namely 15% against the basic tax rate of 25% for general enterprises. The purpose of tax policies toward FDI has moved from exportation orientation to innovation.

- **Building of Research & Development (R&D) Infrastructure**

To help domestic firms absorb foreign technology, the government set up over 400 research institutes (RIs) in the early stage of industrialization (Liu and White, 2001). In the 1980s, the science & technology reform restructured RIs to promote the efficiency of R&D infrastructure. The Chinese Academy of Sciences (CAS), the National Natural Science Foundation of China (NNSFC) and the Chinese Academy of Engineering (CAE) are very important components of the current Chinese R&D infrastructure.

Founded in 1949, the Chinese Academy of Sciences (CAS) is China's foremost natural science and technology research institute, administrating some 100 research institutes. CAS keeps close contact with international S&T communities to trace the world frontier knowledge and technology under various forms: sending Chinese researchers abroad; organizing international academic conferences; joining R&D alliance with foreign multinational companies… In 2005, CAS established 6 joint research centers with companies from South Korea and the Unite Kingdom.

The National Natural Science Foundation of China (NNSFC) was established in 1986 to promote and finance basic research. It develops cooperation and exchanges with foreign scientific organizations and runs a Sino-German Center for Research Promotion. However, NNSFC does not directly support R&D activities of firms but provides grants to brilliant researchers in universities and research institutes.

The Chinese Academy of Engineering (CAE) was set up in 1994. It functions as an advisory institution in matters related to engineering and also supports technical research projects financially. It does not own research institutes but carries out research through engineering departments at universities.

These three government-based research institutes are open to international science & technology communities. The wide-ranging network with foreign partners facilitates the inflow of technological information. The mobility of researchers at home and abroad also contributes to the circulation of knowledge. CAS has employed 52 foreign academicians and CAE 35 ones[8]. Hence, these public R&D institutes are directly or indirectly helpful to Chinese firms for acquiring, identifying, assimilating and adapting imported technology.

2.2 Attained objective?

After three decades, has FDI-based innovation system promoted China's innovation? To assess the efficiency of FDI-based innovation system, we here use the quantity of inward FDI and the types of inward technology to measure the acquired

[8] The data collected from CAS and CAE's website respectively. The data of CAS represents the number of employed foreign academicians by 2004 and the data of CAE by 2005.

foreign technology, and use the number of foreign patents, foreign R&D centers and high-tech trade balance to measure the contribution of FDI to innovation.

1) **Acquired foreign technology**

Given that the impact of the Chinese IPR legislation on the inflows of FDI is not conclusive, China’s open policy is widely accepted to have played a positive effect on the growth of FDI in China. Deng Xiaoping’s discourse during his south tour in 1992 and China’s access to WTO in 2001, both events stimulated new foreign entrants and foreign incumbents to invest or reinvest in China. In 1999, China was the third biggest recipient country of FDI in the world, behind UK and the USA. It hosted over a third of the foreign affiliates of multinational corporations (Dahlman and Aubert, 2001). Following China’s adhesion to WTO, the inward FDI increased very fast. China overtook the United States in 2002 and became the world largest recipient of FDI (Bajpai and Dasgupta, 2004). Starting from 2006, high value-added sectors (e.g. banking, insurance) have been gradually open to foreign investors. More FDI is predicted to flow into China in the years to come.

The inward FDI can be divided into three categories: investments from Hongkong, Macau and Taiwan affiliated enterprises, from newly industrialized economies (NIEs) affiliated enterprises (e.g. South Korea, Malaysia), and from advanced country affiliated enterprises. The former two categories normally transfer mature & standardized technology and general purpose equipment, and the third category, especially western multinational companies, mainly transfer product technology and processing technology rather than their core technology in R&D (Shi, 2001). Many imported technologies are embedded in equipments and facilities. The performance of imported capital goods improves productivity, and reduces production cost and materials consumption. Moreover, imported technology rarely takes the form of licensing agreements which is supposed to be more efficient for technology diffusion than physical goods import. Licensed technology import represents comparatively limited spending: less than 0.5% of merchandise imports in China's case, against 0.7% for India, 2.2% for South Korea and 3.2% for Japan (Dahlman and Aubert, 2001).

In general, many inward FDI in the 1990s concentrated in manufacturing, mining and construction industries (Dahlman and Aubert, 2001; Tseng and Zebregs, 2002; Greeven, 2004; Chen, 2005). In recent years, inflow FDI ranges from manufacturing to real estates, leasing and business service, whole sale and retaining business[9].

2) **Innovation promotion**

FDI is a potentially powerful channel for integrating a system of innovation into global networks and influencing its structural change. The effect of FDI on a host country is still arguable, good or bad. The host country may increase its dynamic capability but also takes risk of 'vicious circles' of deterioration where a country or a sector has its initial comparative advantages (Radosevic, 1997). A large literature on inward FDI in China shows that FDI plays a positive impact on the productivity of Chinese industry and on upgrading Chinese export segments (Zhang and Song, 2000; Shi, 2001; Lemoine and Kesenci, 2004; Li *et al*., 2007; Luo, 2007; Ran *et al*., 2007;

[9] See "2005，2006，2007 国民经济和社会发展统计公报"given by National Bureau of Statistics of China

Yao and Wei, 2007). Some scholars find that FDI decreases the R&D expenditure of its Chinese partners (Fan and Hu, 2007) and it may cause economic inequality (Ran *et al.*, 2007). However, they do not measure whether FDI contribute to China's innovation. We now discuss this point through three dimensions: foreign patents, foreign R&D centers and high-tech trade balance.

- **Foreign patents in China**

Although the total number of foreign patents is smaller than domestic patents in the State Intellectual Property Office (SIPO) of China, foreign patenters hold an overwhelming position in invention patent grants, accounting for 60% of total during the period of 1985-2008. The foreign patented technology in China clusters in telecommunication, electronic equipment, electronic engineering, electronic power and information technology, which is in line with domestic patented technology. The constant increase of foreign patentability leads to a patenting competition between foreign patenters and domestic patenters. Actually, the gap between foreign and domestic invention patent grants has been gradually decreased. Japan, USA, South Korean and German are the four leading foreign patenters in China. However, their patented technology mostly comes from their mother company's technology and is modified or transformed to adapt to local market. Original and basic R&D activities are comparatively low.

- **Foreign R&D centers**

Since the late of 1990s, the Chinese governments have implemented a series of preferable policies to encourage the establishment of foreign R&D centers. Attracted by China's abundant human capital and tax holiday policy, a lot of multinational companies set up China-based R&D centers and integrate these centers into their global R&D system. Up to now, over 1100 foreign R&D centers have been settled in China, particularly in coastal regions. Some foreign R&D centers belong to an independent legal person, others are embedded in foreign companies. In spite of little original innovation and basic research in these foreign R&D centers, their presence has increased the innovation activities in China. They are developing close linkage with some elite universities, to tap local talent and conduct cooperative research projects.

- **High-tech trade balance**

In recent years, China's high-tech exports and imports have largely increased. The high-tech exports grew from 13.3% of all merchandise exports in 1992 to 30% in 2005. The progress of high-tech trade is directly associated with China's integration in the international segmentation of the production process. Export-oriented foreign firms played a very important role in helping China integrate the global production chain. Actually, foreign firms dominate high-tech trade in electronic and telecom equipment and in computers and office equipment. In 2005, 88% of China's high-tech exports were produced by foreign owned firms (Jakobson, 2007: p.2).

In short, FDI-based innovation system has succeeded in attracting FDI. Technology embedded in FDI has improved productivity, upgraded export product structure and economic growth. China has become the world's second biggest holder of foreign reserves, the third biggest import-export economy and the fourth biggest economy in the world. The growth of foreign patents and more presence of foreign R&D centers promote innovation activities in China. These facts indicate that FDI-based innovation system performs efficiently.

However, the heavy dependence on foreign technology rather than in-house R&D activities pushes domestic firms away from acquiring key upstream technologies. Without core technological know-how, domestic firms cannot become competitive players in those industries which are traditionally dominated by advanced countries. The rising of Japan in the 1960s-1970s and the South Korea in the 1970s-1980s has proved the importance of indigenous innovation. Moreover, the nowadays economic and political environment is quite different from the past settings. Imitation becomes more and more expensive and the protection of IPRs is much stronger than before. Learning from the historic stories and current world settings, the Chinese government has never given up the building-up of indigenous innovation system for catching up. A set of supporting infrastructure have been constructed to conduct indigenous innovation.

3. Indigenous innovation system

A numerous literature explains the importance of indigenous innovation for catching-up countries (Freeman, 1988; Perez, 1988; Kim, 1993; Fagerberg and Godinho, 2005; Gu and Lundvall, 2006). Some scholars emphasize indigenous technological innovation (Perez, 1988; Nelson, 2000), others focus on organizational and institutional innovation (Fagerberg and Godinho, 2005). We here place organizational and institutional innovation at the core of our analysis.

3.1 Supporting Infrastructure for knowledge generation

Universities and public research institutes are principal knowledge generators. To encourage them to generate more knowledge, the Chinese government has launched various national S&T programs, reformed university and public research institutes, and carried out high-quality talent training and recruitment program since 1985. This section 3.1 focuses on these four points to analyze China's knowledge generation infrastructure.

3.1.1 Major national S&T programs

Innovation sometimes results from cumulative knowledge, and sometimes needs to take enormous R&D investments which may result in radical breaks from the past (Lundvall, 1992). China's national S&T programs aim to enhance China's technological competence through searching and exploring [10] activities. These activities increase the stock of knowledge and provide sources to radical technological innovation.

China's National Natural Science Foundation of China (NNSFC in 1986) and Key Basic Science R&D Program ("973" Program in 1997), emphasize the build-up of a genuinely original innovation capability in basic research. Universities and research institutes are the main actors to carry out the NNSFC and "973" Program. The Key State Laboratories Program (1984) supports the set-up of 182 established laboratories (2005 data), which aim to promote research and advanced training. These laboratories cover both basic and applied research fields, such as life science,

[10] Searching and exploring: the most important difference between exploring and searching is that 'exploring' is less goal-oriented than profit-oriented search. Exploring will sometimes result in breaks in cumulative paths and create the basis for new technological paradigms (Lundvall, 1992: p.11).

engineering, information, chemistry, geoscience, mathematics and physics. By 2005, these laboratories together with 6 state laboratories (in the course of establishment) undertook 12965 research projects among which 22.9% were conducted jointly with industry (Key State Laboratories Report 2005).

Additionally, another three S&T programs center on technology advancement. The Key Technology R&D Program (1983) concentrates resources on key and common technologies linked to industrial need and social sustainable development. For example, the 11th five-year plan (2006-2010) gives top priority to technology connected to energy-water-saving and environmental friendliness. The High Technology R&D Program ("863" program in 1986) identifies the emerging new-tech paradigm and carries out high-tech research so as to help China integrate into the new paradigm. The National New Product Program (1988) supports mainly high-technology-based firms.

The funding mechanism of S&T programs is distributed on the basis of projects competition replacing the former planned allocation. The carriers of such projects have autonomy to organize their research teams and manage the funding obtained (Huang *et al*., 2004; Xue, 2006). The government supervises the process of these projects, and assigns specialized institutions to evaluate the research results arising from the publicly funded projects when they are accomplished. The management of S&T programs pushes executors of S&T programs to take the quality of research into consideration seriously. At the same time, executors have incentives to expand patentability activities, due to being granting the IPR arising from publicly financed S&T projects.

3.1.2 University

The government decreases the budget for universities but compensates it by granting them more autonomy. The aim of cutting-down government grants is to force universities to generate and commercialize more industry-needed knowledge. On the one hand, universities set up new specialties and tap outstanding talents, especially overseas Chinese scholars to meet the requirement of increased student enrollments. At the same time, universities provide more and more option courses for students. Teaching staffs are pushed to widen their knowledge boundaries to meet the changing education system. Some teaching staffs reenter universities to refresh their knowledge, others learn by themselves. On the other hand, universities have strengthened linkage with industry. Industry has become the second financial supporter for academic research. In some prestigious research universities, like Tsinghua University, industry goes ahead of the government and acts as the biggest research financier.

And university reward system has been reformed to value the contribution of professors to teaching, research and knowledge capitalization. The workload arrangement of professors is more flexible. Professors can take less teaching workload and engage in more research. The incentive measures motivate professors to generate new knowledge.

3.1.3 Public research institutes (PRIs)

The reform of PRIs is another measure that the Chinese government embraced in an effort to enhance knowledge production. PRIs were inactive knowledge generators under planned economy. The State Planning Commission designed research projects and allocated related resources to research institutes. The State Science and Technology Commission (replaced by the Ministry of Technology and Science since 1998) managed S&T activities in these institutes. The rigid funding and R&D management hindered researchers' active participation in innovation.

After 1985, the R&D funding system was reformed to a project-based competition one. PRIs were forced to be competitive so as to obtain more government grants. As they gained more autonomy in terms of personnel, finance, property management and international cooperation, research institutes introduced the remuneration differentiation policy which motivated research staff and encouraged the mobility of human resources. Besides, these institutes especially those doing experiment and development were pushed to merge into enterprises. The government concentrated its funding on the unchanged institutes that primarily conduct basic research (Huang *et al*., 2004). By 2001, over 300 research institutes were merged into enterprises, over 600 ones changed to become profitable firms and a few were integrated into universities (Gu and Lundvall, 2006). The reform forces PRIs, who seek to profits, to generate new knowledge and commercially explore research outputs.

3.1.4 Human resources

Human resources build undoubtedly the fundamental of an innovative society (Jakobson, 2007). Targeting to become an innovation leading country in the world, the Chinese government has actively taken measures since the 1990s to mobilize researchers with potential competence and attract overseas Chinese who obtained higher education degrees and career experiences abroad. For example, NNSFC has created several funds to send selected young scholars abroad for training and also attract overseas Chinese scholars to return to work in China. Similarly, CAS has launched "Hundred Talents Program" to recruit promising scientists. Between 1998 and 2004, the program of CAS succeeded in bringing back 778 foreign-based Chinese researchers (Jakobson, 2007).

During the period of 2000-2005, the total number of returned overseas Chinese attained over 119, 000[11]. Many universities and research institutes provide an attractive package of welfare to these returnees, in terms of remuneration, job assignment, housing, school entrance for their children and in some cases a bulk of funds to initiate research programs. They are expected to help China identify the world new tech-economic paradigm and push Chinese technological progress to approach or reach the world forefront.

3.2 Supporting infrastructure for knowledge commercialization and diffusion

In line with knowledge generation infrastructure, the government set up technology markets, Torch Program, productivity promotion centers and national technology transfer centers to commercialize and diffuse knowledge. Technology

[11] Data collected from China Statistics S&T Data Book 2006.

markets and Torch Program were launched in 1988 to facilitate academy-industry technology transfer. Productivity promotion centers, established in 1992, were partially the results of the transformation of public research institutes. They specialize in consulting services for technology-based SMEs. National technology transfer centers were founded in 2001 to commercialize university research outputs. The four components are explained below in detail.

3.2.1 Technology markets

Technology markets play an important role in capitalization and diffusion of knowledge. It makes R&D outputs tradable at market prices. The marketable technology is traded in four categories of contracts on the market: technology development, technology transfer, technology consultation and technology service. Enterprises, research institutes and universities are the main players in technology markets.

Technology development contracts dominate transactions on technology markets in terms of contract value. They are usually traded between university and industry. Enterprises entrust universities with technology tasks, or combine with universities to do some research for a specific topic, or even to set up an entity with universities for long-term research in a special field (Xue, 2006). Technology transfer contract is associated with patent licensing. Both industry and academy have expanded patenting activities in recent years, but patent licensing-based technology transfer in China is not as efficient as in developed countries because of the uncertainty of technology and the weak absorptive capability of domestic firms.

Technology consultation and service contracts are probably much more flexible ways of transferring knowledge and technology. Such contracts often contain technology information supply, talent training and equipment maintenance. Technology service is the most frequent contract traded in the market.

Technology markets facilitate the circulation of technological information and guide universities and research institutes to generate market-oriented knowledge. Enterprises can use purchased technology from the market to replace in-house R&D activities in case of their weak R&D capability, whereas those technology generators can gain revenues through the commercialization of research outputs in the market.

3.2.2 Torch Program

The Torch Program (1988) is a key component of knowledge commercialization and diffusion infrastructure, devoted to the promotion of indigenous innovation through nurturing new technology-based firms. Three institutions were created to carry out the program: Science and Technology Industrial Parks (STIPs), Technology Business Incubators (TBIs) and Innovation Fund for Technology-based Small-Medium Enterprises (Innofund).

Nowadays, 53 national STIPs have been spatially distributed almost throughout China. However, its increasing production of export oriented high-tech manufactures and heavy reliance on foreign investment set China's STIPs apart from upgrading indigenous innovation capabilities. The majority of companies in STIPs are domestic share-holding companies but they have low productivity and export capacity.

A small number of foreign and joint ventures have a strong presence in production and exportation. The gap arises from a lack of competitive high-technology of Chinese companies. The failure of high-tech industrialization in STIPs may be compensated by the performance of technology business incubators (TBIs).

TBIs create a favourable environment for nurturing new technology-based firms to commercially exploit R&D achievements arising from universities, research institutes and enterprises. University incubators are typical ones to foster domestic technology-based firms. Entrepreneurial professors and students bring their R&D results from laboratories and create new innovative firms in university incubators. These technologies may not necessarily be at the world frontier but as least they are new to them or to China. In case of successful performance, these start-ups generate a demonstration effect on other professors and students. More university research outputs would go out of laboratories and be transferred into new products and services. Incubators for overseas scholars and international business incubators tend to foster foreign technology-based firms. These incubators are usually embedded to STIPs so that incubation and high-tech industrialization can be linked together in a same park. Incubated firms bring new foreign technology into China and possibly generate a demonstration spillover effects on other firms.

Market failure problems from technology markets, e.g. information asymmetry about the technology, difficult estimation of the value of tradable technology, potential moral hazards of contract executors, can be to some degree overcomed by the emergence of TBIs.

Innofund represents the main governmental financial support for technology-based SMEs to market innovation. It can accompany SMEs from the incubation stage to the production stage. Innofund is also used as a leverage to attract other investments for the development of SMEs. It helps SMEs solve the problem of market failure linked to difficult financial access. The selection criteria of Innofund emphasize innovativeness, R&D resources and Chinese ownership of SMEs. It indicates that Innofund prioritizes indigenous technological innovation of SMEs. Indeed, technology-based SMEs have become a very important innovation force in the Chinese NIS.

3.2.3 Productivity Promotion Centers (PPCs)

Productivity promotion centers are deemed to be a bridge between universities, firms and research institutes. They are composed of a group of intermediary and consulting organizations, established since 1992 throughout the country to support small-medium innovation-based firms. The Ministry of Science and Technology together with local S&T Commissions manage these centers in terms of macro-policies and business guidance. PPCs provide consulting services in terms of management, technology, the applications of S&T projects and technology-based services. They take advantages of their wide networks with academy and introduce experts in responsive to the demands of small medium-sized enterprises (SMEs). PPCs are a complementary institutional innovation for technology business incubators and technology markets to capitalize and diffuse knowledge. They promote the growth of technology-based SMEs.

3.2.4 National Technology Transfer Centers (NTTCs)

The co-existence of technology markets (TM), Torch Program and productivity production centers does not necessarily mean there are institutional interactions among them. The emergence of national technology transfer centers (NTTCs) in 2001 fille up the connection gap and specialize in managing univeristy IPR issues and the commercialization of academic research outputs. NTTCs establish connections with TM, TBIs, Innofunds, STIPs and PPCs. The connections keep the related institutions informed about research outputs so as to facilitate the marketability and diffusion of academic achievements. Indeed, NTTCs act as intermediaries between university, industry and market.

3.3 Indigenous innovation improved?

Over two decades has passed. How about China's indigenous innovation now? We address the question in terms of published academic papers, patentability and new products. Publications are used as an indicator of knowledge generation, whereas patents and new products are indictors to measure knowledge capitalization.

1) Scientific publications

In recent years, more and more Chinese authors' names appear in international academic journals. Chinese academic papers demonstrated an exponential increase. The number of Chinese scientific publications collected by SCI (Science Citation Index), ISTP (Index of S&T Proceedings) and EI (Engineering Index) reached 153374 pieces in 2005, approaching 7% of the world's total, behind the USA (29.8%), the UK

(7.2%) and Japan (7.1%)[12]. About 30% of these publications resulted from China's major national S&T programs[13]. Elite research institutes and universities were major publishers, such as the Chinese Academy of Sciences, Tsinghua University, Beijing University and so on. China has become the fourth leading nation in terms of its share of the world's scientific publications.

Along with the exponential increase of scientific publications, the citation rates of Chinese publications are increasing exponentially as well (Zhou and Leydesdorff, 2006). Six disciplinary publications were placed in the world top 10 in terms of the citation rate of papers during the period of 1996-2005, namely material science, chemistry, mathematics, synthesis, engineering technology and physics. According to the SCI database, China ranked world 13th in terms of citation rate between 1996 and 2005 which was advanced as compared to world 19th between 1992 and 2001[14]. The growth of publications and of citation rate indicates that supporting infrastructure is efficient to facilitate the creation of new knowledge.

2) **Patentability**

In terms of patentability, domestic patenters have increasingly expanded their patenting activities in the State Intellectual Property Office (SIPO) of China. The annual average growth of filed patent applications attained over 20% between 2000 and 2007. The numbers of filed patent applications and grants in 2007, namely 586,734 pieces and 301,632 pieces, were over 4 and 3 times respectively as compared to the corresponding patentability in 2000. Firms hold the first place in patentability.

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[12] See China S&T Statistics Year Report 2006. http://www.sts.org.cn/zlhb/2007/3.1.htm#4

[13] According to National Statistics Bureau of China, NNSFC published 13610 academic papers in overseas journals, 8218 for "973 Programs", 1637 for Key Technology R&D Program and 9830 for "863 Program" in 2004.

[14] See China S&T Statistics Year Report 2006. http://www.sts.org.cn/zlhb/2007/3.1.htm#4

During the period 2001-2006, the growth of on-duty invention applications filed by domestic enterprises amounted to 43.2%. In 2006, they acquired 51.3% of all invention patents granted to domestic patenters (MOST, 2007). Some technology-based Chinese firms, like ***Huawei*** and ***Zhongxing***[15], are leading invention patenters but the majority of Chinese enterprises have few patenting activities. Universities are the second biggest domestic patentees, behind firms but ahead of research institutes. Their R&D expenditure accounted for nearly 10% of the total but they acquired over 30% of all invention patents granted by SIPO in 2005[16]. Nevertheless, foreign patentees still dominate invention patent grants and domestic patenters take an overwhelming advantage in utility model and design patenting. The less-R&D-intensive patentability may have meaning in the marketplace, but they do not represent significant innovations (Liu and White, 2001).

With respect to overseas patentability, China displays a remarkable growth although its world position is moderate. Its patent applications to the European Patent Office (EPO) increased from 743 units in 2003 to 1403 units in 2005 at the aggregate level. About 27% of these applications were foreign co-invested. The granted patents in triadic patent families[17] to China attained 433 units in 2005 compared to 177 units in 2003, which lagged far behind 16368 USA, 15239 Japan and 6266 Germany. China occupies rank 1 place among all non-OECD countries but only rank 12 among 39 sampled countries by OECD (OECD, 2007).

[15] In 2006, three domestic enterprises were in the top 10 firms in terms of invention patents applications filed in China and the rest were foreign invested firms. Huawei and Zhongxing, two domestic telecommunication equipment manufacturers, took the first and the second top places respectively (MOST, 2007).

[16] The percentage was calculated by the author on the basis of the data which were collected from China S&T Statistics Data Book 2006.

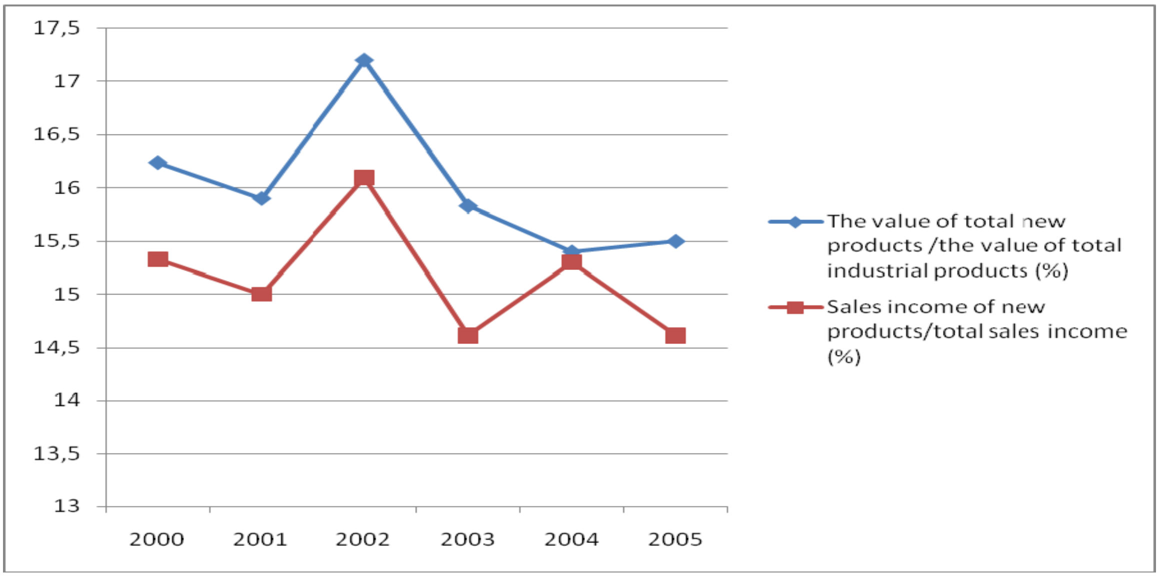
[17] Patents applied for at the European Patent Office (EPO), the Japan Patent Office (JPO) and granted to the US Patent & Trademark Office (USPTO), estimations for priority year 2005. The priority date corresponds to the first international request for protection.

The slow increase of invention patents mismatches the fast growing scientific publications. The patentability ranking of China is much lower than its scientific publications ranking. It shows that Chinese enterprises have a weak absorptive capability from open science on the one hand, and on the other hand universities and research institutes may not generate much market-oriented knowledge to meet industrial needs.

3) **New products**

Since large medium-sized enterprises (LMEs) are the major domestic patenters, we use LME's new products to assess the innovation capability of Chinese firms. New products reflect the capabilities of LMEs in transforming new knowledge into visible new goods. In contrast with the rising patentability of firms, new products do not follow the increasing trend (see Figure 1). The value of total new products as to the value of total industrial products attained the peak of 17.5% in 2002 but soon dropped to 15.5% in 2005. The ratio of new product sales to total sales was even lower, standing only at 14.61% in 2005. One reason may be a result of LMEs' insufficient capability to transform their rising patents into commodities, while the other reason may be linked to LMEs' less knowledge-intensive patents which add little value to new products.

Figure 1: The evolution of LME's new products in terms of value and sales income



Source: China Science & Technology Statistics.

http://www.sts.org.cn/KJNEW/maintitle/MainMod.asp?Mainq=8&Subq=1;

http://www.sts.org.cn/KJNEW/maintitle/MainMod.asp?Mainq=8&Subq=2

4. Conclusion

This paper discusses what kind of national innovation system (NIS) is built up in China and whether the NIS is helpful for China to catch up. We find that Chinese NIS is composed of two complementary systems, namely FDI-based innovation system and indigenous innovation system. Both systems are found to have a positive influence on attaining China's catching-up objective but indigenous innovation system seems not as influential as FDI-based innovation system for the moment. A large bulk of FDI has flowed into China and the acquired foreign technology presents varieties. The growth of foreign patents and the coming of more foreign R&D centers in China promote the total growth of patentability. FDI has upgraded China's export structure, contributing to the progress of high-tech trade. But heavy dependency on foreign technology pushes domestic firms away from acquiring key upstream technologies. Without core technological know-how, domestic firms cannot become competitive players in those industries which are traditionally dominated by advanced countries.

Indigenous innovation system has helped China make great progress in world scientific publications and patentability but the presentation of new products grows very slowly to the market. All these facts indicate that indigenous innovation system facilitates knowledge generation but is not conclusively influential to promote knowledge commercialization and diffusion. This is related to the weak capability of domestic firms to absorb research outputs arising from open science on the one hand, and on the other hand it is linked to the mismatching of knowledge output with the market need. A further reform of the Chinese NIS is needed to strengthen the absorption and innovation capability of domestic firms and to strengthen university-enterprise-research institute interactions.

Our future study will be placed on whether foreign patentability has a spillover effect on domestic patentability and how recent national policies (e.g. China's national medium and long-term S&T development plan (2006-2020), government procurement regulations and national IPR strategic outlines) impact on the innovation capability of China.

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