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The innovation systems of Taiwan and China: a comparative analysis

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Abstract

This paper presents an analytical framework to compare two distinguishing innovation systems. For recognizing the structural characteristics of innovation systems, six major functions of generic types of institutions involved in the systems are examined: policy formulation, performing R&D, financing R&D, promotion of human resource development, technology bridging, and promotion of technological entrepreneurship. Not only does it describe the role and performance of particular institutions, but this framework also explores four major interactions among these institutions for illustrating the dynamics and efficiency of innovation systems, that is, R&D collaboration, informal interaction, technology diffusion, and personnel mobility.

The framework is applied to compare the innovation systems of Taiwan and China, revealing that they both have unique characteristics, while also sharing numerous complementary features. In addition, the two economies have the linguistic, cultural, racial and historical similarities, plus their geographical proximity. Consequently, these phenomena suggest the possibility of future cooperation between the two innovation systems, and then this paper proposes possible approaches to achieving cooperation for the two sides.

Keywords: Innovation system; Taiwan; China; Institution; Research and development; Science and technology; Cooperation

1. Introduction

The Chinese Civil War resulted in the political separation of Taiwan and China in 1949. Taiwan followed the western model, adopted capitalism and implemented a free market economy, while China followed the Soviet model, adopted communism and implemented a planned, centralized economy. Similar to the situations of South and North Korea, and of West and East Germany before unification, such differences in economic and political systems have led to big differences in the national innovation systems (NISs) and their performances (Chung, 2001). Taiwan's economy clearly surpassed that of China from the 1950s through the 1980s. However, the implementation of economic reforms since the late 1970s has seen China become a rapidly developing economy enjoying a high economic growth rate, e.g. 7.1% in 1999; 8.0% in 2000 (National Bureau of Statistics, 2001). In contrast, Taiwan's economic performance has been deteriorating recently. Meanwhile, the Taiwan's government allowed its citizens to travel to mainland China to visit relatives in 1987, opening up interaction between the two sides. Besides visiting relatives and traveling, many of Taiwan's companies used the newly opened links to invest in mainland China, forcing policymakers on both sides to accelerate the schedule of exchange-related policies. According to the statistics of Taiwan's Ministry of Economic Affairs (MOEA), the total number of Taiwan's companies investing in mainland China as of 2001 was 51,258, with a declared total investment of US$55.47 billion (Industrial Development and Investment Center, 2002). Taiwan is China's fourth largest source of foreign investment, trailing only Hong Kong, the US, and Japan. However, since many of Taiwan's companies invest in mainland China via subsidiary companies registered in third countries such as the Virgin Islands, HK, Singapore, and so on, the real scale of Taiwan's investment in mainland China is significantly higher than the official statistics.

The main result of the large and increasingly business oriented interaction between Taiwan and China is

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increased economic growth for both sides. As economic activity becomes more knowledge-intensive, economic growth becomes increasingly dependent on the accumulation of knowledge, which itself mainly results from innovations. Therefore, given their common language, culture, race and history, plus their geographical proximity, Taiwan and China have been and will continue to influence and even cooperate with each other in science and technology (S&T) activities. For this reason, this study attempts to examine the similarities and differences in the innovation systems of Taiwan and China. Specifically, this study aims to compare their advantages and disadvantages and clarify whether benefits could be accrued from cooperation between the two innovation systems.

To monitor the performance of NISs, Taiwan and China imitate the developed countries by publishing numerous studies discussing their NISs as well as issuing relevant S&T indicators, and thus these studies and statistics are used here as a data source. Furthermore, we conducted a series of intensive interviews with relevant experts and officials in Taiwan and China to verify the data.

2. Analytical framework

Freeman (1987) proposed the concept of NISs in his study of Japan's technology development, defining it as the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies. Lundvall (1992), Nelson (1993), Patel and Pavitt (1994) and Metcalfe (1995) developed essentially similar definitions thereafter. Although no universally accepted definition exists, NIS is generally recognized as comprising the complex functions and interactions among various actors and institutions (Smith, 1996; Kumaresan and Miyazaki, 1999; OECD, 1999). The performance of NISs largely depends on how these actors, which include government, enterprises, universities, public and private research institutes, bridging institutes, and other contributing institutions, function and interact with each other to develop and apply innovative knowledge. Therefore, the functions and the interactions of institutions involved in NISs are the main contexts of studying NISs, and thus this study examines them as the two analytical and comparative dimensions.

Regarding the institutions involved in NISs and their functions, Capron et al. (2000) suggest that four groups of actors are involved in NISs, that is, the administrative organizations that formulate and co-ordinate the S&T policy and that control public-financial organizations, the private research sector, the higher education institutions, and the bridging institutions that act as intermediaries among the other actors. Senker (1996) and Shyu (1999) respectively propose similar functions. Meanwhile, OECD (1999) suggests that an NIS requires institutions with six different functions: technology and innovation policy formulation, performing research and development (R&D), financing R&D, promotion of human resource development, technology diffusion, and promotion of technological entrepreneurship. This study is based mainly on the OECD idea, but since the technology diffusion involves several actors, we will discuss it in the section of interactions. However, both in innovation theory and in policy, a shift occurred from a focus on knowledge and technology creation towards diffusion and absorption. Bridging institutions emerged to facilitate the interactive aspects of the innovation process and to resolve mismatches among different types of actors in the innovation system. Therefore, we add technology bridging as one of the institution's functions within NISs. In addition to policy formulation, performing R&D, financing R&D, promotion of human resource development, and promotion of technological entrepreneurship, there are six institution functions of the innovation system in our analytical framework.

Once innovation is considered to be an integrated process that needs to be considered at the system level, the interactions among various actors become as important as the functions of each institution. Furthermore, the performance of NISs as a whole becomes increasingly reliant upon the effectiveness of these actors in gathering and utilizing innovative knowledge. OECD (1997) discusses four main interactions within NISs, namely joint industry activities, public/private interactions, technology diffusion, and personnel mobility. Collaborations are forms of strategic alliance between firms and other organizations, which are developed for assisting partners in collaborating to complete the innovation process by completing resources and reducing risks (Liyanage, 1995). Second, all actors in a national economy are involved in diffusion processes (Hubner, 1996). Technology diffusion is especially important for the traditional manufacturing sector and service industries, which may not be involved in R&D or innovation themselves. Effective technology diffusion can still serve as a reward for those who invest in and implement innovation. In addition, most studies of technology diffusion demonstrate that the skills and networking capabilities of personnel are the key to implementing and adapting new technology. Personnel movement is an important channel for transferring the tacit knowledge that they carry. Finally, the informal linkages and contacts among institutions through which knowledge and information are transferred are also important. OECD (1997) finds that some countries innovate more effectively through informal relations than formal ones. This study employs OECD's four types of interactions, but merges the two concepts of joint industry activities and public/private interactions into R&D collaboration, retains the next two interactions, technology diffusion and personnel mobility, and adds a new interaction, namely, informal interaction.

The innovation processes are implemented by the functions and interactions created by actors and institutions within the innovation system. Fig. 1 summarizes the above discussions regarding the main institutions and interactions within NISs and proposes our analytical framework.

3. Comparative analysis

According to the research results of OECD (1999), two sources of NIS diversity exist. The first source is country size and level of development. In 2000, Taiwan's population was 22.28 million and its per capita GDP was US$13,985 (Directorate General of Budget Accounting and Statistics, 2001), which compared to China's population of 1265.83 million and per capita GDP of just US$885 (National Bureau of Statistics, 2001). Compared to China, Taiwan is thus a small and high-income economy, while China is a large and catching-up economy. These differences certainly influence the diversity of innovation systems in these two economies. The second source relates to the respective roles of the main actors in the innovation system, and the forms, quality, and intensity of their interactions. The following section compares the functions and interactions of the innovation systems of Taiwan and China.

3.1. Institution functions

3.1.1. Technology and innovation policy formulation

Technology and innovation policy formulation in Taiwan is based on the achievement of consensus at several national levels of conferences or meetings, as detailed below. At the highest level, National Conferences on Science and Technology have been held every four or five years since 1978. These conferences bring together relevant experts from industries, universities, government, and foreign S&T advisors, and generate long-term plans that articulate the basic direction of national S&T policies. The second level comprises the Science and Technology Advisory Board Meeting held every year by the Executive Yuan, which produces policy recommendations on major issues involving national S&T development plans and cross-department R&D practices. At the third and final level, the Executive Yuan calls the relevant ministers and experts to hold the Executive Yuan Science and Technology Meeting once every two months to execute the functions of S&T policy coordination, supervision, and assessment. In addition, the execution of S&T plans in Taiwan follows the principles of integrated planning and decentralized implementation (National Science Council, 2000b). Specifically, the National Science Council (NSC) is responsible for the overall execution of S&T plans, while other relevant government agencies have established their own advisory offices for implementing the R&D practices of the agency.

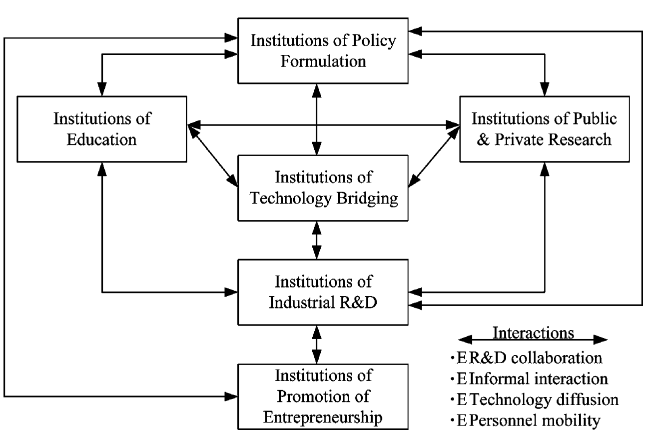

Fig. 1. Main institutions and interactions involved in the national innovation system.

In contrast, the government in China centrally develops a series of S&T plans, and then uses these plans as a basis to allocate resources and assign R&D work to relevant institutes. The national S&T plans, generally proposed by State Science and Technology Commission, State Planning Commission, and State Economic and Trade Commission, are the fundamental policy tools for organizing and developing S&T activities in China. Each national S&T plan outlines the main direction of S&T development during a particular period. The performers of S&T activities fulfill the tasks assigned to them from above and depend upon official allocations for necessary resources. These performers of S&T activities do not need to suffer the full losses resulting from failure in innovation activities but nor do they benefit fully from success.

3.1.2. Performing R&D

The major performers of R&D in Taiwan are enterprises, research institutes, and universities, which accounted for 63.3, 25.0, and 11.7% of national R&D spending in 1999, respectively (National Science Council, 2000a). Enterprises are the primary performers of R&D in Taiwan, but Taiwan's industry is dominant by small- and medium-enterprises (SMEs), which generally lack resources to devote to R&D. Therefore, Taiwan's government has established a series of financial subsidy policies for enterprises to share their R&D risk. The major research institutes in Taiwan include Academia Sinica and Industrial Technology Research Institute (ITRI). The two main sources of financing for Taiwan's research institutes derive from NSC or MOEA support and from other public or private organizations which commission them to implement R&D. NSC mainly sponsors research projects by institutes devoted to academic research, e.g. Academia Sinica and the universities, while research at the institutes that focus on industrial technology development, such as ITRI, is mainly supported by MOEA. Universities are the smallest spender among the three major R&D performers in Taiwan, however they exercise approximately one-half of the national basic research expenditure that shares little part of national total R&D expenditure. Most of the executors of research in universities are professors who serve simultaneously as teachers, and who conduct research activities in departmental labs or in research centers established in universities. The research projects implemented in universities are mainly supported by NSC and commissioned by public or private organizations.

Research institutes and enterprises are the two major R&D performers in China. In 1999, the R&D expenditure of research institutes was 43.4% of national R&D spending, while that of enterprises was 41.6% (National Bureau of Statistics, 2000). Although the two ratios are similar, there is a tendency that the former has been decreasing while the latter increasing. China's enterprises have invested in importing technology more than in developing their own R&D capabilities, mainly because of the lack of effective incentives for primary R&D actors to enhance their innovation capacity proactively. Before China's reforms, research institutes were the primary performers of R&D. However, since the reforms, following the principle of enterprises being as the principal actor of R&D performer, China's research institutes have been forced to industrialize and corporatize lines, marking a major reform of China's innovation system (Liu, 2001). Universities, the other R&D performer in China, consumed only 10.6% of the national R&D spending in 1999. As in Taiwan, China's universities are the primary performers of basic research, and represent half of the national basic research expenditure and contain over one half of the researchers engaged in basic research nationally. Encouraging universities to spin off technology-based enterprises, one important reform policy in China's education system as well as innovation system, is an effective measure for urging universities to interact with industries and promote technology diffusion.

3.1.3. Financing R&D

Taiwan's R&D expenditure has been rising steadily. According to the statistics of Taiwan's National Science Council (2000a), its national R&D expenditure increased from NTD 125 billion (1.78% of GDP) in 1995 to NTD 190.5 billion (2.05% of GDP) in 1999. In term of R&D expenditure as a percentage of GDP, Taiwan is now approaching the level of those countries that are most active in R&D investment. R&D funding comes from four sources, namely, government, industry, private institutes, and overseas sources. The share of these actors of national R&D expenditures in 1999 was 32.2, 65.6, 2.1, and 0.1%, respectively. Taiwan's industry is the most important actor in its innovation system, not only in R&D implementation, but also in R&D financing. Meanwhile, the government is the second largest source of R&D funding in Taiwan, and provides most of the funding for R&D activities in universities and research institutes.

China's R&D expenditure almost doubled from RMB 34.8 billion in 1995 to RMB 67.8 billion in 1999 (National Bureau of Statistics, 2000), demonstrating that China has enormously increased its R&D intensity recently. However, as a percentage of GDP, China's R&D expenditure was just 0.60% in 1995 and 0.83% in 1999, showing that China continues to suffer from a shortage of R&D investment. China's S&T expenditure is mainly financed by three sources, that is, the government, industry and banks, whose ratios of national S&T expenditures in 1999 were 32.4, 34.9, and 8.8%, respectively. China's industry and government are the two major sources of S&T funding in its innovation system. However, the industry provides most of their funding for their own R&D activities, while the government is the main source of S&T funding for both research institutes and universities. Meanwhile, bank loans for S&T activities, since the "Notice of Bank's Loans for Technology Development" issued by State Council and the People's Bank of China in 1985, are used to supplement the shortage of national S&T investment, and have successfully supported over 10,000 items of new technology development.

3.1.4. Promotion of human resource development

Taiwan had 91.7 researchers per 10,000 labors in 1999 (National Science Council, 2000a), a ratio similar to that in the US, and demonstrating that Taiwan has plentiful human resources for S&T activities. The distribution of research personnel is 58.4% in industry, 21.6% in research institutes, and 20.0% in universities. Several specific organizations are responsible for different levels of the education and training of S&T personnel in Taiwan: for example, the Ministry of Education (MOE) is responsible for educating the S&T personnel, the NSC is in charge of training academic and research institute researchers, and the Council of Labor Affairs is responsible for training researchers working in private sectors. In addition, the selection of qualified personnel to study abroad with full government support, overseen by the MOE, is an important policy for fostering high R&D personnel and acquiring innovative technology from overseas. The selection standard is based on national development needs, and the personnel accepted for the program must return Taiwan to work for a certain period.

In contrast, the number of researchers per 10,000 labors in China was just 22 in 1999 (National Bureau of Statistics, 2000), indicating a shortage. Meanwhile, the ratio of distribution of research personnel among industry, research institutes, and universities is 49.9, 25.5, and 24.6%. Compared with the reforms achieved in other areas, China's education system has made slow progress (Hu, 2000). The education system and the education method restrict the nurture of students' innovative capabilities, and thus China's education system is unable to generate an adequate quality and quantity of S&T personnel. Hu (2000) thinks that the main reforms of China's education system should be to foster innovation by focusing on basic education, aiming to achieve a fundamental change in knowledge components and learning orientation.

3.1.5. Technology bridging

Taiwan is a small and open economy, and consequently should focus on a limited range of innovative technologies. Additionally, Taiwan's industry is dominated by SMEs, and the average R&D capacity of each company is low. Therefore, bridging institutions should act as intermediaries between technology suppliers and demanders, select specific technologies suitable for development in Taiwan and transfer innovative technologies to enterprises within Taiwan's innovation system. For example, ITRI, which is not only an important R&D performer in Taiwan but also an important bridging institute, followed government policy in developing the semiconductor industry and related technology two decades ago, acting as the key intermediary between foreign and local semiconductor companies, and as the training center that fostered the technical personnel needed by industry. In addition, Taiwan would select some specific innovative technologies as the main development targets, and then establish relevant research centers under the direction of NSC, to concentrate and allocate national R&D resources. For instance, Synchrotron Radiation Research Center, National Nano Device Laboratories, and so on. In summary, the technology bridging institutions in Taiwan are characterized by emphasizing direct guidance and support for specific fields of innovative technology based on national innovation direction in order to concentrate and allocate relevant R&D resources.

During the economic reform process, China's government employed bridging institutes to transfer the relevant functions of the innovation system formerly implemented by public research institutes to the principal performers of innovation, namely enterprises. China's bridging institutes serve as intermediaries among actors in the innovation system, as well as providing the innovation-related infrastructure for these actors. China's technology bridging system has progressed rapidly recently, but still lags that of developed countries and is unable to satisfy the needs of the other actors in its NIS. Liu (2001) perceives an ambiguity within China's technology bridging system. Specifically, China's technology bridging system has followed the American model and emphasizes indirect support as the basis for the construction of an innovation-related environment. However, current national conditions make it very difficult for China to achieve a transparent financial and legislative environment like that of the US. On the other hand, compared to Taiwan or Japan, China lacks the function of direct support for S&T activities within its technology bridging system.

3.1.6. Promotion of technological entrepreneurship

Taiwan used to rely on its cheap and high quality human resources to gain a competitive advantage in manufacturing, but has recently lost this traditional advantage as neighbors such as China have adopted a similar competitive strategy. However, during the previous economic boom period, Taiwan has established a mature venture capital and incubation environment, as well as its people having high entrepreneurial capacity. From 1983 until 2000, a total of 184 venture capital firms have been established in Taiwan, and these firms have raised total funds of over NTD 128 billion, invested a total of NTD 125 billion in high-tech enterprises, and accumulated over NTD one trillion in capital (Venture Economics, 2000). Venture capital has been an important source of financing for Taiwan's start-ups, particularly in high-tech industries. Furthermore, Taiwan's entrepreneurial incubation institutions have successfully supported and incubated numerous high-tech companies. For example, the Hsinchu Science-based Industrial Park (HSIP), established in 1980, has successfully assisted Taiwan's information industry to become the third largest globally in terms of output, and has helped the semiconductor industry to reach fourth place (National Science Council, 2000b).

Numerous entrepreneurial opportunities currently exist in China owing to its huge internal demand, cheap supply of productive resources, and increasingly reformist economic policy. However, new companies seeking to establish themselves in China still face numerous legal limitations. In addition, China lacks the mature entrepreneurial infrastructure required to incubate start-ups effectively. For example, people invest primarily in banks because of the lack of acceptable investment channels, and venture capital is unable to function effectively because of the absence of mechanisms for withdrawing capital, the lack of a restrictive regulatory environment system, and so on. All these conditions lead to the situation where China is unable to supply sufficient start-ups, or entrepreneurs, to satisfy its entrepreneurial opportunities. In addition, the employment system in China hampers the development of entrepreneurs. Liu (2001) finds that the reasons for the lack of enthusiasm for pursuing entrepreneurship in China are as follows:

first, managers of state-owned enterprises are selected by the government and run the companies according to government directions; second, numerous officials also serve simultaneously as managers in enterprises, hence there would be much conflict between their two different roles; third, the realizable benefits from start-up cannot satisfy entrepreneurs; fourth, managers serve for fixed terms, and so lack the incentives and motives to engage in innovation.

3.2. Interactions of institutions

3.2.1. R&D collaboration

Taiwan's industry is dominated by SMEs, which have problems in competing with foreign companies alone (Hsu and Chang, 2000). Additionally, the distribution of Taiwan's total 17,556 PhD researchers in 1999 heavily favored academia, with 11,517 researchers working at universities (National Science Council, 2000a). Furthermore, research institutes such as ITRI act as the key hub for allocating and transferring R&D-related resources within Taiwan's innovation system. Therefore, to complement the research resources of each actor, Taiwan's government promotes and encourages R&D collaboration by offering financial support and tax deductions. The idea of joint university–industry research is relatively new for the reason that universities have only been allowed to cooperate with industry since the early 1980s (Luo, 2001). However, from the 1980s onward, Taiwan's government has worked at promoting and developing relationships among enterprises, research institutes, and universities as a way of coping with pressure for innovation. R&D collaboration has become an important innovation policy for complementing the research resources of each institution in Taiwan, in which research institutes are engaged in both critical and shared technology development, universities dominate basic research, and industries commercialize the results of R&D collaboration.

The real situation of R&D collaboration in China can generally be revealed through statistical analysis of joint Chinese S&T papers. The number of joint papers has been increasing steadily, from 13% of total papers in 1992 to 18% in 1997 (China S&T Information Institute, 1997). Universities are the main collaborative objects for enterprises, research institutes, and other universities, for the reason that the majority of research resources gather at universities, especially advanced human resources. Though the R&D collaboration is more and more active in China, Kuo (2001) finds that it just creates limited contribution to the efficiency of China's innovation system. He analyzed 342 papers that addressed R&D collaboration during 1989~1996, and summarized that three types of obstacles restrict the effect of R&D collaboration in China. First, sectionalism seriously harms the effect of R&D collaboration, and most organizations focus exclusively on the function and mission assigned by the central government. Second, lack of integrated management systems and a healthy legislation environment also creates difficulties for effective utility of the collaboration achievements. Third, no suitable communication channels and intermediaries exist, meaning that research institutes and universities are unaware of the technical needs of industry, while industry is unaware of what research institutes and universities can offer them.

3.2.2. Informal interaction

In Taiwan, a large proportion of the personnel in high-tech companies graduated from a small group of universities, including Chiao Tung University, Tsing Hua University, and so on, or have been employed in certain research institutes, such as ITRI. The relatively small pool of talent sources means that personnel in the high-tech industry tend to utilize their relationship network for assistance when they encounter problems. Since Taiwan's people pay considerable attention to maintaining their relationship network and treat it as the most important component of their social capital, the informal personnel relationship network significantly increases the efficiency of the diffusion of knowledge and information within the high-tech industry. In addition, Taiwan's enterprises, particularly SMEs, regularly organize partnerships with suppliers, and even local competitors, when facing international competition. For example, in the semiconductor industry each company focuses on a certain part of the production process, such as design, mask production, assembly, testing, and so on, and then cooperate with each other, even to the extent of supporting competitors, to meet customer demand. Since the industrial value chain is separated into very tiny segments, each company concentrates on its specialized field and shares its know-how with partner firms, and even competitors, to obtain the benefit of economies of scale. The fact that Taiwan's industry can operate like this is based mainly on the informal interaction of the personnel relationship network.

In contrast, the flow of knowledge and information in China's innovation system is only minimally influenced by informal relationships. The reasons for this phenomenon are as follows. First, China's patent system follows the principles of issuing the patent to the first applicant and publicizing the patent before examining it, which discourages the inventors of innovative technologies to share their ideas before commercializing them. Second, China's employment system is generally government managed, and thus many employees work in the same organization for their entire lives, making it difficult to develop an expansive relationship network. Third, the idea that knowledge should not be transferred to outsiders is very deep-rooted in China, and people generally fear that such transfers will benefit competitors.

3.2.3. Technology diffusion

In Taiwan, the main model of technology diffusion is research institutes and universities transferring their R& D achievements, which are embedded in techniques, personnel, equipment, and information, to enterprises by three mechanisms, i.e. technology transfer, contract services, and spin-off companies. The mechanism of technology transfer can be further subdivided into several varieties, namely, technology announcements, technical services, seminars, speeches, publications, and so on. Contract services involve research institutes or universities signing contracts with enterprises either for collaboration on or commissioning of research projects, or to provide services such as training, consulting, guidance, and so on. Finally, to improve the technological capability of the industry or establish new industries, Taiwan's government takes measures to encourage research institutes to take on a seeding role and spin off new companies in developing industries. For instance, the Taiwan Semiconductor Manufacturing Company, the world's largest dedicated independent semiconductor foundry in terms of output, spun off from ITRI in 1987 and it successfully acted as the seed firm and diffuser of advanced technology in Taiwan's semiconductor industry.

During the planned economy period, R&D in China was conducted by research institutes and universities, while manufacturing was conducted by enterprises, and thus there was little involvement of enterprise in R&D. Therefore, in China's current innovation system, technology diffusion is generally from research institutes and universities to enterprises, and technology transfer among enterprises is rare. Three main mechanisms of technology diffusion exist in China. The first mechanism is the technology transfer contracts, which Kuo (2001) identified as the most popular method of technology diffusion in China. The second mechanism is technology markets. Technology markets are one important measure of the reform of the innovation system in China, and numerous technology markets have been established around the nation. These technology markets contain certain mechanisms to allow the supplier and demanders to reach a technology transfer deal, including consulting, technology transfer, training, technical services, and so on. The third mechanism is spin-offs. A total of 1611 enterprises were spun off from universities and 4334 from research institutes in 1997 (Touch High-tech Industrialization Development Center, 1999), illustrating that the innovative technology embedded in spin-off enterprises in China's innovation system represents a large-scale transfer from universities and institutes to industries.

3.2.4. Personnel mobility

In Taiwan, a large proportion of the personnel of research institutes, especially ITRI, work in institutes for a period and then move over to enterprises, which efficiently advances the effect of transfer and interaction of the tacit knowledge they carry with them in the innovation system. Since 1973, over 12,000 personnel have moved from ITRI to work in various industries, including 5000 personnel working in HSIP (National Science Council, 2000b). ITRI may thus be said to be the largest incubator of high-tech personnel in Taiwan. In addition, numerous Taiwanese people have worked aboard and then returned to work in Taiwan, bringing back a wealth of knowledge and technologies, and thus benefiting Taiwan's innovation system.

In contrast, the movement of personnel in China is not active, owing to the planned employment system and restrictive social culture. Personal interactions in China, whether formal or informal, have contributed little to efficiency of interaction within the innovation system. On the other hand, 320,000 Chinese studied aboard between 1978 and 1998, of whom over 110,000 returned to China (Touch High-tech Industrialization Development Center, 1999). While, a large portion of these returnees are graduates without work experience, unlike in Taiwan, these overseas students still act as an important channel for the import of foreign knowledge and technology into China's innovation system.

4. Discussion and prospects

Compared to China, Taiwan is a small and high-income economy, while China is a large and catching-up economy. OECD (1999) has studied the innovation systems of its member countries and finds that small and high-income countries generally have to internationalize more rapidly and concentrate on a narrower range of fields to reap these benefits. The small and high-income countries will profit most from free flows of technology across borders and their innovation systems are often focused on capturing the benefits of inflows of technology. However, they face proportionally higher costs for maintaining institutions that cover a boarder range of subjects than can be taken up by their industries. The characteristics of Taiwan's innovation system as described in the preceding section closely reflect the findings of the OECD study. Taiwan generally concentrates on specific industries, and rapidly changes its fields of focus. For instance, the industries that Taiwan has been competitive in have developed from umbrellas, shoes, and so on during the early period of development, to computers, semiconductors, and so on more recently. In addition, Taiwan's small domestic market means that its enterprises have to internationalize rapidly and to encounter strong competition from overseas. The advantages of Taiwan's innovation system essentially derive from the efficient interactions among institutions, particularly the informal personnel relationships. However, Taiwan is extremely dependent on inflows of foreign technologies, and thus is compelled to pursue the process innovation that generates lower value-added benefit than the product innovation or market can do. Enterprises in Taiwan are far from the end user market, and so are easily influenced by global economic fluctuations. Consequently, Taiwan often suffers from the lack of R& D of original, pioneering and self-contained technologies.

Regarding large and catching-up economies, OECD (1999) notes that they offer large markets with poor customers and may benefit from late development. Their R&D intensity is relatively low, and their innovative activity also tends to be quite low compared to high-income countries. The economic structure of these countries is often more geared towards low- and medium-technology industries. However, as the transfer and adoption of technology plays a very large role, their system of innovation has a strong focus on technology transfer, adoption and diffusion. Although the expenditure of S&T in China has been increasing, its still remains below 1% of GDP, and the ratio of R&D personnel to the total labor force also remains low. The low R&D intensity mainly results from the low R&D investment in both the public and private sectors. The public sector in China tends to be the major financer of R&D, but distributes most of its resources to S&T activities of national importance, for example, defence, public health, national security, etc. Meanwhile, the private sector has just been undergoing a reform of its role and function in NISs, and hence its R&D capacity remains immature. Consequently, total R&D is quite low in China, and China continues to be mainly engaged in low- and medium-technology industries. Regarding the source of innovative technology, China generally imports technology rather than developing this technology itself, and thus must concentrate on how to effectively transfer and diffuse the imported technology to the sectors that require it. China's innovation system is thus quite similar to the description in OECD's study of a large, rapidly catching-up country.

Facing rising labor costs, Taiwan's enterprises are being forced to move production overseas. Besides looking for suitable places to set up factories, Taiwan must also adjust its focus from the back end (process) to the front end (product, market). These phenomena impact the innovation system of Taiwan. Economic and organizational reforms of China over the last two decades, including a large number of S&T policy initiatives, have had a clear impact on the structure, dynamics and performance of its innovation system (Liu and White, 2001), and in particular enterprises have been forced to enhance their R&D capability because of the strong competition from overseas. Given the linguistic, cultural, racial and historical similarities between Taiwan and China, plus their geographical proximity and the increased opening up of public and private sector exchanges between the two sides, Taiwan's enterprises should make China their top priority for investment and the establishment of factories. Meanwhile, China's enterprises should enthusiastically absorb and learn from the technologies and experience of Taiwan. The concept of a "national" innovation system is becoming less meaningful as cross-border linkages and information flows increase along with the internationalization of corporate R&D (Patel and Pavitt, 1998). To pursue higher economic growth, both Taiwan and China could benefit from increasing the interaction among the actors and resources of their respective innovation systems.

Table 1 lists the distinguishing characteristics resulting from country size and level of development, and also compares the functions and interactions of Taiwan's and China's innovation systems. We find that Taiwan and China have complementary resources and capabilities, and would benefit from increasing exchange and even cooperation in S&T activities. We suggest the following as possible co-operative approaches.

1. The large China's consumer market could satisfy Taiwan's need for internationalization, arising from the small size of Taiwan's own internal market. By establishing a regional economic alliance, Taiwan's enterprises could directly contact the end users and thus increase the incentives for them to engage in developing product and market innovations, instead of pursuing process innovations owing to the present "original equipment manufacturer (OEM)" business model. Via the Chinese economic alliance, China could cooperate with Taiwan to develop Chinese-related innovative technologies themselves rather than relying on imported technologies.
2. China's economy is still going through the catch-up stage, and thus generally needs to import technology and may benefit from late development. However, Taiwan has successfully established several high-tech industries and developed the relevant technology, with examples of these industries including semiconductors, computers, precision instruments, and so on. Taiwan could thus serve as an example and import sources to help China develop these industries and technologies. Meanwhile, Taiwan could benefit from cooperation with China to help these industries increase the economic scale of their manufacturing capacity, and also in R&D activities.
3. China has plenty of entrepreneurial opportunities due to its large internal market and recent reforms, but entrepreneurial capacity is still lacking, and the entrepreneurial infrastructure remains immature. As a result, China does not have enough entrepreneurs to meet the market demand. Meanwhile, Taiwan's previous economic boom has left it with a mature incubation system and numerous entrepreneurs. However, Taiwan is facing an economic recession, and so its

Table 1
Comparison of the innovation systems of Taiwan and China

	Taiwan	China
Institution functions		
Policy formulation	Consensus	Very centralized and planned
	Integrated planning and decentralized implementation	Top-to-down assigned implementation
Performing R&D	Enterprises as the primary performer, industry dominant by SMEs	Both enterprises and research institutes as the primary performers
	Research institutes as the role of hub	Enterprises invest in importing technology more than in developing their own R&D capabilities
	Universities as the primary performer of basic research	Research institutes follow government's policy and allocation
		Universities as the primary performer of basic research
Financing R&D	2.05% of GDP	0.83% of GDP
	Ratio of investment: government (32.2%), industry (65.6%), private institutes (2.1%), overseas (0.1%)	Ratio of investment: government (32.4%), industry (34.9%), banks (8.8%)
	Ratio of spending: industry (63.3%), research institutes (25.0%), universities (11.7%)	Ratio of spending: industry (41.6%), research institutes (43.4%), universities (10.6%)
Promotion of human resource development	91.7 researchers per 10,000 labors	22 researchers per 10,000 labors
	Ratio of distribution: industry (58.4%), research institutes (21.6%), universities (20.2%)	Ratio of distribution: industry (49.9%), research institutes (25.5%), universities (24.6%)
	Several specific organizations are responsible for different levels of S&T personnel development	The education system and the education method restrict the nurture of students' innovative capabilities
Technology bridging	Emphasizing direct guidance and support for specific fields of innovative technology	Emphasizing indirect support as the basis for the construction of an innovation-related environment
Promotion of technological entrepreneurship	Good entrepreneurship	Poor entrepreneurship
	With mature entrepreneurial infrastructure	Lacks of mature entrepreneurial infrastructure
	Fewer entrepreneurial opportunities relatively	Plenty of entrepreneurial opportunities relatively
Interactions of institutions		
R&D collaboration	Government promotes R&D collaboration by offering financial support and tax deductions	Universities are the main collaborative objects for enterprises, research institutes, and other universities
Informal interaction	Personnel relationship network developed well	Inactive relationship and partnership result from the restrictions of patent system, employment system, and social culture
	Strong and close partnership network within industry	
Technology diffusion	Research institutes as the primary diffuser	Innovative technologies diffuse from research institutes and universities to enterprises
	Mechanisms: technology transfer, contract services, and spin-offs	Mechanisms: technology transfer contract, technology markets, and spin-offs
Personnel mobility	Plenty of personnel move from research institutes to industry	Inactive personnel mobility results from planned employment system and restrictive social culture
	Returnees with work experience from abroad increasing	Returnees from abroad increasing

entrepreneurs are currently suffering from a lack of good entrepreneurial opportunities. Therefore, both China and Taiwan could benefit if they cooperated in promoting entrepreneurship in China.

4. China's capital markets are immature, making it difficult to collect sufficient R&D funds from the private sector, and thus forcing the government to play a large role in financing R&D activities. Consequently, China suffers a shortage of R&D investment. However, Taiwan has mature venture capital and capital markets, but these markets are currently suffering from reduced marginal benefit on investment compared with previously. Therefore, opening free capital flows between the two sides could allow China to utilize Taiwan's capital market to raise funds to increase its R&D investment, while Taiwan could increase its investment targets and improve its investment returns.
5. Basic research in both Taiwan and China is quite poor. Basic research is the kind of work that requires plentiful resources, and it is also time consuming and risky, and thus its achievement depends heavily on the scale and the scope of resources invested in it. If Taiwan and China could collaborate on basic research, both sides would have a good opportunity to enhance the quantity and quality of their basic research.
6. Research institutes in China have evolved from the major performers of R&D to become importers and

diffusers of innovative technologies. Taiwan's research institutes, like ITRI, generally act as key hubs within its innovation system. Therefore, research institutes on both sides could act as intermediaries between Taiwan and China for technology transfer, diffusion, and adoption, as well as enhancing collaboration and interaction among the enterprises, universities and institutes on both sides.

7. Both relationship networks and personnel mobility contributes little to the interaction efficiency of the China's innovation system. In contrast, personnel in Taiwan are highly mobile, and strong personnel relationship networks are one of Taiwan's key advantages. If both China and Taiwan could enhance the flow of personnel between the two sides, interaction efficiency in China would improve, while Taiwan would benefit as its personnel expanded their own relationship networks.

Taiwan's enterprises are currently very aggressive in promoting cooperation between Taiwan and China at both official and unofficial levels. These enterprises have urged both governments to accelerate the removal of obstacles to cooperation between the two sides. For example, Taiwan's government allowed semiconductor companies to export 8-inch wafer fabs to China in 2002. In addition, Taiwan's industrial structure is dominated by SMEs. Chung's (2001) study of the German experience of reunification suggests that SMEs can be positive and encouraging actors during the integration of national innovation systems. Therefore, whether from pull or push perspectives, there are significant incentives and advantageous conditions for both Taiwan and China to cooperate in S&T activities, and consequently this would lead to a win–win situation.

5. Concluding remarks

This study proposes an analytical framework for comparing the innovation systems of Taiwan and China. The functions of generic types of institutions involved in innovation are individually examined and compared to reveal the structure characteristics and performance of the two systems, and the interactions among these institutions are analyzed to illustrate their dynamics and efficiency. We believe that the approach developed here could be applied to the study of a single national innovation system as well as to compare innovation systems in different countries.

The comparison of the innovation systems of Taiwan and China has revealed that while each has unique structural characteristics, numerous complementary features also exist. In addition, both systems also share numerous objective conditions in common, and Taiwanese enterprises have aggressively invested in China and established production facilities there. All these phenomena suggest the possibility of future cooperation between the two sides on S&T subjects. However, Taiwan and China currently remain in a politically antagonistic situation, and the numerous ideological conflicts mean that this antagonistic political relationship is unlikely to change fundamentally in the short term. Even so, the private sectors of the innovation systems on both sides have been influencing each other and this will speed up academic and industrial cooperation. Pursuing higher economic growth will force policymakers on the two sides to accelerate the opening of the public and private sectors to increased cooperation, thus enhancing the efficiency and effectiveness of the innovation systems on both sides.

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References

Capron, H., Cincera, M., Dumont, M., 2000. The national innovation system of Belgium: the institutional profile. CESIT Discussion Papers, No 2000-01.

China S&T Information Institute, 1997. The Statistical Analysis of S&T Papers of China. China S&T Information Institute, Beijing.

Chung, S., 2001. Unification of South and North Korean innovation systems. Technovation 21, 99–107.

Directorate General of Budget Accounting and Statistics, 2001. Statistical Yearbook, Republic of China. Directorate General of Budget Accounting and Statistics, Taipei.

Freeman, C., 1987. Technology and Economic Performance: Lessons from Japan. Pinter Publishers, London.

Hsu, W.S., Chang, P.L., 2000. Innovative models of small & medium-sized enterprises—case studies of industry–university cooperative projects. (in Chinese) Journal of Technology Management 5 (1), 167–187.

Hu, Z.J., 2000. National Innovation System: A Theoretical Analysis and an International Comparison. (in Chinese) Social Science Literature Press, Beijing.

Hubner, H., 1996. Decisions on innovation and diffusion and the limits of deregulation. Technovation 16 (7), 327–339.

Industrial Development and Investment Center, 2002. The general situations of Taiwan's enterprises in Mainland China. Industrial Development and Investment Center. Available from http://www.idic.gov.tw/.

Kumaresan, N., Miyazaki, K., 1999. An integrated network approach to system of innovation—the case of robotics in Japan. Research Policy 28, 563–585.

Kuo, X.C., 2001. Collaboration for Technology Innovation: A Theoretical and Empirical Analysis of Collaboration between Universities and Enterprises. (in Chinese) Economic Management Publishers, Beijing.

Liu, X., 2001. Chinese Technology Innovation System in 21 Century. (in Chinese) Peking University Press, Beijing.

Liu, X., White, S., 2001. Comparing innovation systems: a framework and application to China's transitional context. Research Policy 30, 1091–1114.

Liyanage, S., 1995. Breeding innovation clusters through collaborative research networks. Technovation 15 (9), 553–567.

Lundvall, B.A. (Ed.), 1992. National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning. Pinter Publishers, London.

Luo, I.Y.L., 2001. The Knowledge Alliance: Tripartite Collaboration in the Information Age. National Science Council, Taipei.

Metcalfe, S., 1995. The economic foundations of technology policy: equilibrium and evolutionary perspectives. In: Stoneman, P. (Ed.), Handbook of the Economics of Innovation and Technological Change. Blackwell Publishers, Oxford (UK).

National Bureau of Statistics, 2000. China Statistical Yearbook on Science and Technology 2000. China Statistics Press, Beijing.

National Bureau of Statistics, 2001. China Statistical Yearbook 2001. China Statistics Press, Beijing.

National Science Council, 2000a. Indicators of Science and Technology, Republic of China, 2000. National Science Council, Taipei.

National Science Council, 2000b. Yearbook of Science and Technology, Republic of China, 2000. National Science Council, Taipei.

Nelson, R.R. (Ed.), 1993. National Innovation System: A Comparative Analysis. Oxford University Press, Oxford.

OECD, 1997. National Innovation Systems. OECD, Paris.

OECD, 1999. Managing National Innovation Systems. OECD, Paris.

Patel, P., Pavitt, K., 1998. National system of innovation under strain: the internationalization of corporate R&D. Electronic working paper series, Paper No. 22. Available from http://www.sussex.ac.uk/spru/.

Patel, P., Pavitt, K., 1994. National innovation system: why they are important and how they might be measured and compared. Economics of Innovation and New Technology 3, 77–95.

Senker, J., 1996. National systems of innovation, organizational learning and industrial biotechnology. Technovation 16 (5), 219–229.

Shyu, J.Z., 1999. National Innovation System and Competitiveness. (in Chinese) Linking Publishers, Taipei.

Smith, K., 1996. The Norwegian National Innovation System: A Pilot Study of Knowledge Creation. STEP Report, Oslo.

Touch High-tech Industrialization Development Center, 1999. China New & High-tech Industrialization Development Report. Science Press, Beijing.

Venture Economics, 2000. Taiwan Venture Capital Association Yearbook 2000. Thomson Financial Press, Newark.

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