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Knowledge diffusion, market segmentation and technological catch-up: The case of the telecommunication industry in China☆

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Abstract

This paper examines the growth of technological capability in the telecommunication industry in China. We apply a modified version of Lee and Lim's [Lee, K., Lim, C., 2001. The technological regimes, catch-up and leapfrogging: findings from the Korean industries. Research Policy, vol. 30.] model of technological learning and catching-up. Using the three cases of the Shanghai Bell, the CIT-led R&D consortium, and indigenous companies such as Huawei, we analyze how the catching-up in the telecommunication industry occurred We find that the important factors in the catch-up are the strategy of "trading market for technology," the knowledge diffusion from Shanghai Bell both to the R&D consortium and to Huawei, and industrial promotion by the government. As a condition for successful catch-up, the paper points out that the technological regime of the telephone switches is featured by a more predictable technological trajectory and a lower cumulativeness. These conditions and strategies helped the Chinese firms to achieve a stage-skipping catch-up, namely, by skipping the stage of analogue electronic switches to jump to digital electronic switches.

1. Introduction

China's successful reform, that is now often called another East Asian miracles, has been attributed to policy changes to take advantage of comparative advantages in labor-intensive goods (Lin et al., 1996; Lin, 2003), although differences between China and her neighbors South Korea and Japan have also been pointed out (Lee et al., 2002). Among the many aspects of success, this paper pays attention to the rise of the technological capability of the Chinese firms, which we consider to be the real basis of the miracle. Particular focus is placed on the telecommunication industry.

The telecommunication industry in China achieved rapid growth during the last two decades or so. In

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1980, the number of telephone sets in China and the world were 4.18 million, and 450 million, respectively (Wu, 1997). By August 1997, however, the switch capacity in China amounted to more than 110 million lines, and the telephone network had become the second largest in the world (MII, 1997). At the end of 2001, the number of fixed-line telephone subscribers in China was 180,390,000, the second largest in the world (MII, 2001). The number of mobile phone subscribers reached 250,000,000 or so by the end of 2003, which was the largest in the world. In addition to the growth of market and services, also noteworthy is the growth of the technological capability and competitiveness of the telecommunication industry in China. The case of the digital automatic telephone switches, which is often called the stored programmed control (SPC) switches in China, is a notable example (Li, 2000; Liu, 2001).

In the digital automatic switch, the market share of local firms' (including Sino-foreign joint-ventures and indigenous firms) products increased from less than 50% in the 1980s to more than 90% in 1996. It was only in 1981 that the first set of foreign digital automatic switches was imported and installed in China, but 10 years since then, indigenous Chinese firms developed and produced digital automatic switches themselves. Apart from the products of Sino-foreign joint ventures such as Shanghai Bell, there are many digital switches that were manufactured by indigenous (or non-FDI local) firms. In 1998, 98% of the newly added digital automatic switches in China were made by local firms, and since then, non-FDI based indigenous firms such as the Great Dragon, Zhongxing and Huawei have begun exporting to foreign countries. This means that the Chinese-made digital switches have become internationally competitive. This paper aims to provide a systemic explanation of the process of technological catch-up in the telecommunication equipment industry in China.

There are several studies on the telecommunications industry in China from diverse perspectives but with less focus on technological development (Zhou, 1998; Wang, 1998; Wu, 1997; Liu, 2000; Renmin Youdianbao, 1999; Yam et al., 2004).[1] There is also some research focusing on technological development in China (Shi, 1999; Yam et al., 2004; Wen and Kobayasi, 2002).[2] Liu and White (2001) and Gu (1999) focus on the concept of national innovations systems and/or make comparisons between before and after the reforms. Four studies more closely related to theme of this paper would be Shen (1999), Fan (2004), Kwak (2000), and Zhang and Igel (2001). Shen (1999) discusses the Chinese road to high technology using the case of the telephone switch. Her research focus is, however, on industry policy by the government rather than on technological innovation at the firm level, and, moreover, substantial changes have taken place since her research was completed in September 1997. Fan (2004) discusses the history of China's telecom-equipment industry with a focus on four indigenous firms, but does not investigate at depth the origins of these four firms. That is, Fan does not extend the analysis backwards to the Shanghai Bell and other JVs in terms of knowledge diffusion and linkages. Kwak (2000) observes the factor of organizational learning through Sino-foreign joint ventures, but does not mention other key factors. While appreciating the achievement of Chinese firms, Zhang and Igel (2001) approach the telephone switch industry from the perspective of the management of complex products and systems (CoPS) and suggest what is to be done to maintain competitiveness.

Among the studies on technological catch-up at the firm level, there is one by Lee and Lim (2001), which, although not specifically for China, attempts to answer the question of what the conditions were for technolog-

[1] Zhou (1998) and Wang (1998) take an industrial organization theory perspective that addresses the issue of monopoly break-up, or how to open the telecommunication service market to foreign firms. Other studies focus on industrial policy by the government, centering on such concepts as "import-assimilation-improvement or innovation" to derive implications for market-oriented reform (Wu, 1997; Liu, 2000; Renmin Youdianbao, 1999). Yam et al. (2004) conducts regression analysis of the relationship between measures of innovation capability and firm performances in the telecommunication equipment industry.

[2] Shi (1999) compared the USA, Japan and Korea's practices in terms of catching-up through imitative innovation (Kim, 1997), arguing that imitative innovation is a necessary phase for latecomer's catching-up. Beyond this argument, however, detailed study of the Chinese case has not been done. Another interesting phenomenon in China that is related to the transitional nature of the economy is the emergence of the university-run or spin-off companies, which are discussed in Lu and Lazonick (2001), Liu and Jiang (2001), and Gu (1999). Regarding the role of the government during the transition, there is a study by Wen and Kobayashi (2002) on the development of the CAD industry in China.

ical catch-up and leapfrogging. They have built a model of technological and market catching-up to explain the evolution of selected industries in Korea. Applying the Neo-Schumpeterian concept of the technological regime (Nelson and Winter, 1982; Breschi et al., 2000) to the context of catch-up economies, they argue that technological regimes of the industries are important elements in catch-up by late-comer firms. Although Lee and Lim's (2001) model is developed based on, and applied to, the case of six industries in Korea, it can also lend some insight to explaining catching-up in China. However, taking the specificities of China into account, we will modify the model and identify new and different factors responsible for the catch-up by the Chinese firms.[3] For example, regarding the access to the foreign knowledge base, we emphasize the factor of knowledge diffusion in the Sino-foreign joint ventures and the fact that the Chinese side commanded powerful bargaining power based on her huge market size in the negotiating technology transfer. Regarding the sources of the competitive advantage of indigenous firms, we will emphasize the segmented nature of the Chinese market and the fact that the initial growth of the indigenous firms was based on rural or peripheral markets where the presence of the MNCs was less.

This story of technological catch-up in China is also related to the "leapfrogging" hypothesis originally proposed by Perez and Soete (1988) and Perez (1988), and later studied in Hobday (1995), Lee and Lim (2001), and Lee et al. (2005), although some differences exist among these authors.[4] The basic idea of this hypothesis is that, in the catching-up process, the late-comer does not simply follow the path of technological trajectory of the advanced countries or firms. They often skip some stages or even create their own path that is different from the forerunners. Such leapfrogging is possible, as noted in Perez (1988), because every country is a beginner in terms of the newly emerging techno-economic paradigm, which implies the possibility of leapfrogging by late-comers like NIEs. The idea of leapfrogging is that some late-comers may be able to leap-frog older vintages of technology, bypass heavy investments in previous technology system and catching-up with advanced countries (Hobday, 1995).

Although this case of telephone switches in China does not seem to fit perfectly the leapfrogging thesis, there exists some element of leapfrogging. Hence we propose that this is a case of stage-skipping catch-up, according to Lee and Lim's typology of the concept. In terms of the technological trajectory of telephone switches, China skipped analogue-based telephone switches but leapfrogged into digital-based telephone switches (Shen, 1999). This phenomenon is interesting, because we can observe other cases of leapfrogging in China.[5]

In what follows, we first provide a brief overview of the evolution of the telecommunication equipment industry in China in Section 2, and then discuss a theoretical model of technological learning and catching-up applied to the case of telecommunication industry in China in Section 3. Section 4 investigates the transfer of the digital automatic switch technology through the establishment of joint ventures in China. Using a case study of the Shanghai Bell Company, we explore how China "traded market for technology" by establishing a joint venture and absorbing the switch technology from that foreign firm. Section 5 investigates the research and development (R&D) process by the indigenous organizations and firms to develop the digital automatic switches. Here, the focus is on the case of the first large-capacity central office switching system (HJD-04 system), and on how related knowledge diffused from Shanghai Bell (foreign joint venture) to the indigenous firms and R&D organizations. Section 6 discusses the emergence and growth of indigenous firms such as Huawei, focusing on the origin of its knowledge base, the sources of competitive advantage, and the role of the government. Finally, we provide a summary and concluding remark.

[3] For a discussion of the difference between China and the NIEs in the color TV industry, see Xie (2004).

[4] In the case of Soete, it is competition among technology suppliers that provides the opportunity for leapfrogging, while Perez argues that it is the "long waves" that provide a targeting point for technological development and adaptation. A stronger contrast is Hobday, whose skepticism regarding the feasibility of leapfrogging is based on his case studies of the industry in Singapore. On the other hand, Lee et al. (2005) discuss successful cases of leapfrogging, such as mobile phones and digital TV by the Korean firms.

[5] We can observe other cases of technological leapfrogging in China. In the Chinese market, there was no VCR era, as the market skipped the VCR to grab the VCD or DVD. Also in telecommunication services, even before the fixed line telephone services are more widely installed, mobile phone service began and surpassed the fixed line telephones in terms of penetration ratio.

Table 1
Evolution of the telephone switch technology

Name of switch	Time of invention	Time of commercialization	Switching pattern	Controlling pattern
Magneto telephone switchboards	1878	1880s	Jacks and plugs	Manual
Step-by-step switch	1891	1892	Step-by-step	Electro-mechanical
Crossbar switches	1917	1926 (in USA); 1938 (in Sweden)	Cross-bar	Electro-mechanical
Analogue electronic switch	1960	1960s	Reed-relay	SPC
Digital electronic switch	1970[a]	1970s	Digital	SPC

Source: Zhu (1993), Flood (1994), and Lee and Lee (1992).
[a] The time of installation.

2. Evolution of the telecommunication equipment industry in China: an introductory overview

The evolution of the telephone switch technology can be divided into three stages: the manual switches (1880s–1920s), the electro-mechanical switches (1920s–1960s) and the electronic (stored program control: SPC) switch (1965–till now). The first “manual switch” stage includes magneto telephone switchboards and common battery exchanges. There are two types of “electro-mechanical switches.” The first that appeared was the ‘step-by-step switches’, after which the ‘crossbar switches’ emerged. The third stage product, the “electronic stored program control (SPC) switch,” can also be divided into two phases: the analogue automatic switches and the digital automatic switches (Zhu, 1993; Flood, 1994; Lee and Lee, 1992). The evolution of the switch technology is shown in Table 1. As shown in the table, the switching pattern in the analogue electronic switch is reed-relay, and the controlling pattern is SPC. However, the switching pattern of digital electronic switch is digital, and the controlling pattern is SPC (Mody and Sherman, 1990).

After the founding of the People’s Republic of China, a telecommunication administration system was established, and a communication network centered in Beijing and connecting the whole country was built (Zhang, 2000a,b). The first step-by-step telephone switch equipment factory, Beijing Wired Factory, was set up in 1957 under the help of the former Soviet experts. Since 1958, Beijing Wired Factory began to produce JZB (47 type) step-by-step telephone switches, which replaced the imported equipment in China. Due to the disadvantages of step-by-step switches such as slow speed, big noise, adjustment and frequent maintenance needs, the Ministry of Post and Telecommunication (hereafter MPT) decided to stop their production in 1974 (Zhu and Lu, 1999).

In 1966, the Tenth Research Institute of the MPT developed the first coded crossbar telephone switching system that became widely employed in telephone networks throughout the country.[6] The major models of crossbar switches developed by this institute include the JT-801 switching exchange series, the HJ09 trunk-local-rural switching system, and the HJ10 terminal switching system. In 1975, a slightly improved version of crossbar switches was developed by the Academy of Telecommunications Science and Technology under the MPT, and passed the MPT’s approval. Until then, owing to the closed-door policy, China, had not been able to absorb advanced telecommunication technology from the West, and the level of technological capability was very low. Only after the open door policy, namely in May 1984, a more advanced crossbar switching system with more than 10,000 ports capacity was developed and produced in Tianjin, and China had not developed or produced the analogue electronic switch (Zhang, 1999). But, in other parts of the world, fully automatic digital switches had already been widely installed. In sum, in China the step-by-step switches were mainly used in the 1960s and 1970s, and the crossbar telephone switches were mainly used in the 1980s.

According to Mr. Wu, the former minister of the MPT, as of 1980 China lagged 20–30 years behind the developed countries as the step-by-step switches comprised about 29% of the telephone network, and crossbar switches, 33.7%, while analogue electronic switches, imported from foreign countries, represented only 6.7% of the network in China (Wu, 1997, p.

[6] The Tenth Research Institute of the Ministry of Posts and Telecommunications, http://www.xdz.com/wenzhang/zlzy/kyjg/leaf/html/2290_0.html.

13).[7] Thus, it can be said that the telecommunication network in China had been dominated by the out-of-date step-by-step and crossbar central office switches before the first digital automatic (SPC) switch made by Fujitsu (Japan) was imported and installed in the Fujian Province in 1981 (Wu, 1997, p. 73; Xin et al., 2000, p. 21; Cheng, 1999, p. 47).[8] After the first installation, all the major multinational SPC switch manufacturers began to sell their switches in China.

Realizing the attractiveness of its market size and the resulting bargaining power, the Chinese government actively approached multinational suppliers for technology transfer and joint venture negotiations. In 1984, the first foreign direct investment (FDI) was approved to establish a very large joint venture (JV) in China, namely the Shanghai Bell Telephone Equipment Manufacturing Corporation (Shanghai Bell hereafter) with the Bell Telephone Manufacturing Company (hereafter BTM), a son company of the ITT at that time and later the Alcatel, as the partner in the JV. Another JV agreement between Siemens in Germany and a factory owned by the Ministry of Electronics Industry (MEI) in Beijing was signed in October 1988 to establish company called the Beijing International Switching System Corporation (BISC).to produce the EWSD (Electronic Worldwide Switch Digital) switches from 1991 (IGI, 1997, pp. 143–144). Fearing that the two JVs would dominate the Chinese market, other multinational suppliers started to actively pursue JV negotiations with their Chinese partners and eventually established their own ones after 1993.[9] As a result, the involvement of FDI had transformed China's switch market from one dominated by "direct imported goods" to a "JV dominated" one in the early 1990s.

Large-scale installation of imported switches in China's telecom networks and the presence of many JVs in China fostered the diffusion of technology know-how across the country. As Section 5 elaborates, there was a broad-ranging knowledge transfer and exchange involving R&D, production, subcontracting, marketing, after-sales services, and local human resource training (Tan, 2002; Zhang, 2000a,b, p. 148). Domestic researchers and engineers, teamed with entrepreneurs, quickly grasped the opportunity to develop competitive indigenous products. A specific project to develop indigenously digital electronic telephone switches started in the mid 1980s (or 1984), with the initiation of a Professor Wu at the Center for Information Technology (CIT) under the Zhengzhou Institute of Information Engineering of the People's Liberation Army. Wu's team at the CIT was joined by the LTEF under the MPT that used to produce crossbar (electro-mechanical) switches. Some of the specialists who formerly worked at the Shanghai Bell also participated in this project to develop digital automatic switches (Shen, 1999, pp. 76–77).

What this team developed first in 1987 was a small capacity (1000 lines), or branch-level, digital switch with model name HJD-03 (Shen, 1999, p. 108). Although this HJD-03 was registered officially with the MPT, it was notorious for software bugs and repeated breakdowns, and was installed for small private network but never in public network (Pyramid, 1996, p. 110). This small success was a stepping-stone for bigger success a couple years of later. In 1987, a contract to develop a switch with 2000 lines was signed between the CIT and the PTIC (Posts and Telecommunications Industrial Corporation) under the MPT. Since then, the PTIC had played the role of general project manager and financial sponsor, with the CIT as the main technological force and the LTEF as technical assistant and test workshop.

[7] In his original text of Wu (1997, p. 13), he used the words "electronics telephones switches (including electronics and semi-electronic telephone switch)," which must be referring to imported analogue electronic switches, since he also stated that digital switches were not installed in China until 1980s, or until the introduction of the one made by Fujitsu in 1981.

[8] For this reason, the telecommunications system in China was one of the poorest in the world. There were merely 3,972,000 telephone lines for a population of over 900 million, with about 4 phones per 1000 people in 1978 (Wu, 1997 pp. 7–8; Xin et al., 2000, p. 7; Shen, 1999, p. 16–17).

[9] Since 1 January 1993, in response to conditions imposed on China to rejoin the GATT (General Agreement on Tariffs and Trade), the tariff for direct imports of SPC switches has been reduced, and other SPC switches technologies transfer projects have been approved by the government (Shen, 1999, p. 21). Thus, several new JVs were established: Tanjin NEC Electronic and Communications Industry, AT&T Qingdao Telecommunications Equipment and Services Co., Beijing Nokia Hangxing Telecommunications, Nanjing Ericsson Communications Co. Ltd., Jiangsu Fujitsu Telecommunication Technology Co., Ltd., and Guangdong-Nortel Telecommunication Switching Equipment. For more details, Mu (2002) and Pyramid (1996, pp. 104–105).

As Section 5 will elaborate later, it was in 1991 that this three-party consortium of the CIT, LTEF, and the PITC finally developed a central-office digital automatic switch (HJD-04). Domestically designed and manufactured central office SPC switches (a kind of digital automatic switch) started to serve rural markets in 1992. Since the mid 1990s, indigenous manufacturers began to compete directly with JVs first in rural and, subsequently in urban markets, with significantly improved product quality and added features. Starting from a 10.6% market share in 1992, the four indigenous manufactures – led by Great Dragon (Julong), Datang, Zhongxing, and Huawei (the so-called Ju Da Zhong Hua in Chinese, which means "great China") – held 43% of China's digital automatic switch market in 2000 (see Fig. 1). Their switches even began to be exported to many developing countries in East Asia, Central Asia, Eastern Europe, and Latin America.

The preceding overview indicates that in catching-up in the telephone switch technology, China experienced a "stage-skipping catch-up," to use the term of Lee and Lim (2001). China had only some experience in developing or producing electro-mechanical switches but skipped the development and production of analogue electronic switches to jump directly to the digital automatic switches. According to Shen (1999), cross-bar switches mainly installed in provincial capital cities had been replaced by digital automatic switches (skipping analogue automatic switches). In rural areas, manual switches were replaced by digital automatic switches (skipping step-by-step switches, crossbar switches and analogue automatic switches), and in some areas, the first telephone switch installed directly entered the digital age (skipping all stages).

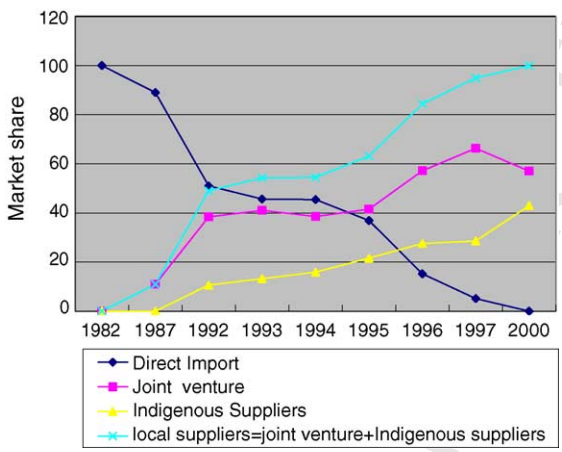

Fig. 1. Local products vs. imported products in the switch market in China (1982–2000). *Source*: authors adaptation based on SPC TISS Project Team (1998) and Tan (2002).

3. Modifying the model of catch-up and the "Chinese" factors: a theoretical framework

3.1. The model of technological and market catch-up

Breschi et al. (2000) argue that the specific ways in which the innovative activities of an industrial sector are organized can be explained as the outcome of different technological regimes implied by the nature of technology. The technological regime is defined by the combination of technological opportunities, appropriability of innovations, cumulativeness of technical advances, and the property of the knowledge base (Breschi et al., 2000). Lee and Lim (2001) introduce the idea of technological regime to the context of technological catch-up by the late-comer firms to derive a model of technological and market catch-up as depicted in Fig. 2.

We utilize the catch-up model of Lee and Lim (2001) as a basis, but point out several new elements as important variables in the Chinese context (see Fig. 2). In the model, the technological capability of the firms is determined as an outcome of the interaction between the available R&D and the amount of R&D effort (or technological effort). The available R&D resources include the internal knowledge base as well as financial and other resources.

Since the amount of available R&D resources is more or less fixed in the short-run, the critical factor for future success is how much new R&D input the firms devote to new R&D projects. In the model, the amount of a firm's R&D efforts depends on the probability of the success of the R&D project or product. The firms assess two kinds of probability in this regard: first, the probability of the successful development of target products, and, second, the expected marketability (competitiveness) of to-be-developed products. Hence, the physical development of products is separated from

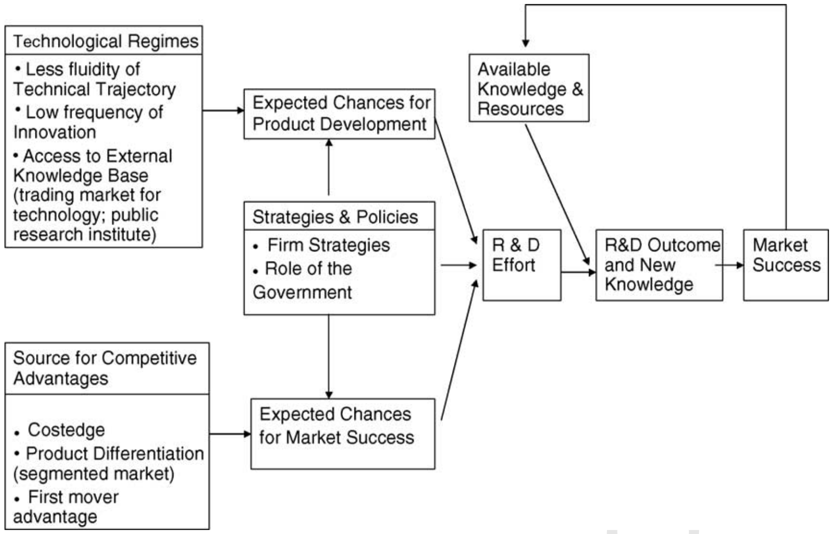

Fig. 2. Model of technological and market catch-up: the Chinese factors.

their success in markets, as in the case of the distinction between invention and innovation. Such separation is needed, because the market success of products is not guaranteed even if the target product is developed. In general, firms will devote more R&D resource when they are confident of the linkage between more R&D input and more R&D outputs (product development and market success).

Technological regimes enter the model as determinants of the expected chance for product development, as argued by Breschi et al. (2000). As one element of the technological regime relevant for product development by the late-comer, what Lee and Lim have added is the predictability of the technological trajectory. They assert that a technological trajectory with a greater uncertainty implied a smaller chance for success, because it would be more difficult for the late-comer firm to predict the direction of the technology's future development and to fix the R&D target. The model also observes that the technological regime featured by higher cumulativeness implies a smaller likelihood of success, because more R&D effort would be necessary for the latecomer firms to catch up. Lee and Lim (2001) also take into account the access to the external knowledge base (technology transfer) as one element relevant to the success of the R&D project. This access can be arranged in diverse forms: informal learning, licensing, FDI, strategic alliance, co-development, and so on. As will be shown below, we will emphasize the role of FDI in the case of the telecommunication industry in China.

Now, as determinants of the expected competitiveness of the to-be-developed products, which is the second factor affecting the amount of R&D effort, the model considers such factors as cost edge, product differentiation, and first-mover advantages. In the Chinese context, we will emphasize the segmented nature of domestic markets as an important feature of competition in China.

Finally, the model considers the importance of strategies by the firms and of the role of the government. As shown in Fig. 2, these factors affect not only the opportunity for product development and subsequent market success but also the level of the firms' R&D inputs.

Once the R&D outcome (and the new level of R&D resources) of the latecomer firms in a certain industry is determined as an interaction of both R&D effort and the existing level of R&D capabilities (knowledge and financial resources), then the new R&D outcome is combined with the firms' capabilities in manufacturing, marketing and logistics and so on, as parts of the value chain to produce a commodity that is headed for market testing. Then the product will succeed or fail in markets. If success prevails, the profits from market success are, of course, a source of investment for future

R&D, which thus constitutes one element of the firms' R&D capacities.

We will examine this whole process with the case of telephone switches developed by China. Below is a brief explanation of how we will utilize this model to elaborate the process of technological catch-up in the Chinese telecommunication industry.

3.2. Application of the model to the telecommunication industry in China and the hypothesis

First, let us examine the technological regime of telecommunication equipment, telephone switches in particular. The nature of the technical trajectory can be addressed by examining the ages and life cycles of new technologies in switches, and the frequency of innovation, by patent counts.

Given the history of telephone switches from the Manual switch (1880s–1920s) to the Electro-mechanical switch (1920s–1960s) and then to the electronic switches such as the stored program control (SPC) switch (1965-now), we can notice that the lifespan of each generation of telephone switches is relatively long. The average lifespan of an electro-mechanical switch in service was roughly 35–40 years, while some individual users had adopted the electro-mechanical switches for as long as 55 years (Dittberner, 1977). It has been over 35 years since the inception of the digital automatic switch, but this switch is still in use all over the world. This shows that the telephone switch industry is characterized by a technical trajectory that is more predictable than that of other industries such as the computer industry. Whereas computer products are characterized by life cycles of about 6 years, telecommunication switch equipment traditionally had life cycles of 20–40 years, and transmission equipment was replaced every 10–20 years (Duysters, 1996).

Next, the patenting trend in telephone switches shows that the regime is featured by low frequency of innovation (see Table 2). Checking the number of patents related to telephone switches by key word search in the USPTO website, we find that, during the 1977–1992 period,[10] the average annual growth rate of the related patents is only minus 0.6%, while other emerging technologies such as DRAM (dynamic random access memory chips) show much higher growth rates, per example 30% in the case of DRAM during the same periods; the same is true of wireless communication technologies and so on.[11] Frequency of innovation is also related to the age of technologies, such that old technologies tend to exhibit more stable technological trajectories.

The above discussion shows that the technological regime of the telephone switches is featured by a more predictable technological trajectory and less fre-

Table 2
Trends of the US patents in telephone switches and DRAM

	Telephone switches patents		Dynamic RAM + DRAM patents	
	Counts	3 years moving average	Counts	3 years moving average
1976	13		1	
1977	13	16.67	3	2.00
1978	24	17.00	2	2.33
1979	14	16.00	2	2.67
1980	10	10.67	4	4.67
1981	8	10.67	8	9.00
1982	14	10.33	15	11.67
1983	9	11.67	12	13.00
1984	12	11.00	12	14.33
1985	12	11.00	19	18.67
1986	9	15.00	25	31.33
1987	24	16.00	50	42.00
1988	15	18.33	51	50.00
1989	16	15.33	49	59.00
1990	15	17.00	77	70.33
1991	20	14.67	85	85.67
1992	9	15.33	95	103.67
1993	17	13.33	131	130.67
1994	14	18.67	166	159.67
1995	25		182	

	Average annual growth rates of the patents	
	Telephone switch (%)	Dynamic RAM + DRAM (%)
1977–1982	−9.1	42.3
1982–1987	9.1	29.2
1987–1992	−0.8	19.8
1977–1992	−0.6	30.1

Source: USPTO website: keyword search.

[10] We observe this period, because the Chinese project to develop indigenously digital electronic telephone switches started in the mid 1980s to succeed in 1991.

[11] For a comparison of the growth rates of US patents in several technology categories, see Lee and Lim (2001).

quent innovation, at least as of the 1980s—the time the Chinese were starting their catch-up effort. It implies that, according to the model, the telephone switch is a relatively easy target for late-comers to emulate and develop. But, a higher chance cannot be realized unless there is effective access to the available foreign knowledge. This is a finding that is common to the six industries analyzed in Lee and Lim, although the six industries resorted to different channels of access.

As the channel for access in the Chinese context, we emphasize the knowledge transfer through FDI or JV's. Given the huge market in China, access to knowledge was made possible by a purposeful strategy adopted by the Chinese authorities—the so-called "trading market for technology" policy in the JVs. As detailed analyses in the following Section 4 (on the transfer agreement) and Section 5 (on the knowledge diffusion from the JV to other Chinese firms and workers) will show, the case of a joint venture, Shanghai Bell, is a remarkable example in which China took advantage of its large market size to push the Bell Telephone Manufacturing Company (BTM) to sign a contract for transfer of core technology, even though it was restricted by COCOM. Through the establishment and operation of the Shanghai Bell, the Chinese side was able to acquire related technologies of manufacturing, installing and engineering. Shanghai Bell and other joint venture establishments fostered the diffusion of technological know-how across the country.

Now, we must examine the chance for market success of developed products. According to the model, such factors as cost edge, product differentiation, and first-mover advantages enter as determinants of market success. In the Chinese context, we emphasize a new element, the segmented nature of the Chinese market, featured by a kind of dualism: rural–urban dualism and core–periphery dualism. As the detailed analysis in Section 5 will show, the non-JV, indigenous Chinese firms, although they were technologically inferior to foreign firms and JVs, took advantage of rural, peripheral, or lower-end markets to sell their own digital automatic switches with a simple machine–operator interface and a Chinese-based screen menu that was easy to operate. Due to its low development and production costs, this kind of switch was provided to the Chinese users at much lower prices, making them initially popular in rural areas.

Finally, regarding the remaining components of the model, namely the strategies of the firms and the role of the government, we will investigate the role of the consortium of public (even military) research institutes (CIT) and the manufacturing company (LTEF) in Section 5, as well as government policies during the initial development and promotion stage of the digital automatic switches in Section 6.

Lee and Lim (2001) identify three patterns of catch-up. First, a path-following catching-up refers to instances in which latecomer firms follow a path that is identical to that of the forerunners. However, the latecomer firms go along the path in a shorter period of time than the forerunners. The second pattern is a stage-skipping catching-up, in which the latecomer firms follow the path to an extent but skip some stage and thus save time. An example is the development of fuel injection type engines by the Hyundai Motors in Korea. The third pattern is a path-creating catching-up, which means that the latecomer firms explore their own path of technological development; an example is the CDMA development by Korean firms. This kind of catching-up may occur when latecomers try a new path after having followed the path of the forerunners, and hence create a new path. Among the three patterns, the first type is the more traditional pattern, while the latter two types contain some aspects of leapfrogging. Of course, the three patterns are not necessarily a once-and-for-all occurrence; there can be a mixed pattern. More often than not, technological catching-up involves certain aspects of stage-skipping.

As explained above, China had only some experience of developing or producing electro-mechanical switches but skipped the development and production of analogue electronic switches to jump directly to the digital automatic switches. Thus we propose the following hypothesis.

Hypothesis. (Stage-skipping catch-up and Technological regime)The growth of indigenous digital switches in China can be considered as a case of "stage-skipping catch-up" according to the model; such a catch-up was possible in part by the fact that the technological regime of the telephone switch industry is featured by a high predictability of technical trajectory and a lower frequency of innovation.

In Lee and Lim (2001), catching-up is measured in terms of both "technological (R&D) capabilities" and "(world) market shares." Such a measure is reasonable, because the Korean firms gained technological capability initially by licensing and then, given the small size of the domestic market, exported the products in world markets outside Korea. In contrast, in the case of the telephone switches in China, the technology was acquired mainly in exchange for markets in the JVs, and the products made by local firms were sold first in the domestic market rather than in markets abroad. Therefore, we will measure technological catching-up by the Chinese firms in terms of whether or not and the extent to which the Chinese firms were able to develop and produce the products to catch-up "market share within China."

In sum, in modifying and applying Lee and Lim (2001) model to the telecommunication industry in China, we emphasize the strategy of trading market for technology as a means of access to the foreign knowledge base for the JVs, and the factor of market segmentation as the source of competitive advantage for the indigenous firms (see Fig. 2). The following sections will give a detailed examination of the hypotheses, and explain how the "stage-skipping catch-up" was realized in the telecommunication equipment industry in China.

4. Trading market for technology and getting access to knowledge

4.1. Bargaining power in the joint ventures

The bargaining power perspective suggests that the implications of resource dependence for joint venture control may be mediated by the bargaining powers of prospective partners (Fagre and Wells, 1982; Lecraw, 1984). Prospective partners negotiate for a level of joint venture control, given the assets that they command (Blodgett, 1991, p. 64). Yan and Gray (1994, 1996) develop a model of IJV (International Joint Venture) focusing on bargaining power that, in effect, incorporates two dimensions, i.e., critical resource provision ("capital" and "noncapital" resource) by each partner and the substitutability of the partners.

Brouthers and Bamossy (1997) explore the role of the governments in the transitional economies in central and eastern Europe as key stakeholders and how they influence international joint venture negotiations. The role is described and analyzed by examining eight cases of western and central/eastern European enterprises that had negotiated agreements. The findings suggest that transitional governments as are key stakeholders that intervene at different stages of the negotiation process, have both direct and indirect influences on the process, and can change the balance of power in the negotiations.

The Chinese government and policy makers seemed to have a good understanding of the market size as a source of bargaining power for the Chinese side. According to Yu Weixiang, the director of the Study Center for the WTO, the Research Institute on International Trade and Cooperation, Ministry of Foreign Economics and Trade, more than 80% of direct foreign investments in China since 1978 have been based on the principle of "trading market for technology," especially in such industries as automobiles, chemicals, and electronics (Chen and Yue, 2002). It is believed that the strategy of "trading market for technology" was first adopted in the automobile industry during the early 1980s.[12] The spirit of such a strategy was implicitly reflected in the first "Law of Sino-Foreign Equity Joint Ventures" adopted in July 1979; its Article 5 states that the technology and equipment contributed by a foreign joint venture as its investment must be advanced technology and equipment that suit China's needs.

Besides the size of the market, the state monopoly must also be mentioned as an additional source of bargaining power for the Chinese side. The state was the sole provider of telecommunication service as well as the single purchaser and/or producer of telecommunication equipment and facilities in China. Within China, the MPT itself was completely responsible for both regulation and operation of networks. The MPT, together with the provincial ministries of post and telecommunication, was the monopoly provider of international, domestic, and local telecommunication services as well as the purchaser of the related equipment throughout the country. Telecommunication equipment were subject to approval by another state agency called the Ministry of Electronic Industry (MEI), until the MPT and MEI were restructured to form a single ministry

[12] Cheng, Yuan, "Over Protection and Inefficient Development Whose Mistakes Brought out Backward Development in Automobile Industry?" (Baohu Guodu yu Fazhan Buzu – Qiche Luohou Shuizhiguo?), http://b-car.com/cywj/11.htm.

called the MII (Ministry of Information Industry) in 1998. Before 1980, the MPT controlled 28 telecommunication equipment factories; after 1980 the Post and Telecommunication Industrial Corporation (PTIC) was formed and took over the management of these 28 factories. However, the PTIC still remained under the control of the MPT.[13]

In what follows, details on how the Chinese side took advantage of their bargaining power for effective technology transfer will be elaborated.

4.2. Details on the technology transfer in the Shanghai Bell

While the Chinese government had allowed the import of large-scale digital switches to alleviate the immediate bottleneck in the telecommunication infrastructure following the reform, its belief was that direct imports of finished foreign digital automatic switches should be only a short-term solution for China. Being the most populous country with a huge potential market, transferring technologies by setting up joint ventures was considered necessary for China, with added benefits of increase in local valued-added and job creation. More importantly, the Chinese side anticipated the effects of technological learning and the building-up of indigenous technological capabilities. The MPT approached almost every major telecommunications company around the world, to explore opportunities for technology transfer through joint ventures. At that time, several state councilors and premiers paid official visits to industrialized countries, and explored the possibility of the ventures (Zhang, 2000a,b, p. 228).

However, at that time, most of the telecommunications companies were only interested in exporting their finished products to China. The Bell Telephone Manufacturing Company (BTM), a son company of the ITT and later the Alcatel, was one of the few firms who were willing to exploit the potentially huge market, while at the same time allowing for some technology transfer in manufacturing components by conducting a comprehensive "turnkey" project.[14] Obviously, the attractions of a potentially large market and the opportunity for long-term partnership with local manufacturers were the key elements for the BTM's decision to show interests in the project (Shen, 1999, p. 64).

As the huge size of domestic market provided the government with strong bargaining power in dealing with multinational corporations (MNCs), the Chinese government could require three conditions to be satisfied when a foreign firm enters China to establish a joint venture in the telecommunication business. The first condition was that the Chinese side must hold a majority share of more than 50% (in the case of Shanghai Bell, the share was 60%), the second was that the foreign side must transfer important technology to the Chinese side, and the third was that the custom large-scale integrated (LSI) chips used in telecommunication equipment must be produced within China (Zhu, 2000).

Following these conditions, the Bell Telephone Manufacturing Company (BTM) agreed to transfer the technologies that the Chinese requested in its joint venture, the Shanghai Bell. The first preliminary agreement between BTM and the Posts and Telecommunications Industrial Corporation was therefore signed at Luoyang in November 1980.[15] PTIC initially proposed that this joint production venture would be situated at the Luoyang Telephone Equipment Factory (LTEF); BTM preferred an alternative location. The final agreement was to build the joint venture at a factory in Shanghai belonging to a telephone exchange producer under the MPT.[16] On November 10, 1980, both sides reached an understanding memorandum. In May 1981, MPT reported the project to the State Planning Commission

[13] The PTIC was renamed as the Pu Tian Information Industry Group of China on 1 January 1999. In 1993, a new division, the Directorate General of Telecommunication (DGT), was split off from the MPT to handle telecom network operation and maintenance. In practice, however, the DGT still depended on the MPT for funding and personnel.

[14] In the early 1980s, when Shanghai Bell was established, BTM was a son company of ITT (International Telephone and Telegram Corporation in the USA) (Zhang, 2000 p. 138). In 1987, Alcatel of France took over ITT's telecommunications business. Thus, Alcatel became the mother company of BTM, and BTM was renamed Alcatel Bell Telephone Manufacturing Company (http://www.alcatel.com/atr/DATR_about.jhtml).

[15] In 1980, BTM was convinced that its technology could be successfully transferred to China, given China's skilled personnel, sound financial policies, and a suitable partner, PTIC (Zhou and Kerkhofs, 1987, p. 186).

[16] This is from personal experience. During the period 1991–1993, the first author of this paper had worked as an engineer at Changchun Telecommunication Equipment Factory (also called MPT 513 Factory), which was initially an affiliate of PTIC but became an affiliate of the Great Dragon Group after 1995.

and the State import and export commission, and got approval. In March 1982, MPT sent a delegation to Belgium for an on-the-spot investigation (Zhang, 2000a,b, p. 228).[17]

The Chinese side was convinced that the digital automatic switching system named System-12 was, at that time, the most advanced as well as the most appropriate technology for the telecommunications network in China. For example, System-12 was the only switching equipment available at that time with fully distributed controls. It was designed to avoid the weakness of central control systems, and to be relatively failure-safe. It was able to handle the complex user-interface and large call-processing densities that were essential for operation in China. International Telephone and Telegram Corporation's (ITT) reputation was an additional attraction, as BTM was one of the son companies of ITT at that time until Alcatel of France took over the ITT in 1987 (Zhang, 2000a,b, p. 138). In addition to these considerations, the Belgian government had agreed to lend a long-term loan at a "country to country" level, which guaranteed the continued financial support from the Chinese government. However, one of the most important factors was that BTM agreed to transfer technologies for component production, including the production technology of its custom LSI (large scale integrated circuit) chip. At that time, no other supplier was willing to offer the transfer of such advanced technology (Shen, 1999, p. 64).

The initiation of the System-12 technology transfer project involved the Belgian and Chinese governments, MPT, BTM, ITT and PTIC. Since this was by far the largest high-technology transaction in the history of China (Zhou and Kerkhofs, 1987), the Chinese side set up a strong negotiating team. Within this team, the chief representative was a deputy minister of MPT (also a senior specialist in telecommunications technology). Many senior experts in both technologies and foreign trade from various state institutes also took part. The negotiation was an arduous marathon lasting 33 months, from November 1980 to July 1983.[18]

As far as the Chinese side was concerned, the major technological issue was whether or not the System-12 technology suited the conditions of the telecommunication network in China. For this, the features of System-12 were checked one after another (Shen, 1999, p. 65). The whole process was a challenge for the Chinese team. As noted above, the serious issue was the transfer of the production technology for the custom LSI chip, as it was an advanced technology within the category of Coordinating Committee for Multilateral Export Control's (COCOM) restrictions.[19] The Chinese side insisted that all the technologies of component production had to be included in the transaction, lest component provision be stopped in the future as a result of a change in political relations between the two countries. On this issue alone, both sides took a year to reach an agreement (Shen, 1999 p. 65). At last, the contract on the establishment of the joint venture, Shanghai Bell Telephone Equipment Manufacturing Company (Shanghai Bell), was signed by Ma Shengshan, the president of PTIC, and Mondeck, the president of BTM in July 30, 1983 (Zhang, 2000a,b, p. 229).

According to the contract, Shanghai Bell was registered with a capital of 27 million US dollars and designed to produce 300,000 lines per year of System-12 switches. BTM equity share amounted to 32% of the total, the Belgian government contributed 8% and the PTIC of MPT held the remaining 60% (Zhang, 2000a,b, p. 228). In addition, depending on the regulation of the contract, PTIC was primarily responsible for providing land, buildings, and necessary facilities for the plant and for selling in the domestic market for locally produced System-12 exchanges; BTM provided the technology together with various services; and the Belgian government contributed the capital (Alcatel Bell Telephone, 1992). We should note that the PTIC in charge of marketing was under control by the MPT, and the MPT itself was completely responsible for both regulation and operation of networks in China (Tan, 1994). It was both the telecommunications equipment supplier and purchaser. This was an additional reason the willingness of foreign side to transfer the technology to the Shanghai Bell.

[17] As a member of the China delegation organized by MPT, Mr. Qingzhong Zhang had visited France and Belgium in 1982. At that time, he was the vice general manager of PTIC (Zhang, 2000, p. 138).

[18] This is a calculation using information provided by Zhang (2000, pp. 228–229).

[19] In 1949, the USA, Japan, and the NATO countries created COCOM to restrict the flow of strategic goods and know-how to communist countries. Industrial sectors such as electronics and telecommunications were of particular concern in this context.

The contract for the rest of the technology, with the exception of the LSI chip, was agreed and signed on 30 July 1983. However, the production technology for the custom LSI chip was under COCOM's restriction, so BTM undertook to lobby COCOM to ease the restriction (Zhang, 2000a,b, p. 231; Shen, 1999, p. 65). The Belgian government, from time to time, took up the matter as its involvement became necessary. In 1983, the Belgian Minister of Foreign Affairs sought to convince the US government to lift the restrictions against China. In June 1985, even the Belgian Prime Minister intervened. The Belgian Embassy in Washington acted on behalf of the Belgian government in obtaining the US government approval for LSI technology transfer. During this period, the BTM delegations had traveled frequently to Washington and Paris to pursue this goal. Even the ITT was involved in these efforts. In March 1987, approval for the transfer of the (LSI) chip production technology to Shanghai Bell was at last obtained from the USA and other relevant governments (Shen, 1999, p. 65).

The technology to be transferred between BTM and Shanghai Bell included manufacturing and installation technology, as well as engineering technology (Shen, 1999, p. 66). This was to be carried out during the contractual period of 15 years with an extension option for a period of 5 years. It concerned the transfer of hardware and software technologies. The hardware technologies included custom LSI chip production of 3-μm Complementary Metal Oxide Semiconductor (CMOS) and 8-μm Bi-MOS; thick film hybrids, double-sided and multiplayer printed circuit boards, and assembly line technology; computerized test facilities; and numerically controlled equipment for piece-part manufacturing. The software included full Country Development Engineering (CDE) and Customer Application Engineering (CAE) capabilities and computer systems.[20]

The BTM was committed to transfer all the technologies that the Chinese requested. However, the Chinese did not order all the technologies, but only those that were considered necessary (Shen, 1999, p. 66). For example, the Chinese did not want the fully automated production assembly that BTM used in its own factories, in order to save on capital costs. They decided instead to conduct manually many jobs that could be carried out by hand without compromising on the production quality. In other words, where possible, the Chinese preferred to use labor rather than expensive automatic machines. Some equipment that they judged could be made in China was also not ordered. One example is the automatic operator-position, which was later jointly developed by Shanghai Bell and a local university.[21]

The first System-12 technology to be transferred was the "release-5.0" based on the evolution line circuit technology, which at that time was the latest version. Subsequently, Shanghai Bell selectively transferred the later innovations of System-12. In 1989, Shanghai Bell obtained the latest development of the version 5 – release-5.2.[22] In 1992, a new contract between BTM and Shanghai Bell was signed, extending the project of technology transfer for another 20 years from 1994 to 2014.[23]

In the process of adopting, assimilating and learning the foreign technology, Shanghai Bell encountered a range of problems. These resulted not only from the technical imperfections of System-12 per se; but also from the inappropriateness of this technology to the Chinese environment.[24] However, Chinese government policy and its direct support for Shanghai Bell helped the company out of a crisis that emerged at the beginning of the production period, and provided the joint venture with privileges (e.g. low tax, autonomy in management, human and material resource supply,

[20] This is from an interview in November 2001 with Mr. Li Dongwen, a marketing manager at Shanghai Bell.

[21] This is from an interview with Ms. Zhang Yuemei, the first author's university classmate, who had worked as an engineer at Shanghai Bell during the period 1991–2002.

[22] This is from an interview on 29 November 2001 with Mr. Xing Tao, chief of the SPC Switch Business Unit, Beijing Bell Telecommunication Equipment Manufacturing Co., Ltd.

[23] According to the new contract, the new version of System-12 to be transferred was release-7. With the hardware, the size of the exchange would be smaller than the existing one – release-5. With the requisite software, release-7 was able to provide ISDN (integrated services digital network), IN (intelligent network) and so on, as well as to meet the new requirements of the international standards body CCITT (Consultative Committee for International Telegraph and Telephone, now renamed ITU, International Telecommunication Union). The new contract also included an updated technology for manufacturing LSI with 1.2 μ the registered capital of the company increased to 40 million US dollars (Shen, 1999). For more details, see also Shanghai Bell newspaper, No. 6, 2000, http://www.shanghaibell.com.cn.

[24] This is from the first author's personal experience.

etc.) which allowed Shanghai Bell to conduct its business free from many of the constraints facing other local firms (Shen, 1999, p. 67). For example, to ensure Shanghai Bell a leading position in domestic market, the MPT even decreed in an internal circular that the System-12 was one of the principal switching systems for use in the telecommunications network in China, and the MPT also helped the Shanghai Bell to obtain funds and loans from relevant government departments.[25] Thus, with the Chinese government's help, it overcame the crisis and ended up capturing 31% of the switches market in 1999.[26]

In sum, due to the huge domestic market that implied strong bargaining power, the Chinese government was able to demand more technology transfer when they approved foreign firms to establish local joint ventures in the telecommunication equipment industry. The technology transferred to Shanghai Bell included manufacturing and installation technology, as well as engineering technology including both hardware and software technologies. As the next section shows, the System-12 technology transfer by the BTM to the Shanghai Bell led to the dissemination of technological knowledge about the central office digital automatic switches across a network of players in the telecommunications equipment producers, users and research institutes in China. This provided a springboard for the later development of the HJD-04 by the indigenous Chinese R&D consortium.

5. Knowledge diffusion and the indigenous development of the digital automatic switches

5.1. Inter-firm knowledge diffusion and innovation

Knowledge diffusion between firms plays a critical role in the development of technology. The existing literature (Rogers, 1982; Von Hippel, 1987; Schrader, 1991) suggests that knowledge diffusion through informal channels, such as via informal contacts, happens in the form of information trading. Studies have shown that this type of informal exchange of knowledge between firms is a frequently observed phenomenon during the phases of product development, production and diffusion of technological innovations (Martilla, 1971; Czepiel, 1974; Allen, 1984). Information trading refers to the informal exchange of information between employees working for different, sometimes competing, firms (Von Hippel, 1987). Colleagues working in different firms provide each other with technical advice in the expectation that their favors will be returned in the future. Inter-personal communication is relatively more important for sharing knowledge with customers than with competitors (Lissoni, 2000). In high-tech industries, another important method of diffusion is through employee mobility (Franco and Filson, 2000).

Knowledge diffusion from multinational enterprises (MNEs) to domestically owned firms of a less developed country is often regarded as a major source of its technical progress and productivity growth. Through its past innovative activity and the professional experiences of its employees, a firm can catch up in a technology current. Using establishment-level panel data for the Indonesian manufacturing sector during the period 1995–1997, Todo and Miyamoto (2002) find the R&D activities and human resource development conducted by MNEs as one more important source of knowledge diffusion. They also find that domestic R&D is effective only when MNEs are present in the same industry, enabling the domestic firms to absorb knowledge from the MNEs through R&D.

5.2. Shanghai Bell as the Source of new knowledge

Before Shanghai Bell's establishment in China, nobody knew how to manufacture digital automatic switches, nor how to develop or design them. Thus, it was strange for the Chinese to operate and maintain digital switches (Zhang, 2000a,b, p. 232; Cheng, 1999, p. 49). The establishment of Shanghai Bell gave the Chinese opportunity to experience the core technological areas, and the operating and manufacturing of the system. It has also generated a batch of trained personnel (Zhang, 2000a,b, p. 232). In the process of adapting the System-12 to the Chinese environment, Shanghai Bell cooperated with local universities and research institutes. This process brought about the diffusion of related knowledge and skills.

[25] Based on an interview (in July 2001) with Ms. Zhou, a senior engineer who had received training at the Shanghai Bell. Now she works at the Jilin branch of the China Net Communications. According to her, the MPT commanded that every long distance switching adopt the System-12.

[26] Company profile of Shanghai Bell, http://www.shanghaibell.com.cn.

As the production capacity of Shanghai Bell expanded rapidly, Shanghai Bell hired several MPT engineers to carry out installation works in neighboring areas which they were familiar with. It also used engineers who had been technically trained in Shanghai Bell to carry out a relatively difficult job in installation–software testing.[27] To provide adequate after-sales-services, Shanghai Bell had established a number of maintenance centers, and Shanghai Bell's computer centers had been providing 24-hour services for its users. Apart from that, it also established a Customer Association with members across the country. Every six months, it invited users to meetings to give feedback on using Shanghai Bell's products. It also arranged a "System-12 Column" of two pages in a telecommunications journal – Telecommunications Technology – whereby Shanghai Bell regularly introduced the system to users and discussed troubleshooting experiences. In addition, Shanghai Bell widely circulated an occasional publication titled Bell Dispatches, where it ran an "information" system, which included many items on the utilization of System-12. Some essays were instructions written by specialists and others were engineers' experiences; all were carefully classified to allow users to search easily on-line. Taking advantage of MPT's traditional arrangement of involving the development of a couple of highly experienced engineers in each district, Shanghai Bell cooperated with them to solve technical problems on-the-spot.[28] These programs and publications were of substantial help to the Chinese in learning the advanced switching knowledge.

Next, when taking advantage of external resources and training, Shanghai Bell fostered a great number of qualified engineers in China. The firm managed to get many highly skilled external staff members working for the company. By agreement between Shanghai Bell and its customers, after their 6-months training course, these engineers would continue their practice in Shanghai Bell for 1.5–2 years. As a result, given their previous experience in the field and their newly acquired knowledge about System-12, they became very capable. They played an important role in helping Shanghai Bell to install and maintain System-12 in the field. At the same time, they could acquire new expertise.[29] The Chinese general manager told the truth jokingly that Shanghai Bell had been a "big school," fostering a great number of qualified engineers for this country (Shen, 1999, p. 83). Every year, around 3 to 4 percent of the engineers left the company to work elsewhere, while more new ones joined. Among those who left Shanghai Bell were many good engineers who could easily find good jobs elsewhere.[30]

5.3. The R&D consortium by the three

Now, before discussing the specific linkages between the Shanghai Bell and the indigenous Chinese firms, we first provide an introduction of the three organizations constituting the R&D consortium, which were also jointly responsible for the indigenous development of digital switches (HJD-04) in China. The three organizations are the Center for Information Technology (CIT) under the Zhengzhou Institute of Information Engineering of the People's Liberation Army, the Posts and Telecommunications Industrial Corporation (PTIC), and the Luoyang Telephone Equipment Factory (LTEF) of MPT. The CIT was the research arm of the Army and served as the initiator of the project; the PTIC was originally the procurement unit of the MPT and played the role of the general project manager and financial sponsor,; and the LTEF was formally a producer of crossbar switches and later emerged as the initial producer of the HJD-04. These three organizations had different backgrounds and motivations for joining this consortium.

The CIT's involvement can be traced back to the early 1980s when this institute worked on national defense-related technology. Once economic growth became the national agenda of China, the state budget for national defense, including military R&D projects,

[27] This is from an interview with Mr. Gao Nan, deputy manager and senior engineer of China Mobile Telecom Changchun Company, who were trained at Shangai Bell for 2 years from 1991 to 1993.

[28] Company profile and the Shanghai Bell Newspaper. http://www.shbell.com.cn.

[29] This is from an interview with Ms. Liu Yan, a university classmate of the first author and a senior engineer of China Net communication Dalian Company. She had received training several times at the Shangai Bell during 1992–1994. According to her, many of her university classmates working at telecom companies had also been trained at Shanghai Bell several times. So they even treated Shanghai Bell as a good place to meet each other.

[30] This is from an interview with Ms. Liu Yan.

decreased. At the same time, the Military Commission of the Central Committee of the Communist Party issued several documents encouraging the army to make a contribution to the civil sectors. Under this pressure, the military research team of CIT began looking for R&D projects that were applicable to civil sectors. Professor Wu Jiangxing played a key role in this episode. Formerly a senior engineer who later became the head of CIT, professor Wu in the early 1980s worked in Fuzhou (the capital of the Fujian province on the southeast coast of China) as a research fellow doing computer design. This was the time and place in which the first foreign digital automatic switches, the Japanese F-150 system, was imported and installed. The Chinese side encountered many problems with this system. From the day the contract was signed, it took 2 years to get the system into operation. This frustrating experience highlighted the dangers for China of lacking its own technology and deeply affected professor Wu. Thereafter, he established a research team in CIT to work on telecommunication technologies (Shen, 1999).

The Luoyang Telephone Equipment Factory (LTEF) was established in the 1970s to produce cross-bar telephone exchanges. As one of the 28 MPT-controlled manufacturing firms, the LTEF was a company with relatively new equipment. However, since the open-door policy went into effect and as foreign-made advanced digital automatic switches began to pour into the Chinese market, the firm encountered a serious crisis in the 1980s. Following the “foreign technology fever,” the LTEF first bid, unsuccessfully, to be the Chinese side of a joint venture with the Belgium Bell Telephone Manufacturing Company (which eventually became Shanghai Bell) and, later, was involved in another bid organized by the MPT, for one of ten joint ventures to produce digital switches. Having failed twice, in 1986 the LTEF decided to cooperate with the military-based CIT’s research team to seek new technological opportunities.

The PTIC was established by the MPT at the start of the economic reforms to co-ordinate the activities of the 28 firms under the MPT. It had previously undertaken the provision of equipment for MPT’s public network. Since the MPT was one of few ministries that were historically quasi-militarized, it enjoyed a strong monopoly-like position in several areas. However, economic reform had not left MPT untouched. The PTIC and the MPT’s R&D institutions were allowed to become increasingly independent of the MPT control. Under the MPT, there were 31 R&D institutes. In the past, any technologies developed from these institutes were freely given to manufacturing firms under the MPT. The reforms changed this relationship, because technologies were now perceived as profitable and valuable in the market. Without an R&D base of its own, PTIC feared the loss of its technological leadership. The pressure to save its loss-making state-owned firms also concerned PTIC. As a result, PTIC took a risk and joined CIT-initiated R&D projects at a later stage.

Although this tripartite R&D consortium played a key role in the development of indigenous digital electronic switches in China, diffusion of knowledge from the Shanghai Bell to this consortium was critical. We illustrate this point below.

5.4. Specific linkages between Shanghai Bell’s system-12 and the HJD-04

Regarding the linkages, we will show below that that the designers of HJD-04 absorbed the knowledge of Shanghai Bell’s System-12, and that the main manufacturer LTEF sought technical help from Shanghai Bell. This was possible, because the LTEF was PTIC’s subsidiary factory, and the PTIC was Shanghai Bell’s major shareholder.

First, Professor Wu, the key designer for HJD-04 at the CIT, acquired information about System-12 and other foreign PDSS through publicly available documents. Some of the other engineers, who had experiences in helping the System-12 project, also contributed the development of HJD-04. For example, the control system of HJD-04 assimilated the advantages of Fujitsu’s F-150 and Shanghai Bell’s S1240 (Zhang, 2000a,b, p. 148). The F-150 adopted a Centralized control system, and the S1240 adopted a Distributed control system. But HJD-04 adopted a multi-processors distributed control system. In particular, the switching network of HJD-04 consisted of up to 32 identical, relatively independent modules, and the interconnection between modules was via cables linking the buffer memories of each module.

Second, many local Chinese were involved in the process of adapting the System-12 to the Chinese environment, and they contributed their learned knowledge and skill to the development of indigenous switches. When producing, installing, and maintaining System-12, they continuously sought help from the MPT engineering teams and experienced engineers in local PTAs (Post and Telecommunication Authorities) in provinces (Zhang, 2000a,b, p. 230). The MPT brought together a group of highly skilled staff from MPT's R&D institutes, universities and factories across the country to Shanghai Bell. Among them there were many experienced senior engineers and knowledgeable professors in the field. They played a crucial role in building up the company in the early stages. Thereafter, most of them returned to their institutes, and some subsequently used the knowledge they had obtained from the System-12 to carry out various R&D projects for Shanghai Bell. Some of these specialists participated at the development of the HJD-04 technology (Shen, 1999, pp. 76–77). This process of technology diffusions gave birth to, and enabled the operation of, new types of digital automatic exchanges developed by the indigenous units (Zhang, 2000a,b, p. 232; Wu, 1997, pp. 75–76).

Third, the LTEF sought help by sending delegations to Shanghai Bell to explore suitable solutions, when developing its production facilities and management approaches (Shen, 1999, p. 153). LTEF was a fairly typical state-owned enterprise, in terms of the institutional structure, incentives, and operating mechanism. It would not have been able to fulfill the task of the production of HJD-04 if it did not reform itself. Under internal and external pressures, LTEF had to restructure its entire organizations, including its management institutions and operating system. It sent delegations to Shanghai Bell to study and explore the suitable solutions for its production facilities and management approaches. As a result, LTEF was able to upgrade its technological capabilities.

Finally, as Shanghai Bell brought up the components-production facilities to meet global quality standards and technologies, the manufacturers of HJD-04 were able to buy such components readily and cheaply within China.

Based on the above points, it can be said that, without the diffusion of the technology related to digital automatic switches embodied in the System-12 and other projects in the Shanghai Bell, the indigenous technological development of HJD-04 might not have been possible. According to the present president Zhang of Great Dragon, HJD04's development can be regarded as an assimilation of Shanghai Bell's System-12 (Zhang, 2000a,b, p. 232).

To summarize, the designers of the indigenous switch, HJD-04, first started with conducting research on Shanghai Bell's System-12, using publicly available documents. Also, some of the other engineers participating in the development of HJD-04 were recruited from those who had participated in Shanghai Bell's System-12 project. Moreover, the main manufacturer (LTEF) of the HJD-04 even sought direct technical help from the Shanghai Bell. Therefore, with some experience of computer technology and the telecommunication technology, together with an array of available foreign technologies from JVs, the institute (CIT/ZIIE) in cooperation with LTEF and PTIC developed the first successful central-office-level digital switches in China in 1991. It should also be noted that the project was initiated by engineers who were led by Professor Wu working in CIT. The CIT first invited the LTEF, and later sought help from the PTIC as a financial sponsor (Shen, 1999, p. 174; Mu, 2002, pp. 233–234). During its early stage, the MPT did not provide much direct help to this project initiated by the CIT. because it was focusing on developing digital switches on its own. This project was called the DS series and was developed in isolation by the MPT's 10th Research Institute in 1991. As explained in detail in Mu (2002), however, the project was not successful. The main cause of failure was the lack or ignorance of access to foreign knowledge and technology transfers.

As a next step, to produce the HJD-04 in a large scale, the consortium cooperated with the joint initiatives by the MPT and MET (Ministry of Electronics Industry) to establish a manufacturing company called the Great Dragon (Julong). The Great Dragon was actually a business group comprising nine affiliated companies including the LTEF (Zhang, 2000a,b, p. 151). With the joint sale activities of the nine affiliated companies, the HJD-04 has experienced rapid growth in sales since 1992. The average annual growth in sales has been over 200% for the past 3 years. In 1994, the market share of HJD-04 reached, from zero to 16%.[31] The annual single shift capacity for HJD-04 was 4.6 million lines in

[31] Consult: The Birth of the Great Dragon (Zouxiang Lianhe – JuLong Dansheng Ji), Renmin Youdian Bao (People's Post and Telecom), 1995.

late 1995. By October 1998, cumulative sales of HJD-04 were 16 million lines, while Shanghai Bell's were 23 million lines.[32]

After the development of the HJD-04 in 1991, knowledge diffusion was further amplified through the inter-flowing of engineers or related persons, which finally led to successive development of other four types of digital automatic switches (C&C08, EIM-601, ZXJ-10 and SP-30) by other indigenous firms. The later development of other types of digital switches by firms such as ZTE (Zhongxing), Datang, and finally Huawei, all benefited from knowledge diffusion via inter-firm mobility of skilled engineers. For example, Huawei's location at Shenzhen and its higher salary levels attracted skilled manpower from the Great Dragon (original manufacturer of HJD-04). Consequently, many skilled young engineers who had mastered or at least had some knowledge of the HJD-04 system left the Great Dragon for Huawei (or ZTE).[33] They contributed to the R&D of another digital switching system, C&C08, in Huawei.

In sum, in the case of digital switches in China, knowledge diffusion from the foreign joint ventures and its absorption by public research institutes was critical.

6. Segmented market and the competitive advantage of indigenous firms

6.1. Market segmentation in China

Since the issue was first introduced by Smith (1956), market segmentation has become a central concept in both marketing theory and practice. Smith states that market segmentation involves viewing a heterogeneous market as a number of smaller homogeneous markets. A segmentation basis is defined as a set of variables or characteristics used to assign potential customers to homogeneous groups. From a market segmentation perspective, China is a typical segmented market, based not only on geography but also on socio-demographics and lifestyle—a market that therefore requires differentiated implementation campaigns (Schmitt, 1997). The Chinese market should not be treated as a single market of 1.3 billion consumers. Geographically, there are at least three markets in China, a developed east coast market, a developing mid-China market, and an emerging frontier market in the far west (Kotler, 2001).

In the color TV industry, major indigenous firms have secured market shares by taking advantage of the segmented market. An example is Changhong company, which originated from the city of Mianyang in the Sichuan province and started to manufacture color TVs in May 1980. The company geographically expanded its market through three phases: it focused on Sichuan and having maintained 90% of the market from 1980 to the mid 1980s, expanded to Southwestern China until 1989, and then entered Northeast China and expanded to cover the entire market. Since 1992 Changhong has been one of the largest color TV makers; its domestic market share was 27% in 1996 (Kang and Ke, 1999a). During this process of expansion, initial success in the geographically segmented market of the Sichuan and Southwestern China regions were important for later expansion to other regions such as the developed market of Beijing and Shanghai.

With a market share of 9%, Konka became the second largest color TV maker in China in 1995. A joint venture established by Hongkong and Guangdong firms, Konka initially exported all of its color TVs from 1983 to 1987. Since 1988 the company also began selling to the domestic market. Upon observing the saturation of the east coast market, however, it swiftly targeted inland areas by establishing joint ventures with "local" inland firms such as Mudanjiang Konka in Helongjiang in 1993 for the northeastern market, Shanxin Konka for the northwestern market in 1995, and Anhui Konka for the eastern market. Konka also developed differentiated color TVs for consumers in rural area in 1995 (Kang and Ke, 1999b, pp. 40–47). Differentiated product development for rural markets and a regionally segmented market–oriented expan-

[32] Woguo Juyong Jiaohuanji Chanye de Fazhan Xianzhuang yu Qianjing Zhanwang (Development and prospects of central office SPC switches in China), http://202.96.31.133//information/industryy.nsf.

[33] This is from personal experience. On one hand, the first author's colleagues who had participated in producing HJD-04 switches at the MPT 513 Factory left for Huawei or ZTE in 1992 or 1993. One became a core engineer of Huawei's R&D division. Another source is the first author's university classmate who is now working at Huawei as a senior engineer. Before joining Huawei, he had worked for several years at a local PTA office. He states that the professional background of many of his colleagues is similar to his own.

sion strategy enabled Konka to capture a larger market share.

The telecommunication equipment market in China is not only huge but also segmented. One of the most important characteristics of this market is a kind of dualism: rural–urban dualism and core–periphery dualism. In other words, there exist two different markets in China: one similar to developed countries and the other more often found in underdeveloped countries. In terms of the level of general economic development as well as the existing telecommunications network conditions, different areas of China vary to a considerable extent. Many inland districts and rural areas lag far behind the coastal urban areas and large cities. Thus demands for telecommunication services from inland districts or rural areas are different from those of large cities. They are often not able to afford expensive foreign digital automatic switches. Given their knowledge about the Chinese market, the Chinese firms first targeted the rural or lower-end market in China's public telecommunications network, while all the foreign companies were aiming at large cities.

Apart from the three international gateways, there were five levels in the public network: levels one to four (known as C1, C2, C3, C4) were transit switches, and level five (known as C5) was comprised of terminal switches. There were eight level-one (C1) transit switching centers; 22 level-two (C2) transit switching centers were located in the capital cities of provinces or autonomous regions; level-three (C3) transit switching centers were located in each district and level-four switches (C4) at the county level; and level-five (C5) terminal switches were located in every major city and town. The HJD-04 system could be used at the C4 or lower level (although technologically it was designed also to meet the requirements as C3 level). It had a capacity of approximately 30,000 (later 60,000) subscriber lines and could be used as local or tandem switches. Up until 1993, the C3 and higher levels were dominated by foreign systems. However, there was a large market for the HJD-04 at the lower levels (about four times bigger than the C3 and higher markets), which foreign systems either had not yet focused on or had difficulties in entering.

This HJD-04 had a simple machine-operator interface with a Chinese-language screen menu. Due to its low development and production costs, this kind of switch was provided at much lower prices, which made them popular in rural areas in the initial stage. According to Shenzhen Special Zone Daily, in the mid 1990s, 90% of Huawei's products were installed in C4 or C5; 100% of Zhongxing's products were applied to C4 or C5. Since 1997, Zhongxing's products began to enter C3; in contrast, 90% of Shanghai Bell's products were installed in C3 or upwards.[34]

Given the ex-post importance of the rural market, one might ask why the MNCs or JV's did not pay attention to this market. Our first answer is that the urban markets were large enough for MNCs to indulge themselves in when they entered China during mid 1980s to the early 1990s. A more important answer is the fact that even if they wanted to go for the rural market, their products were not suitable for it. Transmission quality and transmission lines varied greatly in different areas of China. Under the low networks level and the poor network conditions, the foreign systems were rarely able to work. In addition, many foreign systems were designed around presumptions of lower usage of lines, however, rural market was featured by the combination of low telephone penetration rate and intensive use for each telephone set. Thus the foreign systems ran into problems, sometimes even leading to breakdowns in the local network.[35] Furthermore, the screen menu of all the foreign systems was in English. Outside the big cities, it was difficult to find operators who could understand English. The products of the MNCs and the JV's were more expensive than their local counterparts.

In sum, in terms of the source for competitive advantage, the likelihood of market success was high for indigenous Chinese firms. On the one hand, in its competition with the foreign or local JV firms within China, the indigenous firms took advantage of the segmented nature of the Chinese market. On the other hand, in their later competition in the international export market, the indigenous firms took advantage of relatively cheap labor costs and numerous other resources. The cost of labor in China is no more than one tenth of that in advanced countries. Other costs are much lower than that in other countries. For example, the main custom large scale integrated (LSI) chips for digital automatic switches can be manufactured in China at

[34] Guanyu Woshi Chengkong Jiaohuanji Chanye de Sikao (Thinking about SPC switching industry in Zhenshen city), Shenzhen Special Zone Daily, May 13 1997.
[35] Interview (in July 2001) with Ms. Zhou Hongjie.

a half of the international price. With the volume of production expanded, the price can decrease greatly (Xin and Wang, 2000). Thus the digital automatic switches manufactured by indigenous firms enjoyed several sources of competitive advantage. After having significantly improved product quality and added new features, indigenous manufacturers began to compete directly with local JVs in both the rural and urban Chinese markets after the mid 1990s. They eventually entered world markets.

6.2. The role of the government and catch-up by the indigenous firms

The role of the government also became decisive when the indigenous Chinese firms started to compete directly with the JVs in both rural and urban areas. The basic role of the Chinese government was to provide market protection and to give incentives for the adoption and use of domestic products. In 1996, the government stopped arranging foreign government loans to import digital automatic switch equipment. Instead the Chinese government began to impose tariffs on imported communication equipment, to promote the purchase of locally made equipment. The sum of the market share of local firms (including Sino-foreign joint ventures) was 63.1% in 1995 (see Fig. 1). One year after tariffs on imported communication equipment went into effect, the figure reached 84.8% in 1996, and in 1997, reached over 90, or 94.9% (Fig. 1).

Since 1997, the MPT had organized coordinating conferences every year with the Administrative Bureaus of Post and Telecommunication. Through these conferences, the MPT encouraged the Administrative Bureaus of Post and Telecommunication to purchase indigenous equipment, if the equipment were suitable in character and proper in price. During the first conference, contracts for more than 5 million lines were signed, and at last more than 7 million lines digital automatic exchange were sold. In the second coordinating conference, contracts for 17 million lines digital automatic switch were agreed on and 18 million lines were sold eventually. These two coordinating conferences were a turning point for the growth of the communication manufacturing industry in China (Xin and Wang, 2000). For example, in the second coordination conference, Huawei gained 6.505 million lines orders, which was 40% of the total orders of 1997 and 1998 (Xu and Fu, 1997). Under the encouragement of the People's Bank of China, the China Construction Bank supplied Huawei buyer credit RMB 3.85 billion, which was 45% of the bank's total buyer credit in 1998.[36]

Table 3
Market shares of the four indigenous firms in 1998

Company	Capacity (lines)	Market share (%)
Huawei	7,000,000	24
Zhongxing	5,100,000	20
Great Dragon	3,000,000–3,500,000	13.45–15.6
Datang	1,560,000	7
Total	16,660,000–17,160,000	64.45–66.6

Source: Woguo Juyongjiaohuanji De Fazhan Xianzhuang Yu Qianjing Zhanwang (The Development and Prospects On Central Office Exchange Industry In China), http://sd-ep.cei.gov.cn/fanzhan/shehui/eea5-sd.htm, 1999; Xin and Wang (2000).

Affected by the coordinating conferences and financial support, since 1998 the market share of the indigenous firms increased rapidly, and they became the main suppliers in the domestic market. In the urban market, indigenous firms claimed 21% of the market; but in the rural market, they dominated with a market share of 80%.[37] The four indigenous manufacturers – Great Dragon, Datang, Zhongxing, and Huawei – held more than 60% of China's digital automatic switch market in 1998 (see Table 3).

In Table 4, we can observe the growth of sales of the indigenous firms and joint ventures. Huawei started to produce large-scale central office digital automatic switches in 1995, but it has become the biggest manufacturer since 1998. Also, its sales are much bigger than that of the other companies. The sales of Zhongxing in 1995 and 1996 were clearly less than that of Tianjin NEC and Jiangsu Fujitsu. However, since 1997, the situation has been reversed: Zhongxing became the top five maker, next to Huawei, Shanghai Bell, and BISC. Datang's progress is also substantial. In the domestic central office switching market, Shanghai Bell had remained as the leader until 1998, but after 1998, Huawei surpassed Shanghai Bell and became

[36] Including Zhongxing and other telecommunication manufacturing firms, the volume of buyer credit supplied by China Construction Bank was 8 billion RMB yuan in that year. From Shenzhen Special Zone Daily (Sehnzhen Tequ Bao), July 30, 1998.

[37] Source: China telecommunication, US Department of Commerce - National Trade Data Bank, 3 November 2000 (http://www.tradeport.org/ts/countries/china/isa/isar0024.html).

Table 4
Sales Volumes of the Central Office Digital (SPC) switches by firms, 1995–2000 (unit: line)

	1995	1996	1997	1998	1999	2000 (Jan.–June)
Shanghai Bell	–	–	5,880,000	4,460,000 (Jan.–Aug.)	4,600,000 (Jan.–Jul.)	3, 260, 000
Beijing Int'l Switching Co. (BISC)	1, 472, 754	2,450,978	3,406,708	6,356,042	6,943,610	4, 042, 613
Qingdao Haixin Group Co.	691, 000	992,760	1,628,136	2,394,394	3,381,108	1, 879, 400
Tianjin NEC	955, 600	1,053,300	764,000	834,600	1,367,947	–
Jiangsu Fujitsu	–	1,252,000	1,434,000	1,601,000	1,151,000	–
Shenzhen Huawei[a]	–	–	3,934,678	9,332,734	13,750,445	9, 582, 290
Shenzhen Zhongxing[a]	425, 000	767,000	1,880,000	5,103,600	5,980,000	–
Xin'An Datang[a]	–	58	845,000	1,393,000	1,527,400	–
Great Dragon[a]	1, 508, 518[b]	1,235,072[b]	1,605,136[b]	2,024,493[b]	994,958[b]	675, 321

Source: Production Ranking of Central Office SPC Switch Maker (1995–1999) (Chengkong Juyong Jiaohuanji Chanliang an Qiye Paiming) and sales of switch maker in top 100 IT in China (January–August, 1998; January–July, 1999; January–June, 2000), CCID database.
[a] Refers to indigenous firms.
[b] Refers to the figure that comes from the total capacity produced by its four major factories.

Table 5
Huawei's market share in switches in China (unit: 1000 lines)

	Sales	Market share (%)
1997	4115	20
1998	7000	24
1999	7500	32
2000	16500	35

Source: Xin and Wang (2000, p. 41) and Huawei (2001, p. 15).

the largest digital automatic switch manufacturer in China. The market shares of Huawei and Shanghai Bell can be compared in the two tables that follow (see Tables 5 and 6). Among the four indigenous firms, only Huawei is a private company while the other three are state-owned. It is interesting that Huawei eventually emerged as the leading company. The reasons for its success may be numerous, including ownership and governance, corporate culture and strategy, human capital development, and so on.[38]

Table 6
Huawei and Shanghai Bell's rank in top 100 IT firms in China (1996–2002) (unit: million RMB)

Year	Huawei		Shanghai Bell	
	Rank	Total sales	Rank	Total sales
1996	21	2215.9	8	4574.8
1997	18	4189.3	12	5005.7
1998	10	7180.4	12	6046.1
1999	10	10214.7	11	8646.9
2000	8	15200.0	12	10820.5
2001	7	16229.0	9	15101.1
2002	7	17214.2	12	11138.4

Source: top 100 electronics and information enterprises in China, http://www.ittop100.gov.cn.

In sum, due to the segmented nature of the Chinese market, the indigenous firms were able to utilize the rural or lower-end market as their nurturing bases. They were also given active government support, until they were developed enough to compete directly with foreign JVs in urban or coastal regions.

7. Summary and concluding remarks

This paper has examined the growth of technological capability in the telecommunication industry in China. It develops a technological learning and catching-up model for China, based on a study by Lee and Lim (2001) that focuses on the Neo-Schumpeterian concept of technological regimes. This study first investigates the technological regime of telephone switches and the evolution of the telecommunication industry in China. Then, with case studies of Shanghai Bell, the CIT-led R&D consortium (and later Great Dragon), and the Huawei company, it analyzes how catching-up in the telecommunication industry was realized. Fig. 3 summarizes the whole process. The first digital switches to be made locally were in 1984 by the joint venture Shanghai-Bell (System-12). It was indigenously developed 7 years later in 1991 by the R&D consortium of the CIT-PTIC-LTEF (HJD-04) and

[38] For more details, see Mu (2002).

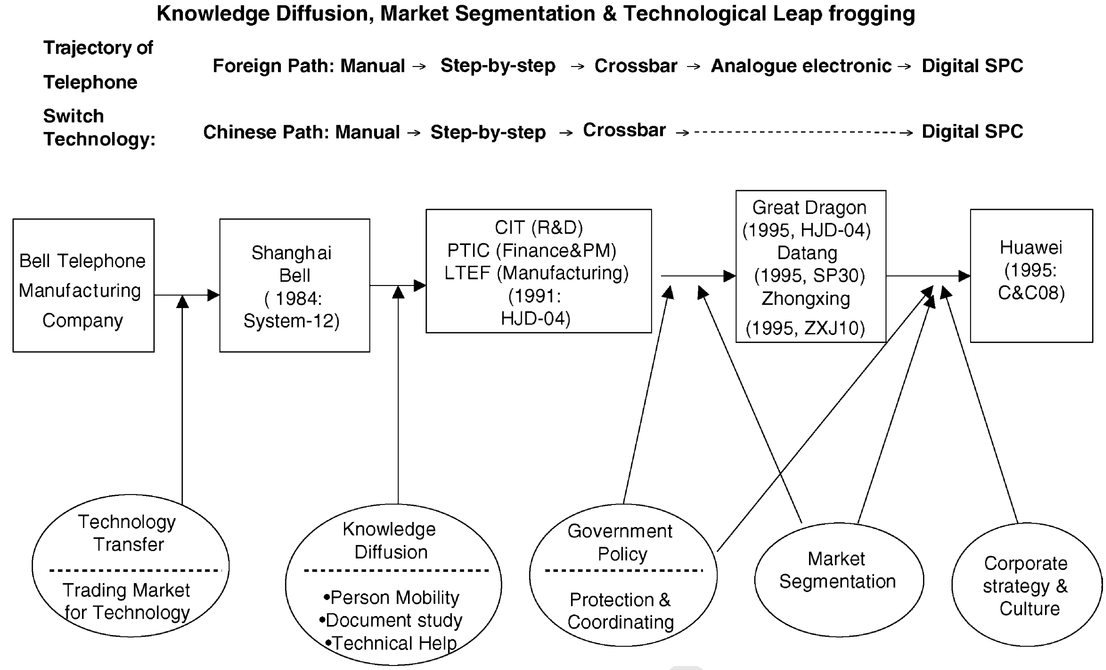

Fig. 3. Summary of stage-skipping catch-up in telephone switches in China.

mass-produced by a state-owned business group, the Great Dragon (Julong). Other state-owned companies also developed and produced diverse variants of the HJD-04. The final winner, however, was a private firm, Huawei, which outpaced its state-owned rivals with its unique corporate culture and strategy.

The major findings of this study may be summarized as follows.

First, regarding the technological regime, we find that the technological trajectory of the switching system is more predictable and less cumulative, and that it is one of the factors, which facilitated the technological catch-up of the telephone switch makers in China. It is a case of stage-skipping catching-up, in terms of Lee and Lim (2001) model. That is, the development of the switching system in China underwent the stages of manual switching, step-by-step switching, and crossbar switching, and then skipped the stage of analogue electronic switches to jump to digital electronic (SPC) switches. One may think that it is inevitable for latecomers to skip some stages or outdated models, and that all kinds of catch-up should contain some element of skipping. But not all cases of catch-up by latecomers include such aspects of skipping; skipping is not always inevitable. The stories of Hyundai Motors and the Samsung electronics validate this point (Lee and Lim, 2001).[39] The point is that whether or not, or the extent to which catch-up involves stage-skipping or even path-creating depends on the initial level of technological capability (or so-called absorption capacity) and the nature of arranged access to knowledge and terms of transfer.

Second, given the huge market in China, access to knowledge was made possible by the strategy of "trading market for technology" in the JVs, while the public

[39] When Hyundai started to develop engines in the early 1980s, the carburetor-based engine was the standard type and the R&D team considered developing and going along this proven technology. But, knowing that the trend of engine technology was moving toward a new electronic injection-based engine, the founding Chairman Wang, after long consultation and debate, firmly decided to target this emerging technology. It was not an inevitable but a deliberate choice. The same was true of Samsung's production of DRAM memory chips. Samsung's DRAM business started with producing 64 K bit D-RAM chips in the early 1980s. At that time, the government's position (Ministry of Industrial and Trade) was that the Korean firms had better start from 1 K bit D-RAM, but it was the purposeful decision of the private firms to skip the 1–16 K bit D-RAM to enter directly into 64 K bit D-RAM.

research institute initially played an important role in the development of the indigenous switching system. The case of a joint venture, Shanghai Bell, shows that China took advantage of its large market size to push Alcatel's BTM into a contract enabling technology transfer. Through the establishment and operation of Shanghai Bell, the Chinese side was able to acquire a related technology of manufacturing, installing and engineering. In return, the JV gained a large share of the new market and kept a dominant position in the Chinese market. Shanghai Bell and other joint venture establishments fostered the diffusion of technological know-how across the country. Having benefited from such technology diffusion, the public research institutes led by CIT developed the first indigenous digital automatic switch, HJD-04, in 1991. Following continuous knowledge diffusion, other switching systems were later developed by other firms.

Third, the indigenous Chinese firms were able to secure their competitive advantage due to the segmented nature of markets. The telecommunications equipment market in China is a segmented one; the indigenous firms differentiated their products to meet different demands in the segmented markets. The HJD-04 system was developed to cater to the less developed market, with characteristics of high processing capacity, simple and open structure, and simple interface. The rural market made it possible for indigenous firms to realize their first-stage growth.

Fourth, initial protection and promotion by the government provided additional competitive advantage for indigenous firms. For example, the new policy of levying high tariffs on imported communication equipment helped the local firms to secure their market share. The two coordinating conferences organized by the MPT in 1996 and 1997 and the state-owned banks' financial support encouraged the telephone service operators to buy the products of indigenous firms.

In sum, the key success factors include the coordinated acquisition of foreign technology by taking advantage of the bargaining power associated with market size, the regulation of the joint ventures to allow knowledge diffusion, and the existence of a plan for domestic capability building given the initial condition of segmented markets. The contribution of this study is that it has devised a model of, and elaborated the process of, technological catch-up in China, thereby identifying new and important factors, which are different from other countries like Korea. Such new factors are the "trading market for technology" strategy, the role of the joint ventures in diffusing knowledge to other firms, and the role of segmented markets as the source of competitive advantage for indigenous firms. This study deviates from other studies on similar subjects by providing a comprehensive elaboration of the long and complex process in a consistent theoretical framework. The question of whether the findings of this study can be generalized to other industries in China would be a subject of separate research in the future.

Uncited references

Brester and Penn (1999), Han (2001), Porter (1980), Treacy and Wiersema (1995).

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